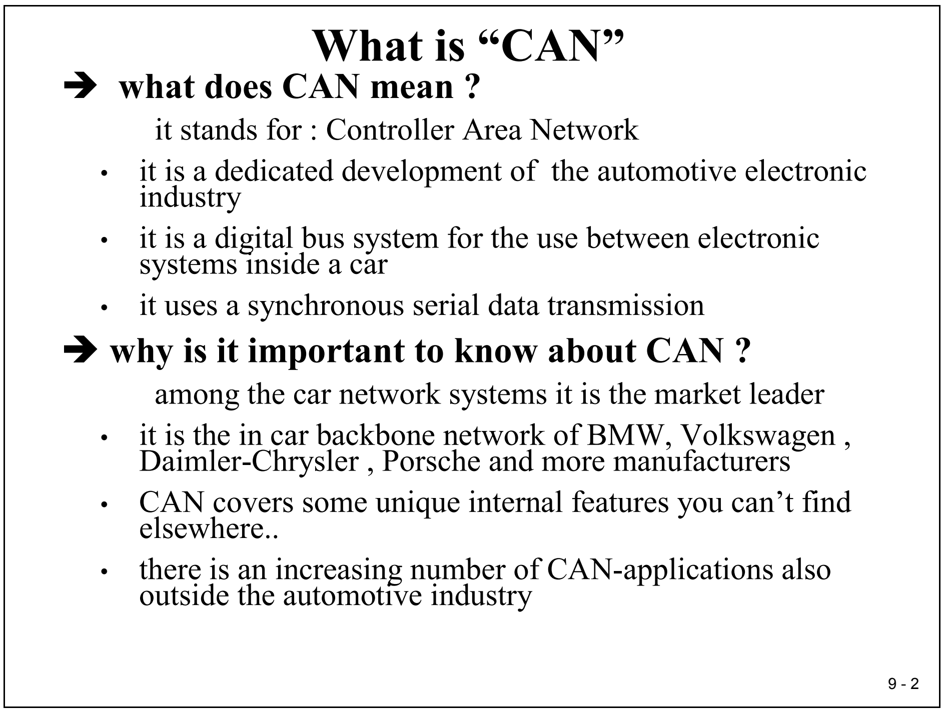
C28x Controller Area Network

Introduction

One of the most successful stories of the developments in automotive electronics in the last decade of the 20th century has been the introduction of distributed electronic control units in passenger cars. Customer demands, the dramatic decline in costs of electronic devices and the amazing increase in the computing power of microcontrollers has led to more and more electronic applications in a car. Consequently, there is a strong need for all those devices to communicate with each other, to share information or to co-ordinate their interactions.

The "Controller Area Network" was introduced and patented by Robert Bosch GmbH, Germany. After short and heavy competition, CAN was accepted by almost all manufacturers. Nowadays, it is the basic network system in nearly all automotive manufacturers' shiny new cars. Latest products use CAN accompanied by other network systems such as LIN (a low-cost serial net for body electronics), MOST (used for in-car entertainment) or Flexray (used for savety critical communication) to tailor the different needs for communication with dedicated net structures.

Because CAN has high and reliable data rates, built-in failure detection and cost-effective prices for controllers, nowadays it is also widely used outside automotive electronics. It is a standard for industrial applications such as a "Field Bus" used in process control. A large number of distributed control systems for mechanical devices use CAN as their "backbone".



What is "CAN"

➔ **what does CAN mean ?**

it stands for : Controller Area Network

- it is a dedicated development of the automotive electronic industry
- it is a digital bus system for the use between electronic systems inside a car
- it uses a synchronous serial data transmission

➔ **why is it important to know about CAN ?**

among the car network systems it is the market leader

- it is the in car backbone network of BMW, Volkswagen , Daimler-Chrysler , Porsche and more manufacturers
- CAN covers some unique internal features you can't find elsewhere..
- there is an increasing number of CAN-applications also outside the automotive industry

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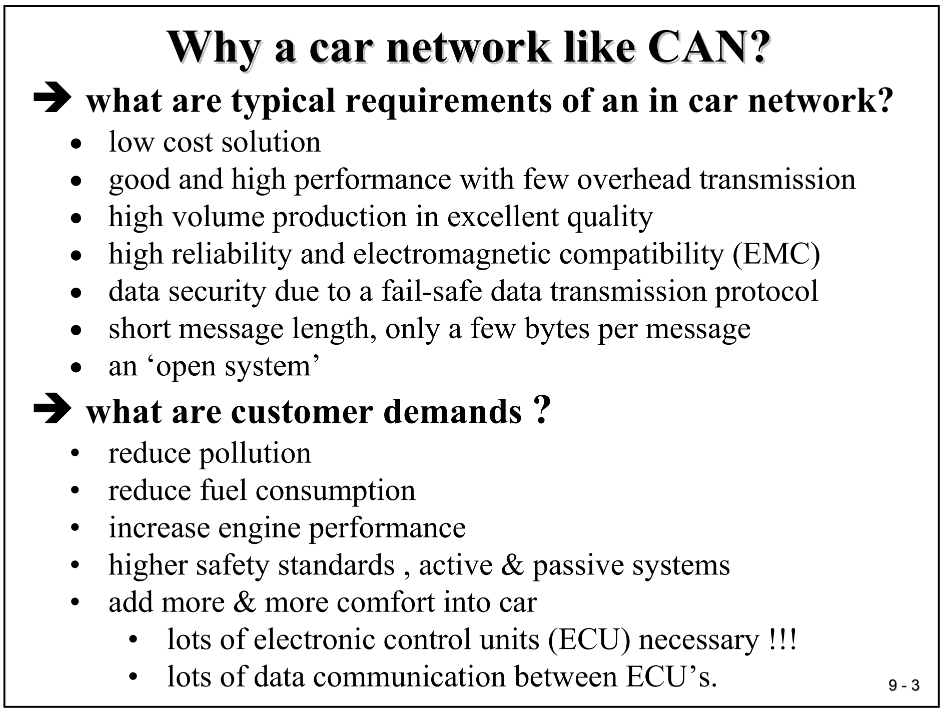
Module Topics

CAN Requirements



Why a car network like CAN?

➔ **what are typical requirements of an in car network?**

- low cost solution
- good and high performance with few overhead transmission
- high volume production in excellent quality
- high reliability and electromagnetic compatibility (EMC)
- data security due to a fail-safe data transmission protocol
- short message length, only a few bytes per message
- an 'open system'

➔ **what are customer demands ?**

- reduce pollution
- reduce fuel consumption
- increase engine performance
- higher safety standards , active & passive systems
- add more & more comfort into car
  - lots of electronic control units (ECU) necessary !!!
  - lots of data communication between ECU's.

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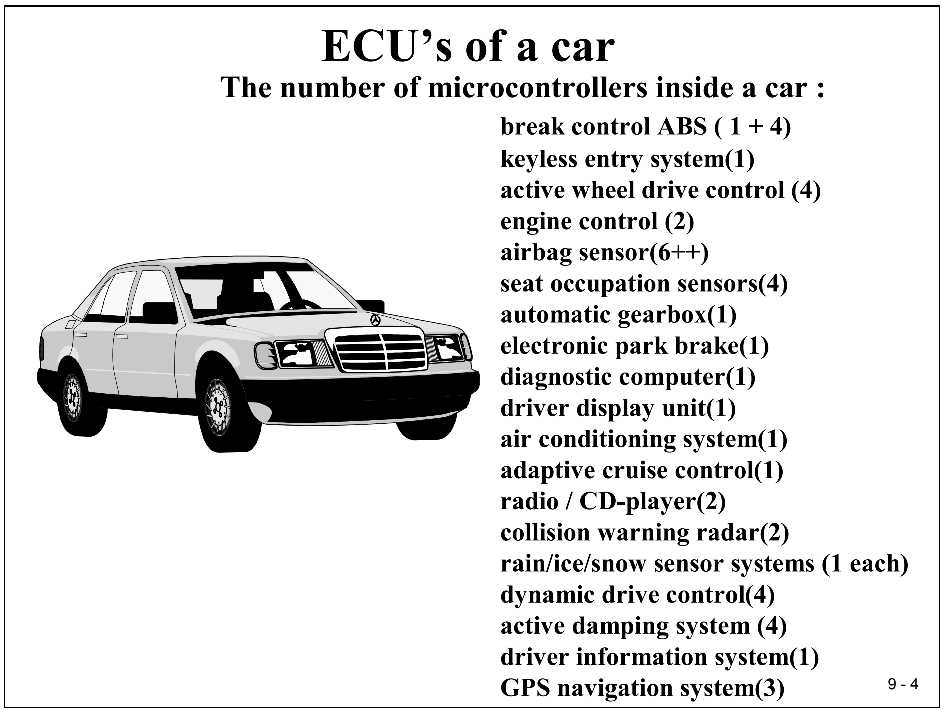

ECU's of a car

The number of microcontrollers inside a car :

break control ABS (1 + 4)
keyless entry system(1)
active wheel drive control (4)
engine control (2)
airbag sensor(6++)
seat occupation sensors(4)
automatic gearbox(1)
electronic park brake(1)
diagnostic computer(1)
driver display unit(1)
air conditioning system(1)
adaptive cruise control(1)
radio / CD-player(2)
collision warning radar(2)
rain/ice/snow sensor systems (1 each)
dynamic drive control(4)
active damping system (4)
driver information system(1)
GPS navigation system(3)

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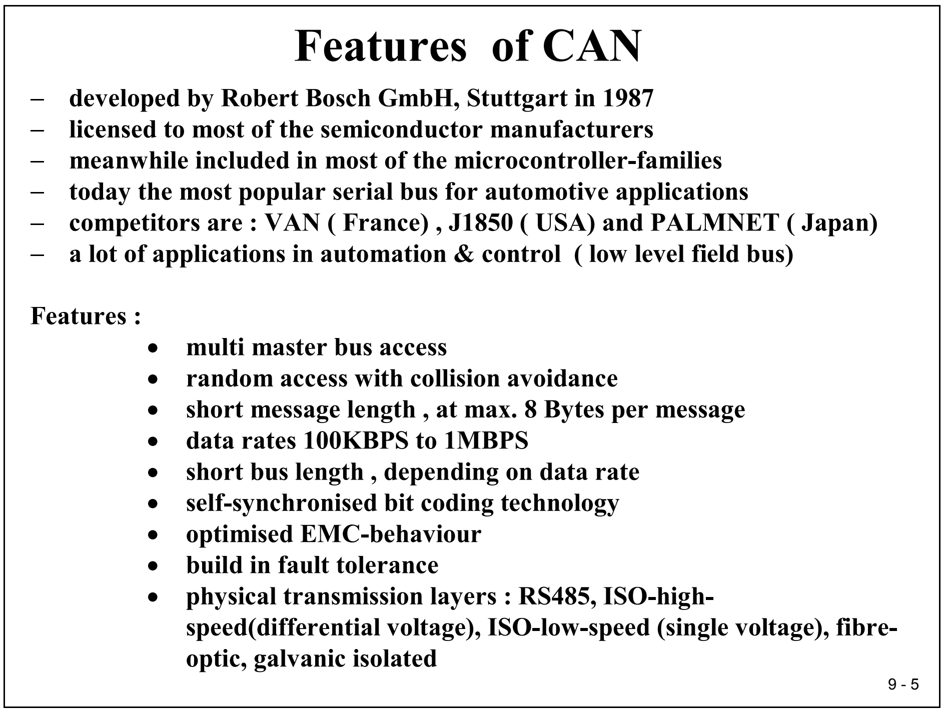
Basic CAN Features



Features of CAN

- developed by Robert Bosch GmbH, Stuttgart in 1987
- licensed to most of the semiconductor manufacturers
- meanwhile included in most of the microcontroller-families
- today the most popular serial bus for automotive applications
- competitors are : VAN (France) , J1850 (USA) and PALMNET (Japan)
- a lot of applications in automation & control (low level field bus)

Features :

- multi master bus access
- random access with collision avoidance
- short message length , at max. 8 Bytes per message
- data rates 100KBPS to 1MBPS
- short bus length , depending on data rate
- self-synchronised bit coding technology
- optimised EMC-behaviour
- build in fault tolerance
- physical transmission layers : RS485, ISO-high-speed(differential voltage), ISO-low-speed (single voltage), fibre-optic, galvanic isolated

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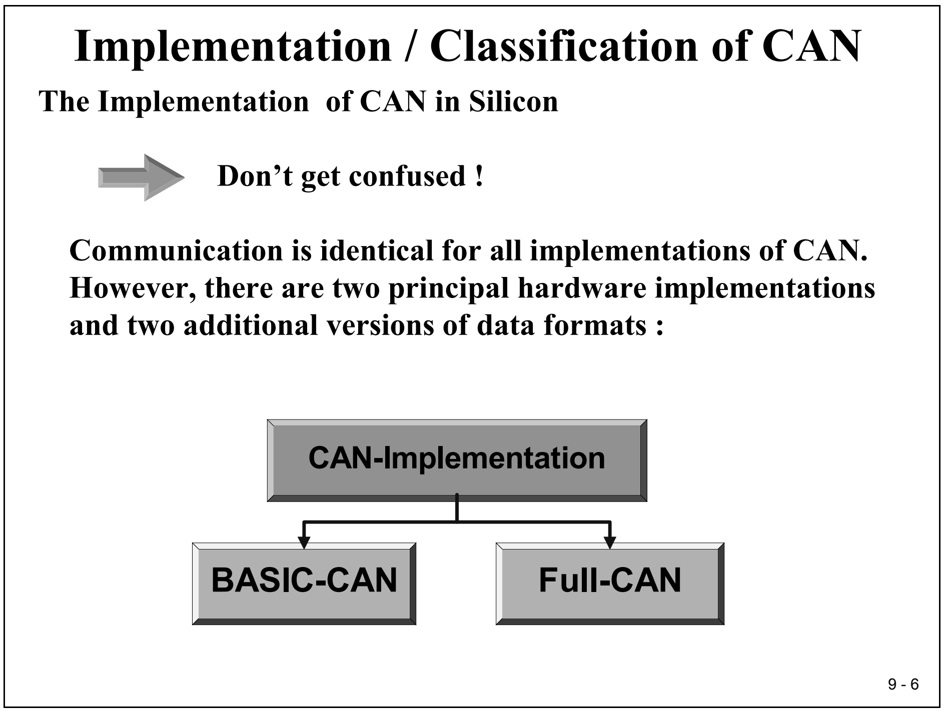
CAN does not use physical addresses to address stations. Each message is sent with an identifier that is recognized by the different nodes. The identifier has two functions – it is used for message filtering and for message priority. The identifier determines if a transmitted message will be received by CAN modules and determines the priority of the message when two or more nodes want to transmit at the same time.

The bus access procedure is a multi-master principle, all nodes are allowed to use CAN as a master node. One of the basic differences to Ethernet is the adoption of non-destructive bus arbitration in case of collisions, called “Carrier Sense Multiple Access with Collision Avoidance“(CSMA/CA). This procedure ensures that in case of an access conflict, the message with higher priority will not be delayed by this collision.

The physical length of the CAN is limited, depending on the baud rate. The data frame consists of a few bytes only (maximum 8), which increases the ability of the net to respond to new transmit requests. On the other hand, this feature makes CAN unsuitable for very high data throughputs, for example, for real time video processing.

There are several physical implementations of CAN, such as differential twisted pair (automotive class: CAN high speed), single line (automotive class: CAN low speed) or fibre optic CAN, for use in harsh environments.

CAN Implementation



Implementation / Classification of CAN

The Implementation of CAN in Silicon

Don't get confused !

Communication is identical for all implementations of CAN. However, there are two principal hardware implementations and two additional versions of data formats :

$$\begin{tikzcd} & \text{CAN-Implementation} \arrow[dl] \arrow[dr] & \\ \text{BASIC-CAN} & & \text{Full-CAN} \end{tikzcd}$$

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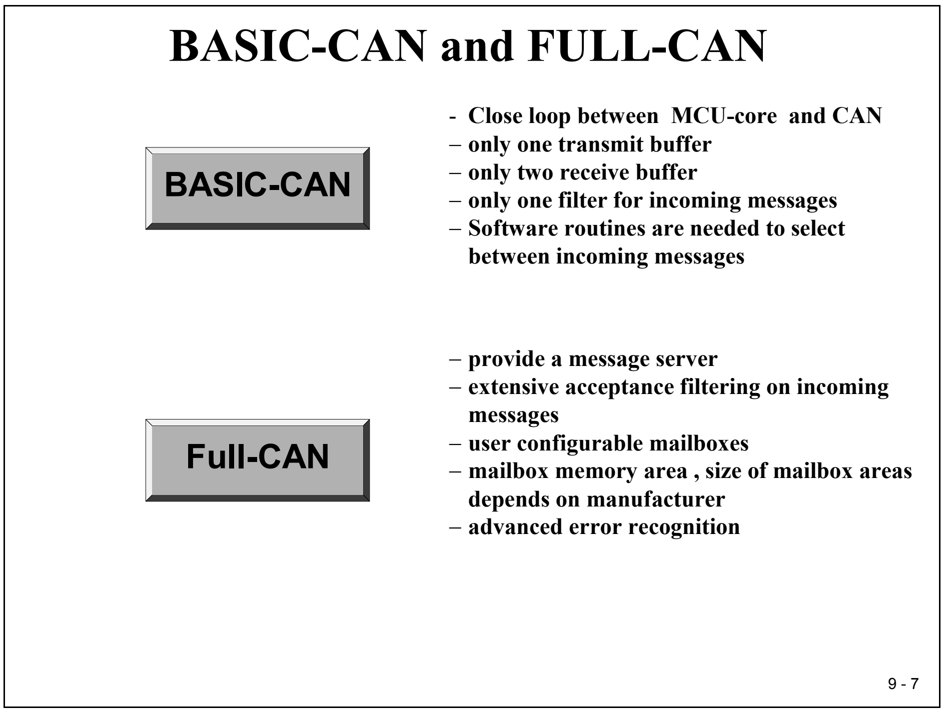
There are two versions of how the CAN-module is implemented in silicon, called "BASIC" and "Full" – CAN. Almost all new processors with a built-in CAN module offer both modes of operation. BASIC-CAN as the only mode is normally used in cost sensitive applications.



BASIC-CAN and FULL-CAN

BASIC-CAN

- **Close loop between MCU-core and CAN**
- **only one transmit buffer**
- **only two receive buffer**
- **only one filter for incoming messages**
- **Software routines are needed to select between incoming messages**

Full-CAN

- **provide a message server**
- **extensive acceptance filtering on incoming messages**
- **user configurable mailboxes**
- **mailbox memory area , size of mailbox areas depends on manufacturer**
- **advanced error recognition**

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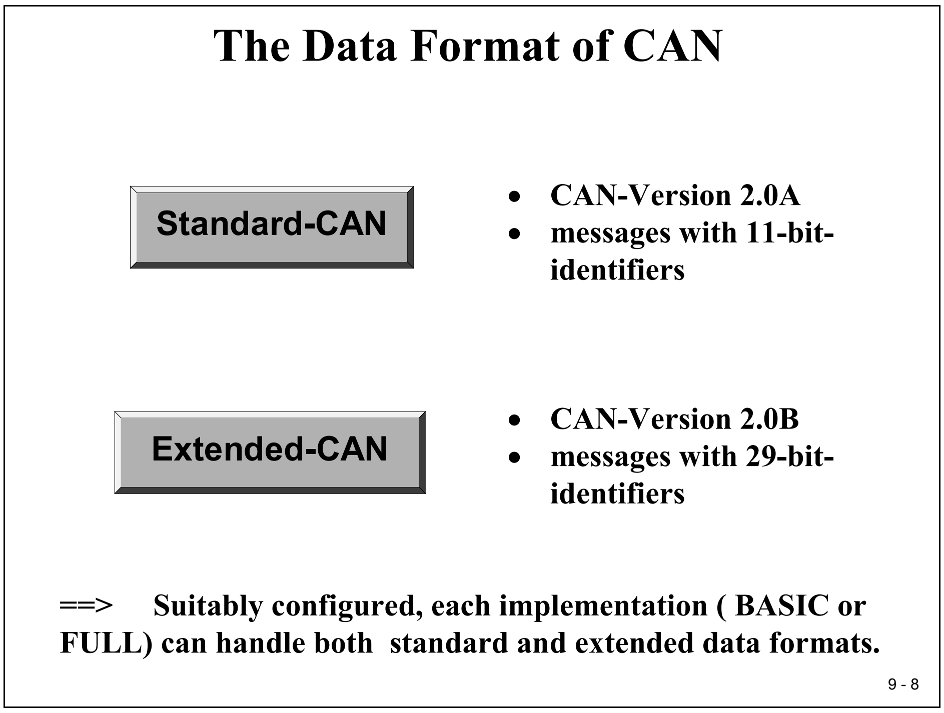
CAN Data Frame



The Data Format of CAN

Standard-CAN

- **CAN-Version 2.0A**
- **messages with 11-bit-identifiers**

Extended-CAN

- **CAN-Version 2.0B**
- **messages with 29-bit-identifiers**

==> Suitably configured, each implementation (BASIC or FULL) can handle both standard and extended data formats.

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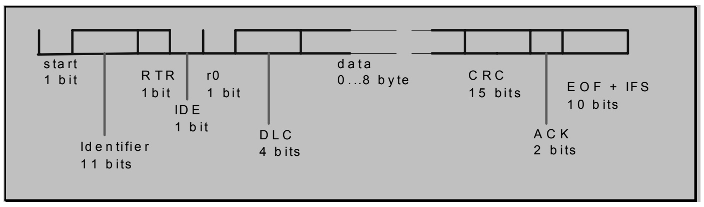
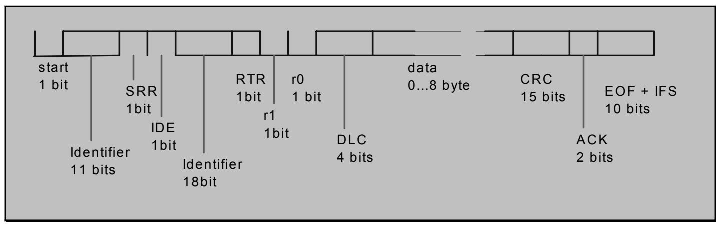
The two versions of the data frame format allow the reception and transmission of standard frames and extended frames in a mixed physical set up, provided the silicon is able to handle both types simultaneously (CAN version 2.0A and 2.0B respectively).

The CAN Data Frame (cont.)



DATA-Frame CAN 2.0A (11-bit-identifier)



DATA-Frame CAN 2.0B (29-bit-identifier)

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The CAN Data Frame

each data frame consists of four segments :

(1) arbitration-field :

- **denote the priority of the message**
- **logical address of the message (identifier)**
- **Standard frame , CAN 2.0A : 11 bit-identifier**
- **Extended frame (CAN 2.0B) : 29 bit-identifier**

(2) data field :

- **up to 8 bytes per message ,**
- **a 0 byte message is also permitted**

(3) CRC field:

- **cyclic redundancy check ; contains a checksum generated by a CRC-polynomial**

(4) end of frame field:

- **contains acknowledgement , error-messages, end of message**

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The CAN Data Frame (cont.)

start bit	**(1 bit - dominant): flag for the begin of a message; after idle-time falling-edge to synchronise all transmitters**
identifier	**(11 bit) : mark the name of the message and its priority ;the lower the value the higher the priority**
RTR	**(1 bit) : remote transmission request ; if RTR=1 (recessive) no valid data's inside the frame - it is a request for receivers to send their messages**
IDE	**(1 bit) : Identifier Extension ; if IDE=1 then extended CAN-frame**
r0	**(1 bit) :reserved**
CDL	**(4 bit) : data length code, code-length 9 to 15 are not permitted !**
data	**(0..8 byte) : the data's of the message**
CRC	**(15 bit) : cyclic redundancy code ; only to detect errors, no correction ; hamming-distance 6 (up to 6 single bit errors)**
ACK	**(2 bit) : acknowledge ; each listener, which receive a message without errors (including CRC !) has to transmit an acknowledge-bit in this time-slot !!!**
EOF	**(7 bit = 1 , recessive) : end of frame ; intentional violation of the bit-stuff-rule ; normally after five recessive bits one stuff-bit follows automatically**
IFS	**(3 bit = 1 recessive) : inter frame space ; time space to copy a received message from bus-handler into buffer**

Extended Frame only :

SRR	**(1 bit = recessive) : substitute remote request ; substitution of the RTR-bit in standard frames**
r1	**(1 bit): reserved**

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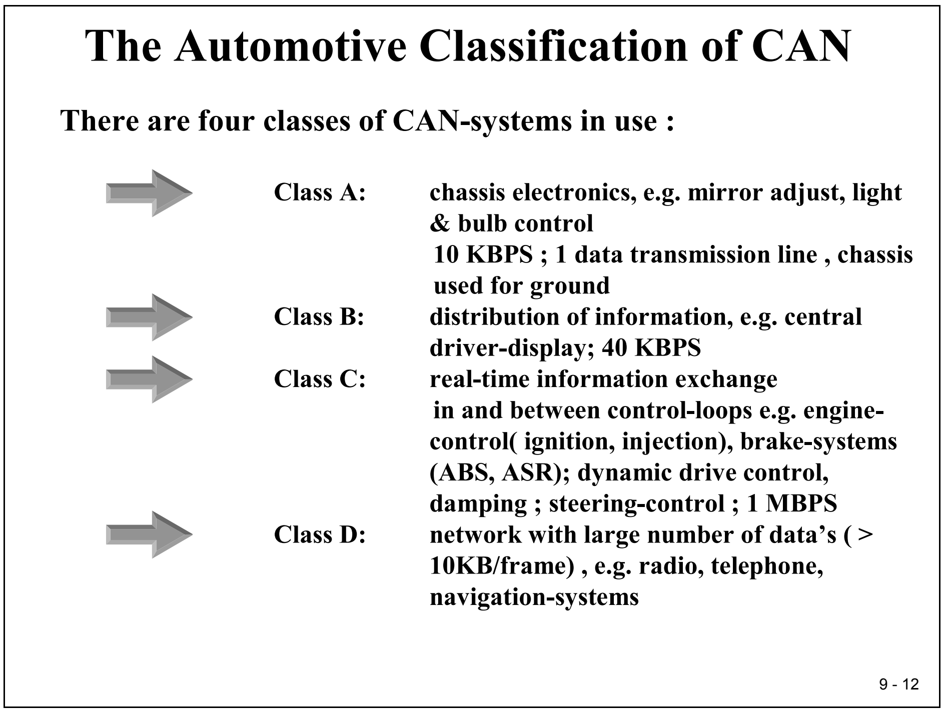
CAN Automotive Classes



The Automotive Classification of CAN

There are four classes of CAN-systems in use :

Class A:	**chassis electronics, e.g. mirror adjust, light & bulb control 10 KBPS ; 1 data transmission line , chassis used for ground**
Class B:	**distribution of information, e.g. central driver-display; 40 KBPS**
Class C:	**real-time information exchange in and between control-loops e.g. engine-control(ignition, injection), brake-systems (ABS, ASR); dynamic drive control, damping ; steering-control ; 1 MBPS**
Class D:	**network with large number of data's (> 10KB/frame) , e.g. radio, telephone, navigation-systems**

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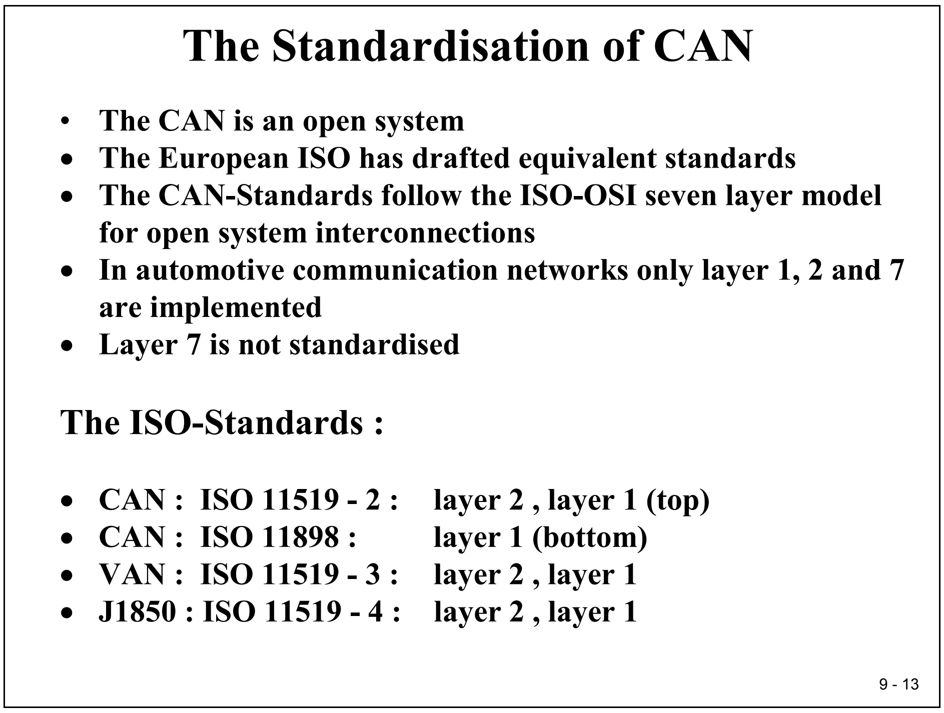
The four automotive CAN classes are used to specify different groups of electronic control units in a car. There are also different specifications for Electromagnetic Compatibility (EMC) compliances and tailored versions of physical transceivers available for the four classes in use. Class A and B are quite often specified as "Low Speed CAN" with a data rate of 100 kbps. Class C usually is implemented as "High Speed CAN", commonly with a baud rate of 500 kbps.

For more details on automotive electronics, look out for additional classes in your university. A highly recommended textbook about CAN in automotive applications is:

"CAN System Engineering"
Wolfhard Lawrenz
SpringerN.Y. 1997
ISBN: 0-387-94939-9

ISO Standardization



The Standardisation of CAN

- The CAN is an open system
- The European ISO has drafted equivalent standards
- The CAN-Standards follow the ISO-OSI seven layer model for open system interconnections
- In automotive communication networks only layer 1, 2 and 7 are implemented
- Layer 7 is not standardised

The ISO-Standards :

- CAN : ISO 11519 - 2 : layer 2 , layer 1 (top)
- CAN : ISO 11898 : layer 1 (bottom)
- VAN : ISO 11519 - 3 : layer 2 , layer 1
- J1850 : ISO 11519 - 4 : layer 2 , layer 1

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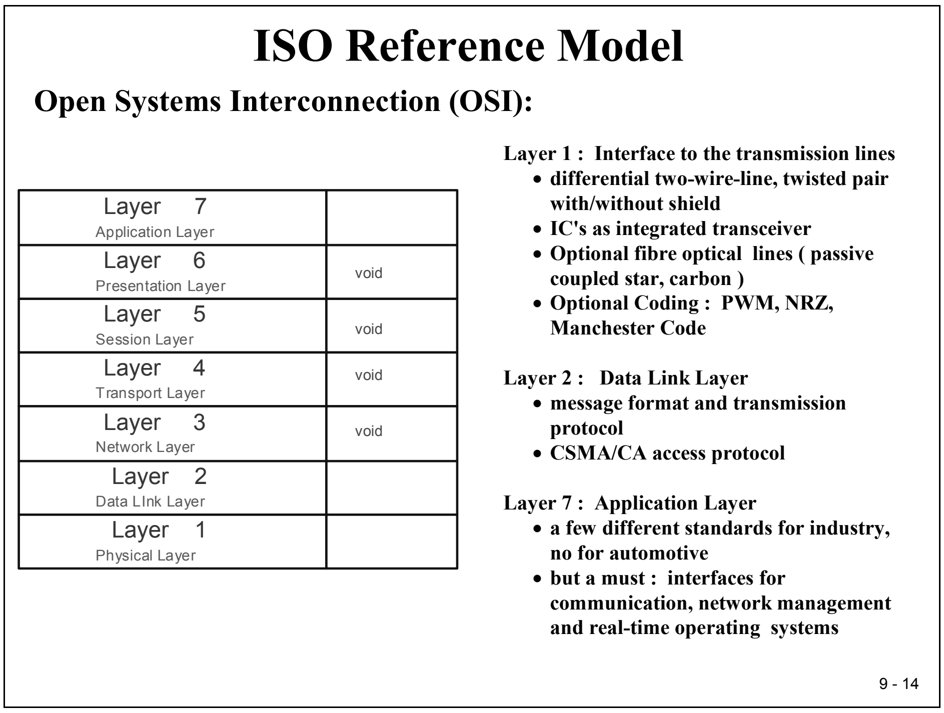

ISO Reference Model

Open Systems Interconnection (OSI):

Layer 7 Application Layer	
Layer 6 Presentation Layer	void
Layer 5 Session Layer	void
Layer 4 Transport Layer	void
Layer 3 Network Layer	void
Layer 2 Data LInk Layer	
Layer 1 Physical Layer	

Layer 1 : Interface to the transmission lines
- differential two-wire-line, twisted pair with/without shield
- IC's as integrated transceiver
- Optional fibre optical lines (passive coupled star, carbon)
- Optional Coding : PWM, NRZ, Manchester Code

Layer 2 : Data Link Layer
- message format and transmission protocol
- CSMA/CA access protocol

Layer 7 : Application Layer
- a few different standards for industry, no for automotive
- but a must : interfaces for communication, network management and real-time operating systems

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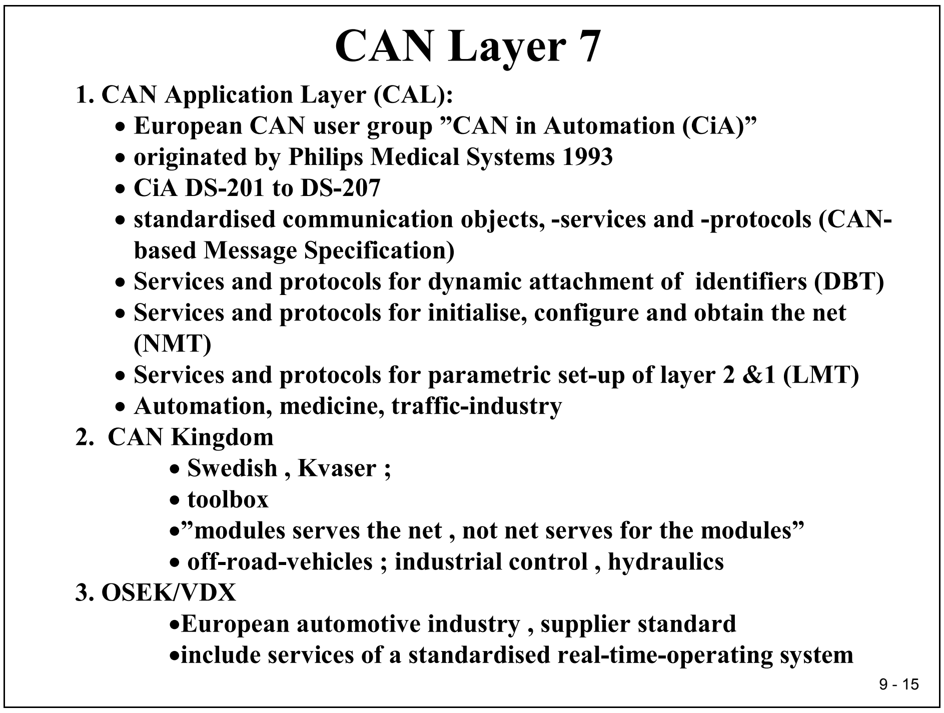
CAN Application Layer



CAN Layer 7

1. CAN Application Layer (CAL):
   - European CAN user group "CAN in Automation (CiA)"
   - originated by Philips Medical Systems 1993
   - CiA DS-201 to DS-207
   - standardised communication objects, -services and -protocols (CAN-based Message Specification)
   - Services and protocols for dynamic attachment of identifiers (DBT)
   - Services and protocols for initialise, configure and obtain the net (NMT)
   - Services and protocols for parametric set-up of layer 2 &1 (LMT)
   - Automation, medicine, traffic-industry
2. CAN Kingdom
   - Swedish , Kvaser ;
   - toolbox
   - "modules serves the net , not net serves for the modules"
   - off-road-vehicles ; industrial control , hydraulics
3. OSEK/VDX
   - European automotive industry , supplier standard
   - include services of a standardised real-time-operating system

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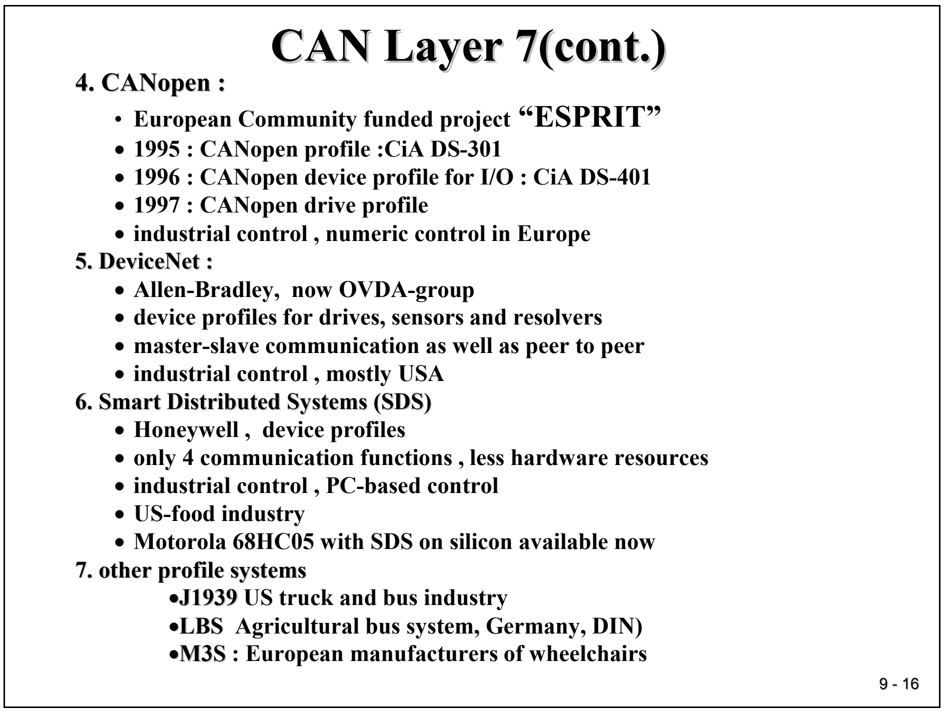

CAN Layer 7(cont.)

4. CANopen :
   - European Community funded project "ESPRIT"
   - 1995 : CANopen profile :CiA DS-301
   - 1996 : CANopen device profile for I/O : CiA DS-401
   - 1997 : CANopen drive profile
   - industrial control , numeric control in Europe
5. DeviceNet :
   - Allen-Bradley, now OVDA-group
   - device profiles for drives, sensors and resolvers
   - master-slave communication as well as peer to peer
   - industrial control , mostly USA
6. Smart Distributed Systems (SDS)
   - Honeywell , device profiles
   - only 4 communication functions , less hardware resources
   - industrial control , PC-based control
   - US-food industry
   - Motorola 68HC05 with SDS on silicon available now
7. other profile systems
   - J1939 US truck and bus industry
   - LBS Agricultural bus system, Germany, DIN)
   - M3S : European manufacturers of wheelchairs

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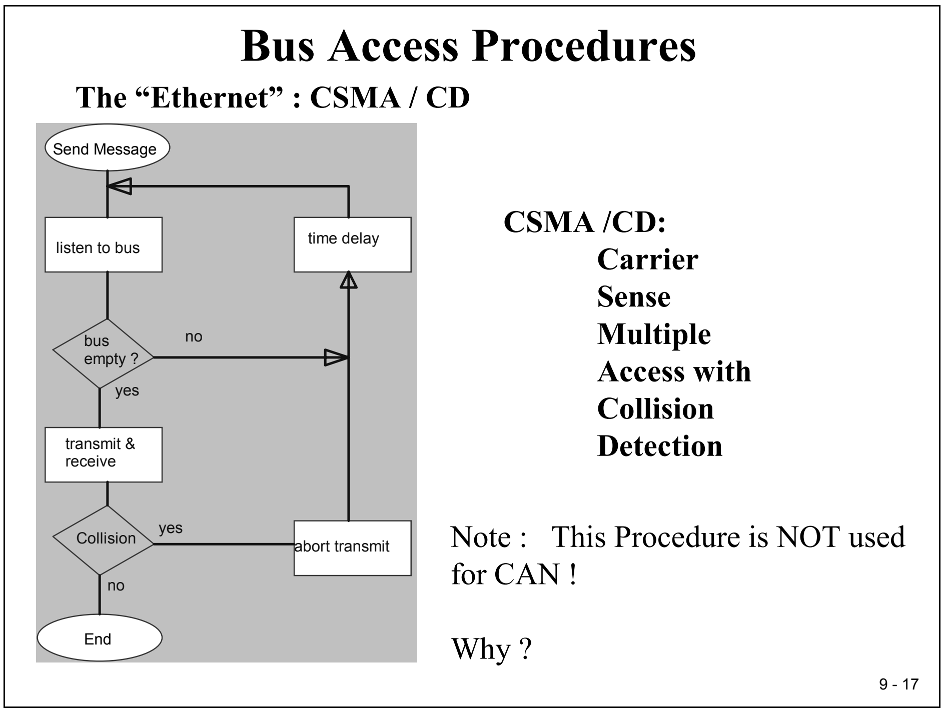
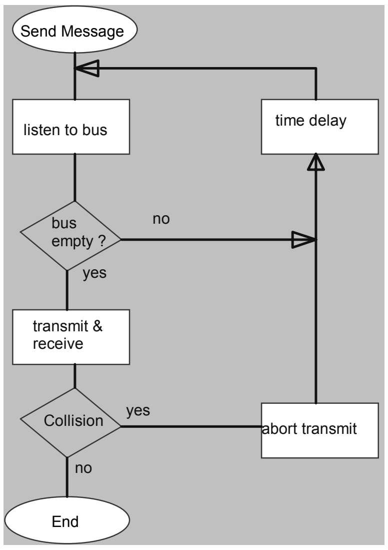
CAN Bus Arbitration – CSMA/CA



Bus Access Procedures

The "Ethernet" : CSMA / CD



CSMA /CD:
Carrier
Sense
Multiple
Access with
Collision
Detection

Note : This Procedure is NOT used for CAN !

Why ?

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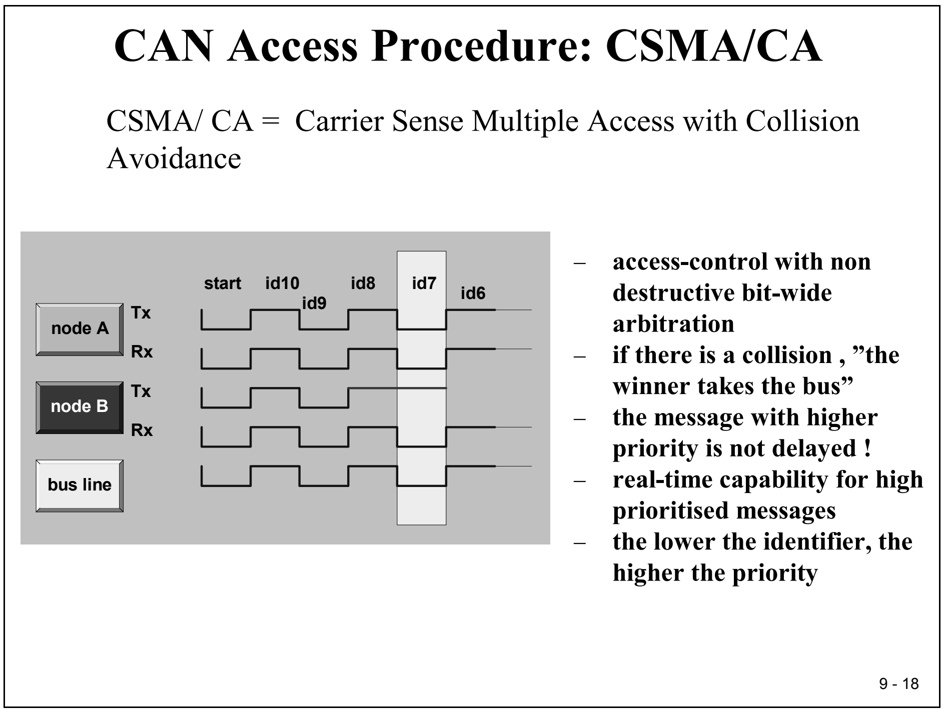
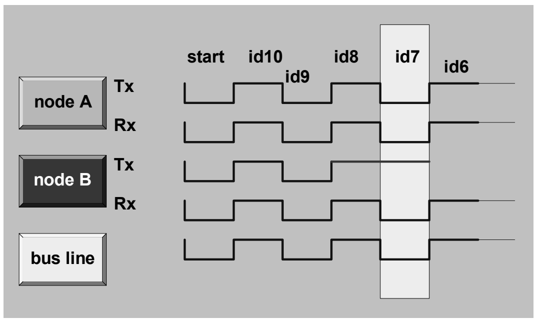


CAN Access Procedure: CSMA/CA

CSMA/ CA = Carrier Sense Multiple Access with Collision Avoidance



- **access-control with non destructive bit-wide arbitration**
- **if there is a collision , "the winner takes the bus"**
- **the message with higher priority is not delayed !**
- **real-time capability for high prioritised messages**
- **the lower the identifier, the higher the priority**

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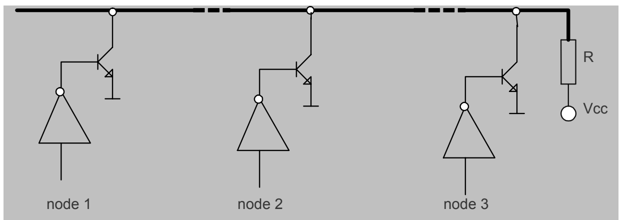
CSMA/CA (cont.)

CSMA / CA =

"bit - wide arbitration during transmission with simultaneous receiving and comparing of the transmitted message"

means :

- **if there is a collision within the arbitration-field, only the node with the lower priority cancels its transmission.**
- **The node with the highest priority continues with the transmission of the message.**



high : reccessive

low : dominant

node 1	node 2	node 3	bus
high	high	high	high
high	low	high	low
low	low	high	low

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As you can see from the previous slide the arbitration procedure at a physical level is quite simple: it is a “wired-AND” principle. Only if all 3 node voltages (node 1, node2 or node3) are equal to 1 (recessive), the bus voltage stays at V_{cc} (recessive). If only one node voltage is switched to 0 (dominant), the bus voltage is forced to the dominant state (0).

The beauty of CAN is that the message with highest priority is not delayed at all in case of a collision. For the message with highest priority, we can determine the worst-case response time for a data transmission. For messages with other priorities, to calculate the worst-case response time is a little bit more complex task. It could be done by applying a so-called “time dilatation formula for non-interruptible systems”:

$$\boxed{R_i^{n+1} = C_i + B_{\max\, i} + \sum_{j \in hp(i)} \left\lceil \frac{R_i^n - C_i}{T_j} \right\rceil * C_j}$$

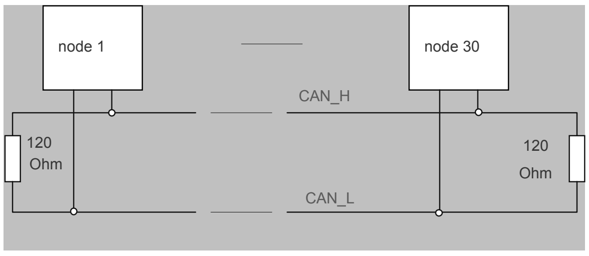
HARTER, P.K: “Response Times in level structured systems” Techn. Report, Univ. of Colorado, 1991

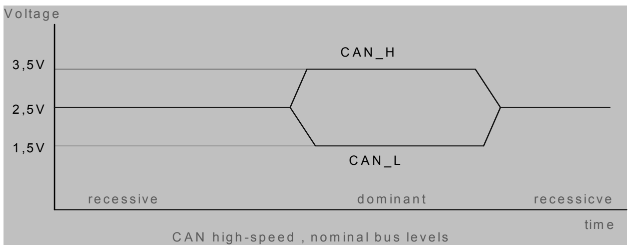
In detail, the hardware structure of a CAN-transceiver is more complex. Due to the principle of CAN-transmissions as a “broadcast” type of data communication, all CAN-modules are forced to “listen” to the bus all the time. This also includes the arbitration phase of a data frame. It is very likely that a CAN-module might lose the arbitration procedure. In this case, it is necessary for this particular module to switch into receive mode immediately. This requires every transceiver to provide the actual bus voltage status permanently to the CAN-module.

High Speed CAN

CAN Physical Layers

CAN - High - Speed (ISO 11898) :





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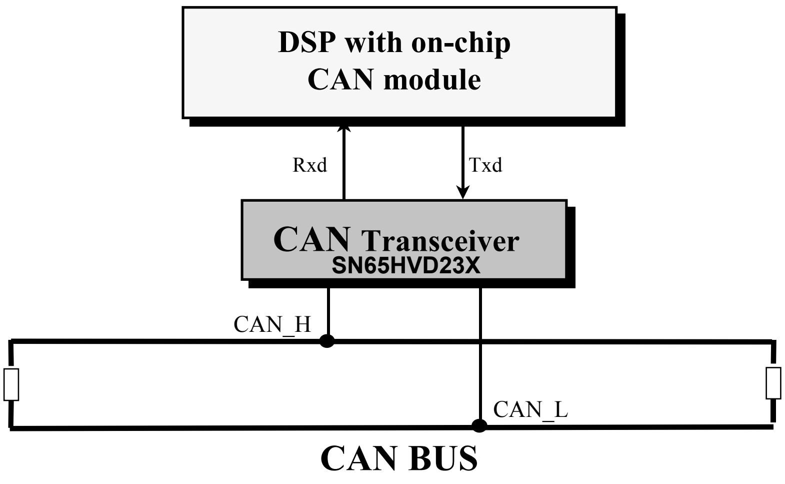
To generate the voltage levels for the differential voltage transmission according to CAN High Speed we need an additional transceiver device, e.g. the SN65HVD23x.

CAN High speed Node



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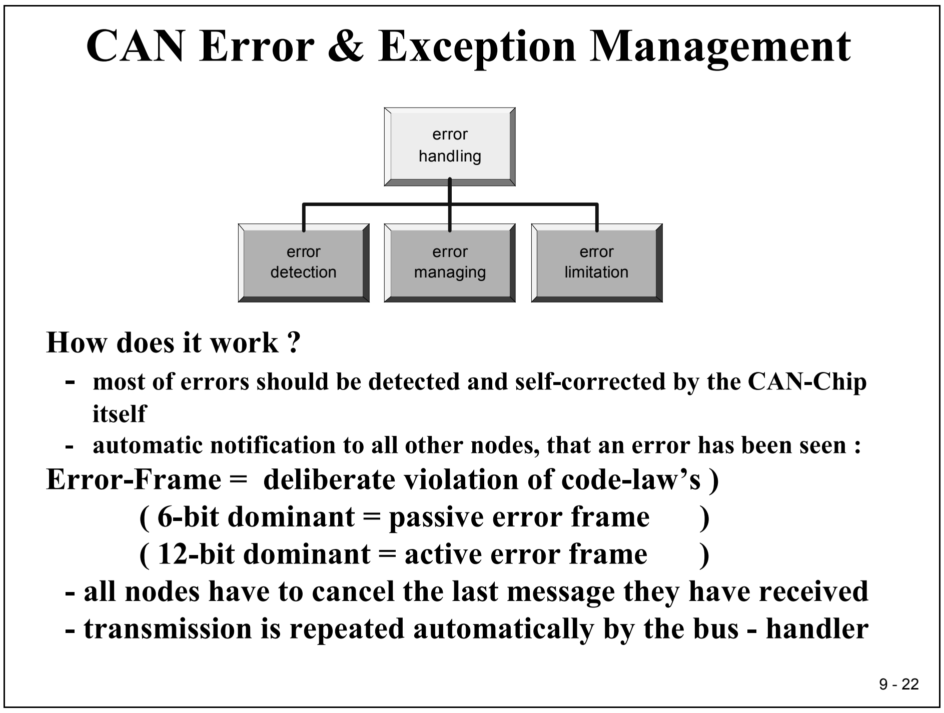
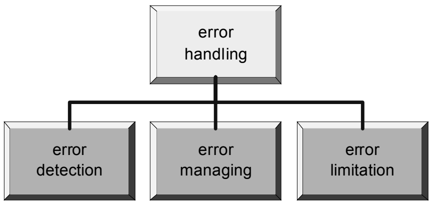
CAN Error Management



CAN Error & Exception Management



How does it work ?

- **most of errors should be detected and self-corrected by the CAN-Chip itself**
- **automatic notification to all other nodes, that an error has been seen :**

Error-Frame = deliberate violation of code-law’s)

(6-bit dominant = passive error frame)

(12-bit dominant = active error frame)

- all nodes have to cancel the last message they have received

- transmission is repeated automatically by the bus - handler

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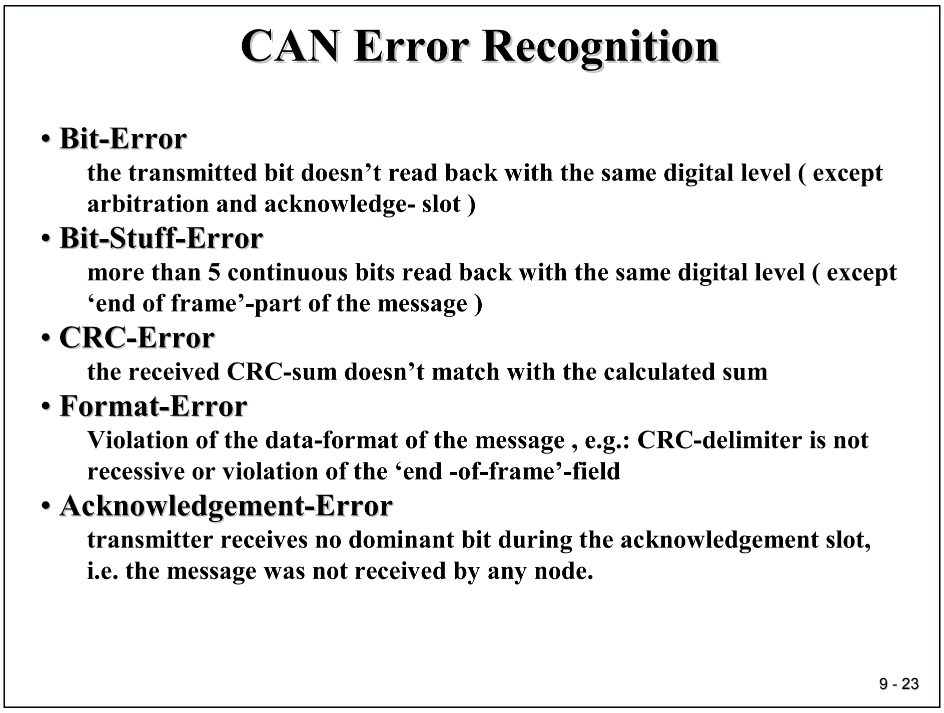

CAN Error Recognition

- **Bit-Error**
  the transmitted bit doesn’t read back with the same digital level (except arbitration and acknowledge- slot)
- **Bit-Stuff-Error**
  more than 5 continuous bits read back with the same digital level (except ‘end of frame’-part of the message)
- **CRC-Error**
  the received CRC-sum doesn’t match with the calculated sum
- **Format-Error**
  Violation of the data-format of the message , e.g.: CRC-delimiter is not recessive or violation of the ‘end -of-frame’-field
- **Acknowledgement-Error**
  transmitter receives no dominant bit during the acknowledgement slot, i.e. the message was not received by any node.

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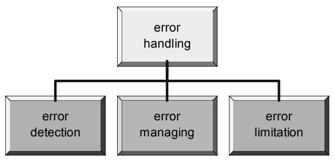
CAN Error Sequence



After detection of an error by a node every other node receives a particular frame , the Error -Frame :
This is the violation of the stuff-bit-rule by transmission of at least 6 dominant bits.
The Error-Frame causes all other nodes to recognise an Error Status of the bus.

Error Management Sequence :

- **error is detected**
- **error-frame will be transmitted by all nodes, which have detected this error**
- **The last message received will be cancelled by all nodes**
- **Internal hardware error-counters will be increased**
- **The original message will be transmitted again.**

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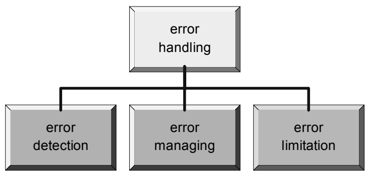
CAN Error Status



* **Purpose: avoid persistent disturbances of the CAN by switching off defective nodes**

* **three Error States :**

Error Active : normal mode, messages will be received and transmitted. In case of error an active error frame will be transmitted

Error Passive : after detection of a fixed number of errors , the node reaches this state. messages will be received and transmitted, in case of error the node sends a passive error frame.

Bus Off : the node is separated from CAN , neither transmission nor receive of messages is allowed, node is not able to transmit error frame's .
leaving this state is only possible by reset !

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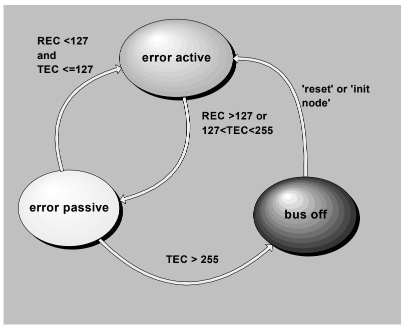
CAN Error Counter

State - Diagram :



- **transitions will be carried out automatically by the CAN-chip**
- **states are managed by 2 Error Counters :**
  Receive Error Counter (REC)
  Transmit Error Counter (TEC)
- **Possible situations :**

a) a transmitter recognises an error:
TEC:=TEC + 8
b) a receiver sees an error : REC:=REC + 1
c) a receiver sees an error, after transmitting an error frame: REC:=REC + 8
d) if an 'error active'-node find's a bit-stuff-error during transmission of an error frame:
TEC:=TEC+ 1
e) successful transmission:
TEC:=TEC - 1
f) successful receive :
REC:=REC - 1

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C28x CAN Module

C28x CAN Features

- **Fully CAN protocol compliant, version 2.0B**
- **Supports data rates up to 1 Mbps**
- **Thirty-two mailboxes**
  - **Configurable as receive or transmit**
  - **Configurable with standard or extended identifier**
  - **Programmable receive mask**
  - **Supports data and remote frame**
  - **Composed of 0 to 8 bytes of data**
  - **Uses 32-bit time stamp on messages**
  - **Programmable interrupt scheme (two levels)**
  - **Programmable alarm time-out**
- **Programmable wake-up on bus activity**
- **Self-test mode**

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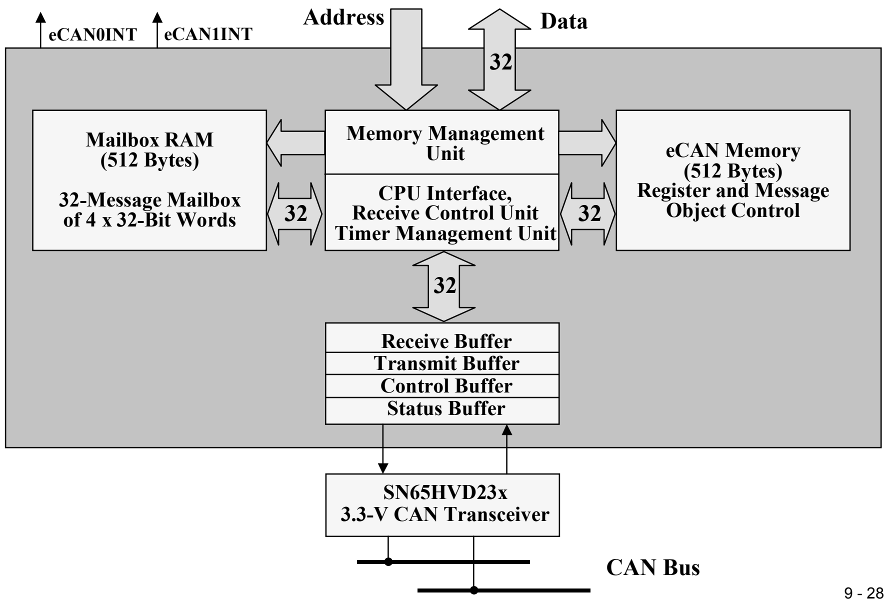
The DSP CAN module is a full CAN Controller. It contains a message handler for transmission, a reception management and frame storage. The specification is CAN 2.0B Active – that is, the module can send and accept standard (11-bit identifier) and extended frames (29-bit identifier).

CAN Block Diagram


eCAN0INT
eCAN1INT
Address
Data
32
Mailbox RAM (512 Bytes)
32-Message Mailbox of 4 x 32-Bit Words
Memory Management Unit
CPU Interface, Receive Control Unit Timer Management Unit
eCAN Memory (512 Bytes) Register and Message Object Control
32
32
32
Receive Buffer
Transmit Buffer
Control Buffer
Status Buffer
SN65HVD23x 3.3-V CAN Transceiver
CAN Bus

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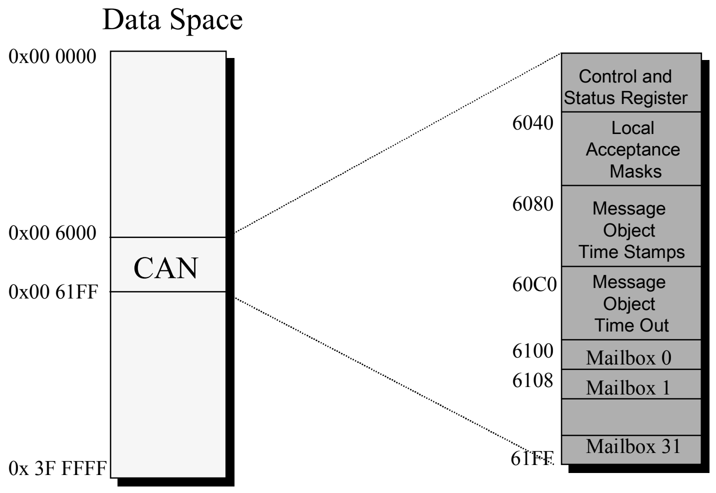
C28x Programming Interface

CAN Memory



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The CAN controller module contains 32 mailboxes for objects of 0- to 8-byte data lengths:

- configurable transmit/receive mailboxes
- configurable with standard or extended identifier

The CAN module mailboxes are divided into several parts:

- MID – contains the identifier of the mailbox
- MCF (Message Control Field) – contains the length of the message (to transmit or receive) and the RTR bit (Remote Transmission Request – used to send remote frames)
- MDL and MDH – contains the data

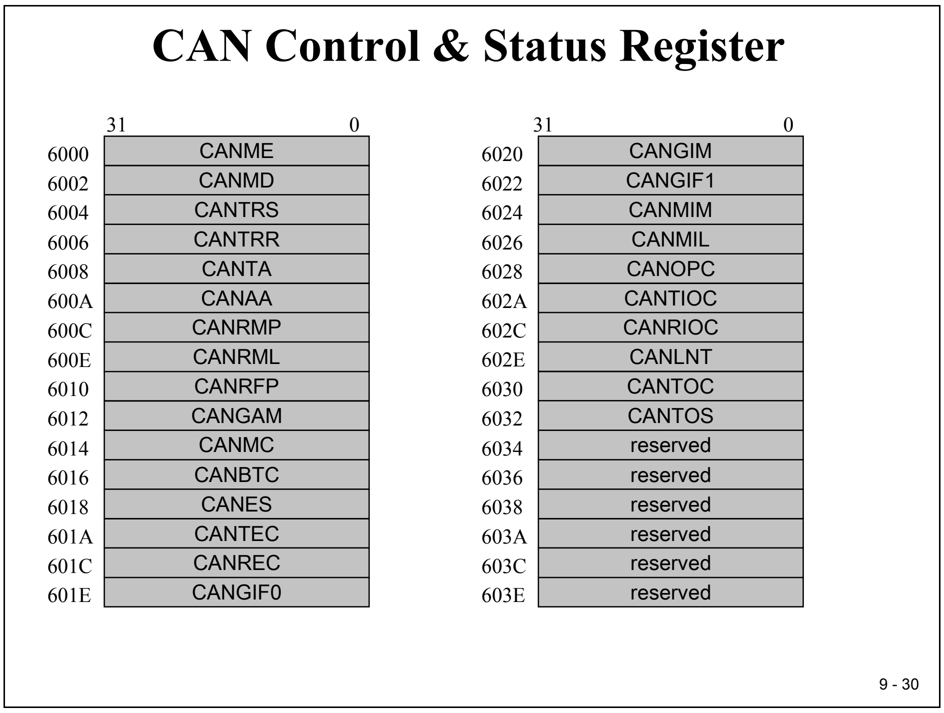
The CAN module contains registers, which are divided into five groups. These registers are located in data memory from 0x006000 to 0x0061FF. The five register groups are:

- Control & Status Registers
- Local Acceptance Masks
- Message Object Time Stamps
- Message Object Timeout
- Mailboxes

It is the responsibility of the programmer to go through all those registers and set every single bit according to the designated operating mode of the CAN module. It is also a challenge for a student to exercise the skills required to debug. So let's start!

First, we will discuss the different CAN registers. If this chapter becomes too tedious, ask your teacher for some practical examples how to use the various options. Be patient!

CAN Register Map



CAN Control & Status Register

	31 … 0		31 … 0
6000	CANME	6020	CANGIM
6002	CANMD	6022	CANGIF1
6004	CANTRS	6024	CANMIM
6006	CANTRR	6026	CANMIL
6008	CANTA	6028	CANOPC
600A	CANAA	602A	CANTIOC
600C	CANRMP	602C	CANRIOC
600E	CANRML	602E	CANLNT
6010	CANRFP	6030	CANTOC
6012	CANGAM	6032	CANTOS
6014	CANMC	6034	reserved
6016	CANBTC	6036	reserved
6018	CANES	6038	reserved
601A	CANTEC	603A	reserved
601C	CANREC	603C	reserved
601E	CANGIF0	603E	reserved

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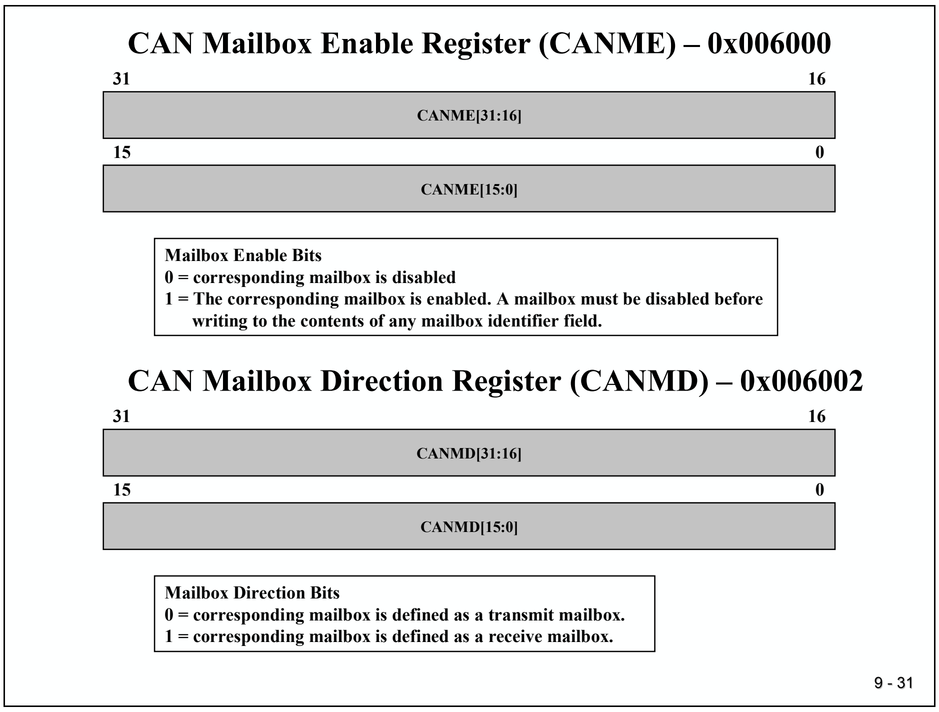
Mailbox Enable – CANME   Mailbox Direction - CANMD



CAN Mailbox Enable Register (CANME) – 0x006000

31 … 16
CANME[31:16]
15 … 0
CANME[15:0]

Mailbox Enable Bits
0 = corresponding mailbox is disabled
1 = The corresponding mailbox is enabled. A mailbox must be disabled before writing to the contents of any mailbox identifier field.

CAN Mailbox Direction Register (CANMD) – 0x006002

31 … 16
CANMD[31:16]
15 … 0
CANMD[15:0]

Mailbox Direction Bits
0 = corresponding mailbox is defined as a transmit mailbox.
1 = corresponding mailbox is defined as a receive mailbox.

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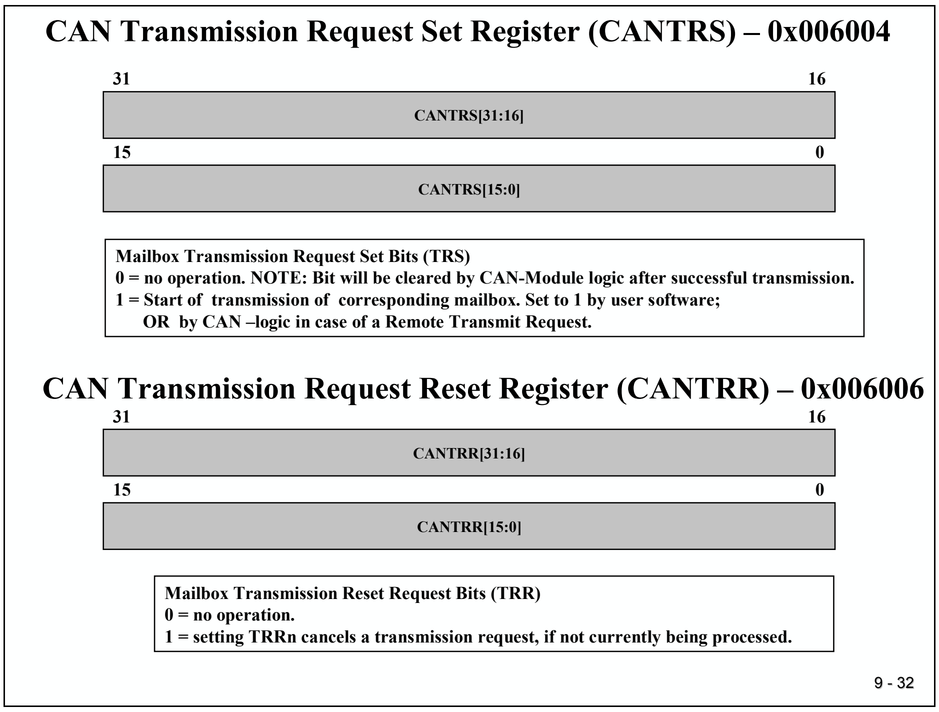
Transmit Request Set & Reset - CANTRS / CANTRR



CAN Transmission Request Set Register (CANTRS) – 0x006004

31	16
CANTRS[31:16]	

15	0
CANTRS[15:0]	

Mailbox Transmission Request Set Bits (TRS)
0 = no operation. NOTE: Bit will be cleared by CAN-Module logic after successful transmission.
1 = Start of transmission of corresponding mailbox. Set to 1 by user software;
OR by CAN –logic in case of a Remote Transmit Request.

CAN Transmission Request Reset Register (CANTRR) – 0x006006

31	16
CANTRR[31:16]	

15	0
CANTRR[15:0]	

Mailbox Transmission Reset Request Bits (TRR)
0 = no operation.
1 = setting TRRn cancels a transmission request, if not currently being processed.

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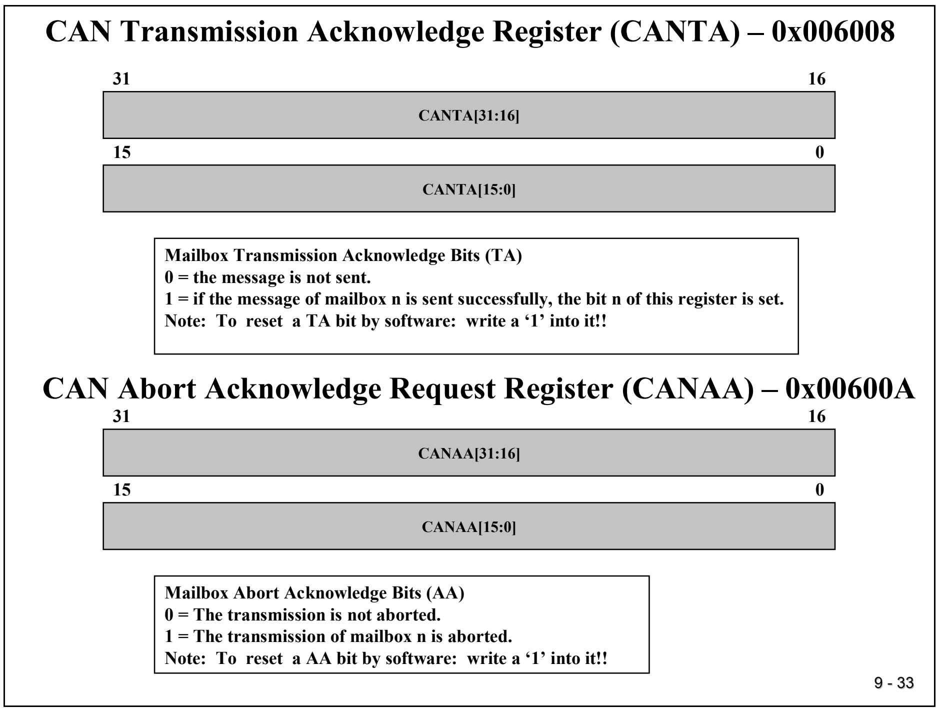
Transmit Acknowledge - CANTA



CAN Transmission Acknowledge Register (CANTA) – 0x006008

31	16
CANTA[31:16]	

15	0
CANTA[15:0]	

Mailbox Transmission Acknowledge Bits (TA)
0 = the message is not sent.
1 = if the message of mailbox n is sent successfully, the bit n of this register is set.
Note: To reset a TA bit by software: write a '1' into it!!

CAN Abort Acknowledge Request Register (CANAA) – 0x00600A

31	16
CANAA[31:16]	

15	0
CANAA[15:0]	

Mailbox Abort Acknowledge Bits (AA)
0 = The transmission is not aborted.
1 = The transmission of mailbox n is aborted.
Note: To reset a AA bit by software: write a '1' into it!!

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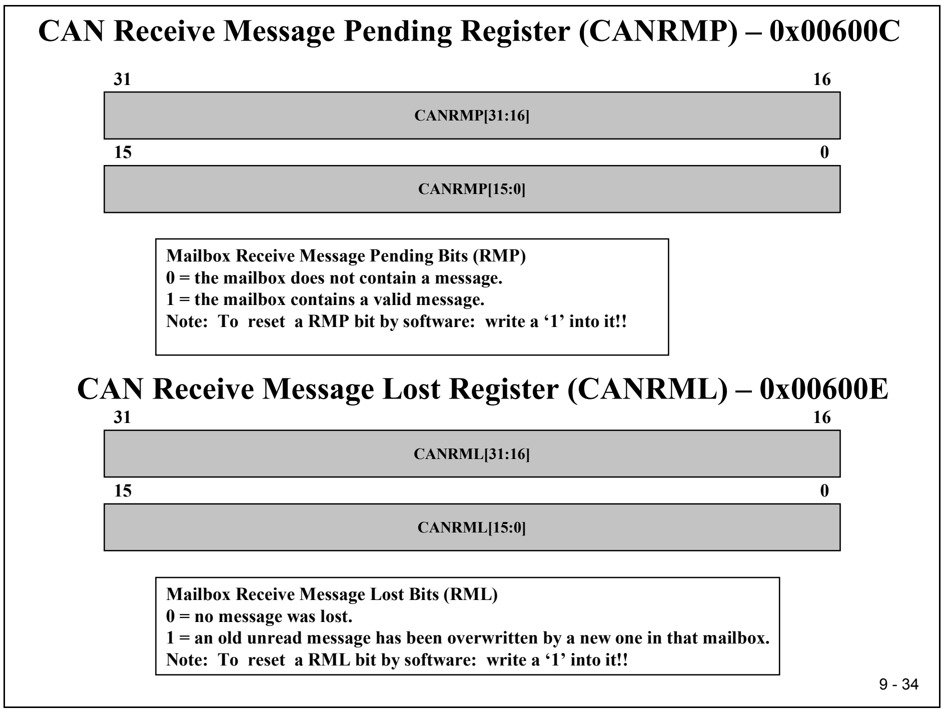
Receive Message Pending - CANRMP



CAN Receive Message Pending Register (CANRMP) – 0x00600C

31	16
CANRMP[31:16]	
15	**0**
CANRMP[15:0]	

Mailbox Receive Message Pending Bits (RMP)
0 = the mailbox does not contain a message.
1 = the mailbox contains a valid message.
Note: To reset a RMP bit by software: write a '1' into it!!

CAN Receive Message Lost Register (CANRML) – 0x00600E

31	16
CANRML[31:16]	
15	**0**
CANRML[15:0]	

Mailbox Receive Message Lost Bits (RML)
0 = no message was lost.
1 = an old unread message has been overwritten by a new one in that mailbox.
Note: To reset a RML bit by software: write a '1' into it!!

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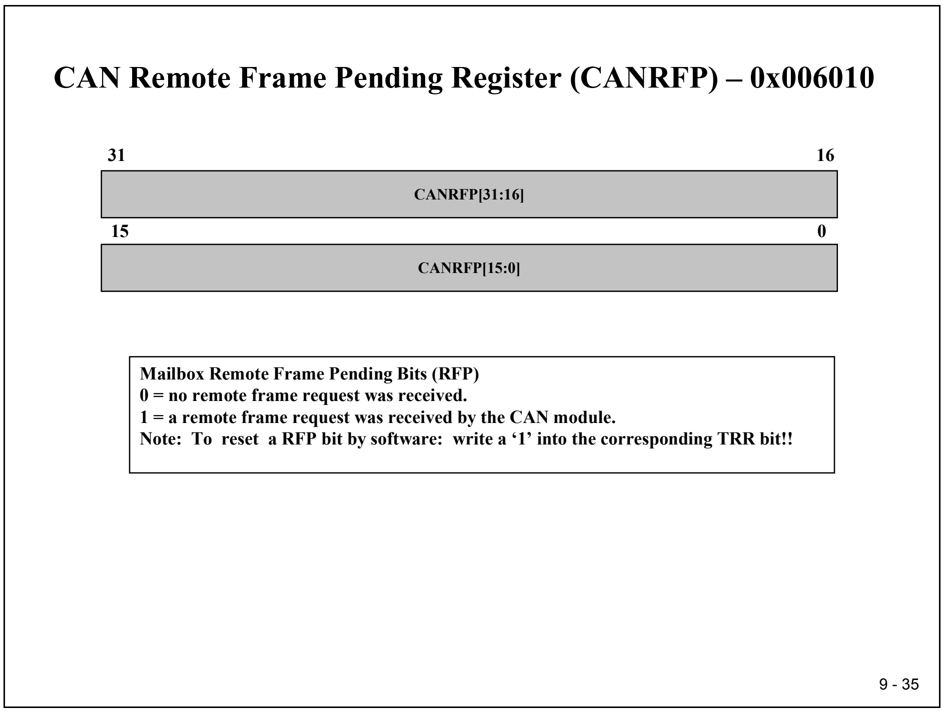
Remote Frame Pending - CANRFP



CAN Remote Frame Pending Register (CANRFP) – 0x006010

31	16
CANRFP[31:16]	
15	**0**
CANRFP[15:0]	

Mailbox Remote Frame Pending Bits (RFP)
0 = no remote frame request was received.
1 = a remote frame request was received by the CAN module.
Note: To reset a RFP bit by software: write a '1' into the corresponding TRR bit!!

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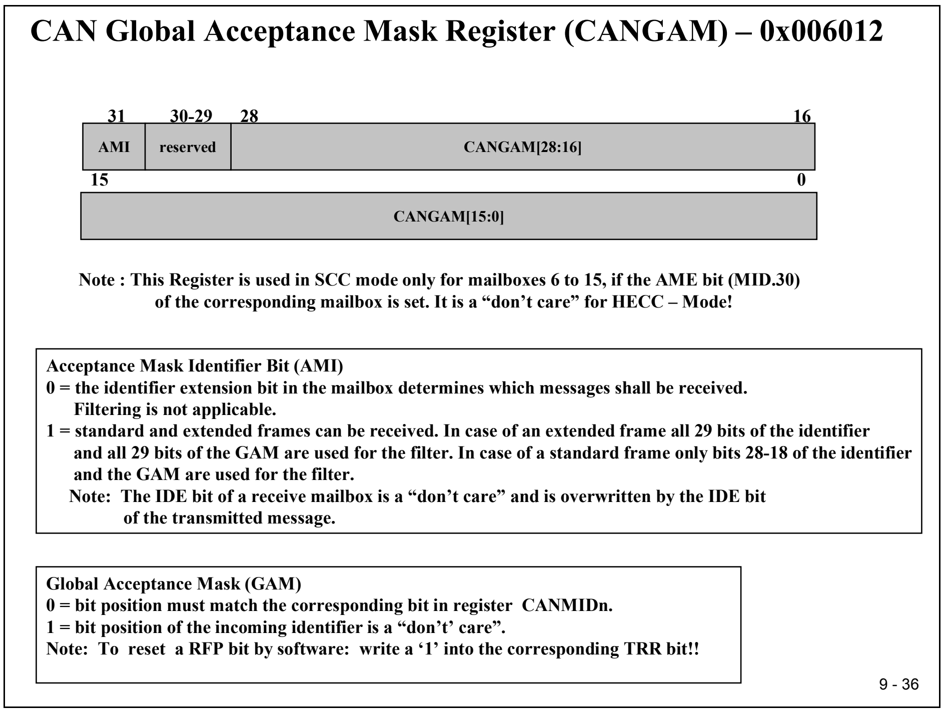
Global Acceptance Mask - CANGAM



CAN Global Acceptance Mask Register (CANGAM) – 0x006012

31	30-29	28 … 16
AMI	reserved	CANGAM[28:16]

15 … 0
CANGAM[15:0]

Note : This Register is used in SCC mode only for mailboxes 6 to 15, if the AME bit (MID.30) of the corresponding mailbox is set. It is a “don’t care” for HECC – Mode!

Acceptance Mask Identifier Bit (AMI)
0 = the identifier extension bit in the mailbox determines which messages shall be received. Filtering is not applicable.
1 = standard and extended frames can be received. In case of an extended frame all 29 bits of the identifier and all 29 bits of the GAM are used for the filter. In case of a standard frame only bits 28-18 of the identifier and the GAM are used for the filter.
Note: The IDE bit of a receive mailbox is a “don’t care” and is overwritten by the IDE bit of the transmitted message.

Global Acceptance Mask (GAM)
0 = bit position must match the corresponding bit in register CANMIDn.
1 = bit position of the incoming identifier is a “don’t’ care”.
Note: To reset a RFP bit by software: write a ‘1’ into the corresponding TRR bit!!

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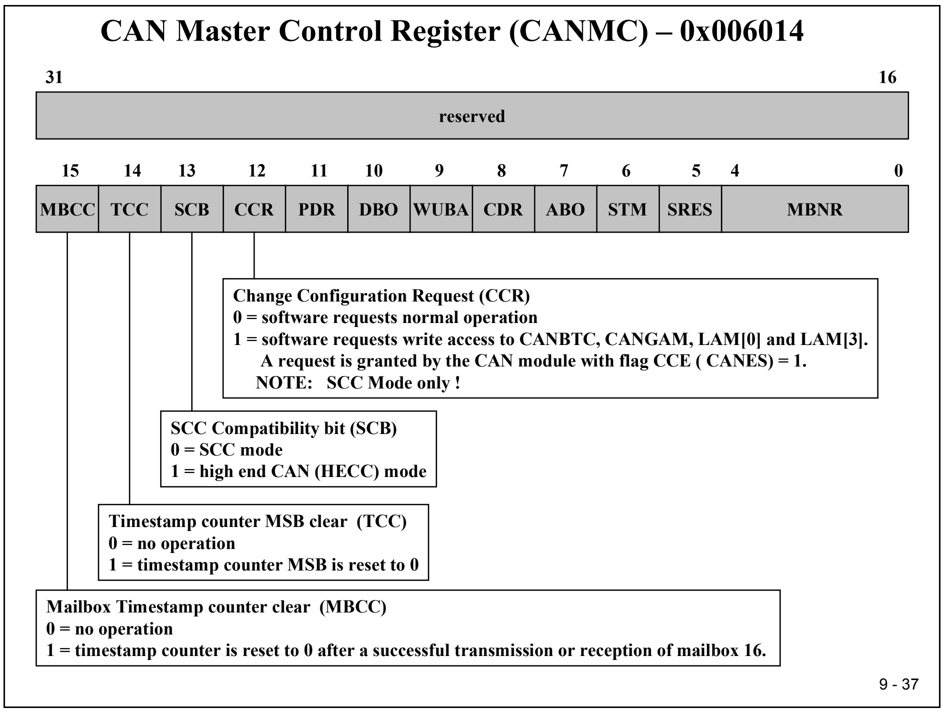
Master Control Register - CANMC



CAN Master Control Register (CANMC) – 0x006014

31 … 16
reserved

15	14	13	12	11	10	9	8	7	6	5	4 … 0
MBCC	TCC	SCB	CCR	PDR	DBO	WUBA	CDR	ABO	STM	SRES	MBNR

Change Configuration Request (CCR)
0 = software requests normal operation
1 = software requests write access to CANBTC, CANGAM, LAM[0] and LAM[3].
A request is granted by the CAN module with flag CCE (CANES) = 1.
NOTE: SCC Mode only !

SCC Compatibility bit (SCB)
0 = SCC mode
1 = high end CAN (HECC) mode

Timestamp counter MSB clear (TCC)
0 = no operation
1 = timestamp counter MSB is reset to 0

Mailbox Timestamp counter clear (MBCC)
0 = no operation
1 = timestamp counter is reset to 0 after a successful transmission or reception of mailbox 16.

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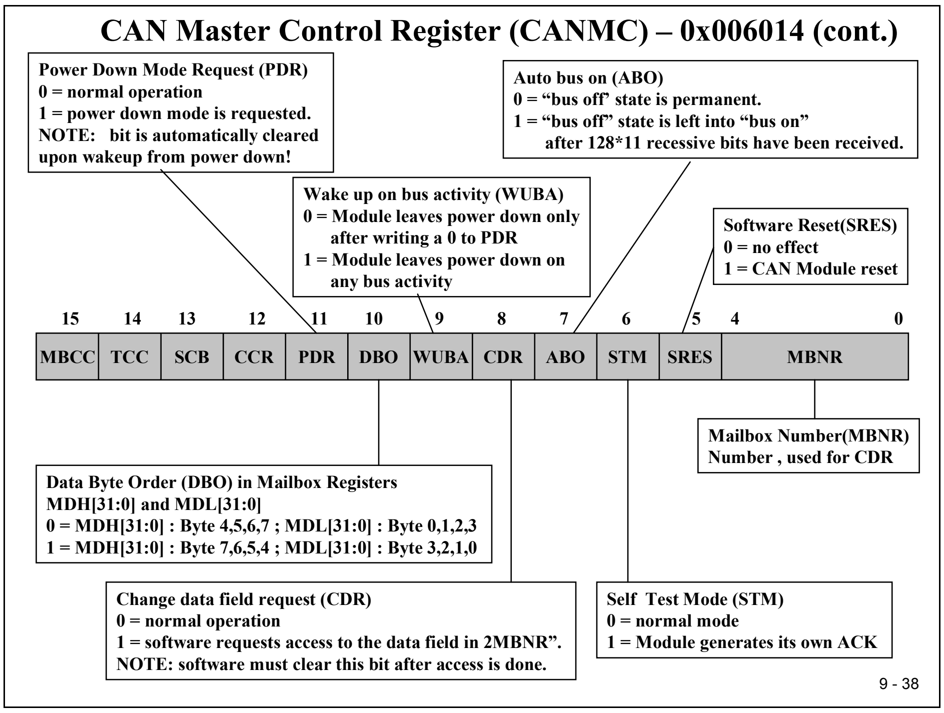

CAN Master Control Register (CANMC) – 0x006014 (cont.)

Power Down Mode Request (PDR)
0 = normal operation
1 = power down mode is requested.
NOTE: bit is automatically cleared upon wakeup from power down!

Auto bus on (ABO)
0 = "bus off" state is permanent.
1 = "bus off" state is left into "bus on"
after 128*11 recessive bits have been received.

Wake up on bus activity (WUBA)
0 = Module leaves power down only after writing a 0 to PDR
1 = Module leaves power down on any bus activity

Software Reset(SRES)
0 = no effect
1 = CAN Module reset

15	14	13	12	11	10	9	8	7	6	5	4 … 0
MBCC	TCC	SCB	CCR	PDR	DBO	WUBA	CDR	ABO	STM	SRES	MBNR

Mailbox Number(MBNR)
Number , used for CDR

Data Byte Order (DBO) in Mailbox Registers MDH[31:0] and MDL[31:0]
0 = MDH[31:0] : Byte 4,5,6,7 ; MDL[31:0] : Byte 0,1,2,3
1 = MDH[31:0] : Byte 7,6,5,4 ; MDL[31:0] : Byte 3,2,1,0

Change data field request (CDR)
0 = normal operation
1 = software requests access to the data field in 2MBNR".
NOTE: software must clear this bit after access is done.

Self Test Mode (STM)
0 = normal mode
1 = Module generates its own ACK

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CAN Bit - Timing

CAN Bit-Timing Configuration

- **CAN protocol specification splits the nominal bit time into four different time segments:**
  - **SYNC_SEG**
    - **Used to synchronize nodes**
    - **Length : always 1 Time Quantum (TQ)**
  - **PROP_SEG**
    - **Compensation time for the physical delay times within the net**
    - **Twice the sum of the signal's propagation time on the bus line, the input comparator delay and the output driver delay.**
    - **Programmable from 1 to 8 TQ**
  - **PHASE_SEG1**
    - **Compensation for positive edge phase shift**
    - **Programmable from 1 to 8 TQ**
  - **PHASE_SEG2**
    - **Compensation time for negative edge phase shift**
    - **Programmable from 2 to 8 TQ**

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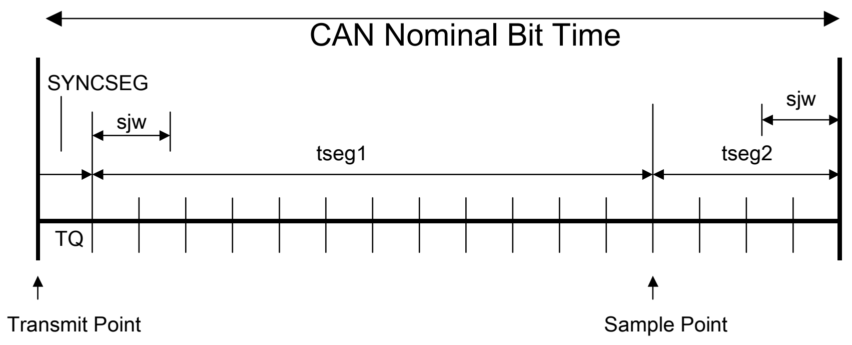
CAN Bit-Timing Configuration



- **tseg1 : PROP_SEG + PHASE_SEG1**
- **tseg2 : PHASE_SEG2**
- **TQ : SYNCSEG**

- **CAN Nominal Bit Time = TQ + tseg1 + tseg2**

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CAN Bit-Timing Configuration

- **According to the CAN – Standard the following bit timing rules must be fulfilled:**
  - **tseg1 ≥ tseg2**
  - **3/BRP tseg1 16 TQ**
  - **3/BRP tseg2 8 TQ**
  - **1 TQ sjw MIN[4*TQ , tseg2]**
  - **BRP ≥ 5 (if three sample mode is used)**

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Bit-Timing Configuration - CANBTC

CAN Bit-Timing Configuration Register (CANBTC) – 0x006016

31 … 24	23							16
reserved	BRP.7	BRP.6	BRP.5	BRP.4	BRP.3	BRP.2	BRP.1	BRP.0

Baud Rate Prescaler (BRP)
Defines the Time Quantum (TQ):

$$\mathbf{TQ = \frac{BRP + 1}{SYSCLK}}$$

Note: with an external clock of 30MHz and a PLL * 5:
SYSCLK = 150MHz

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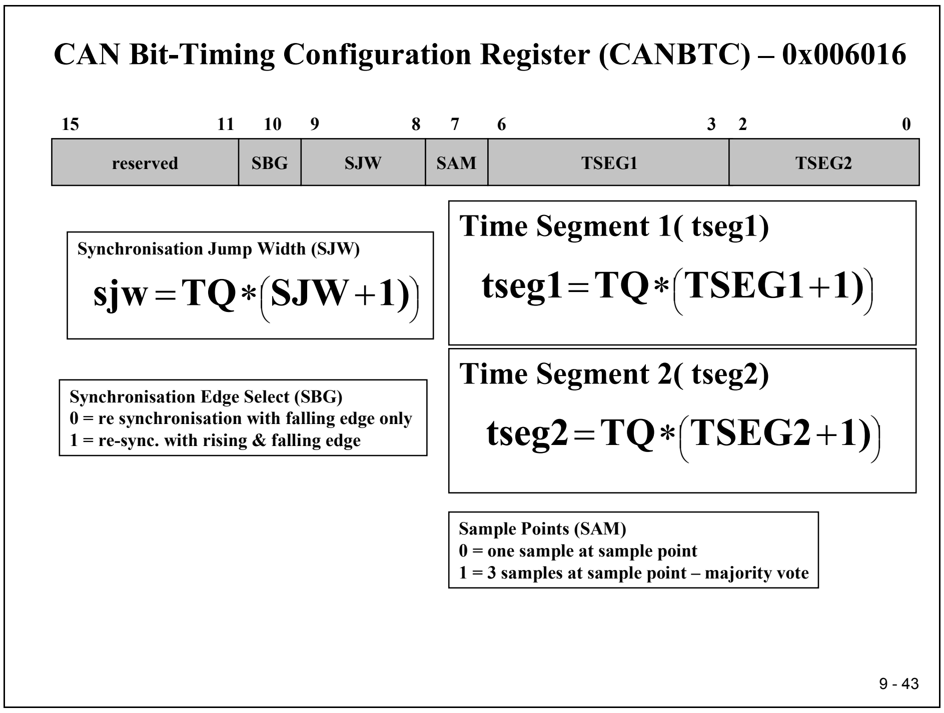

CAN Bit-Timing Configuration Register (CANBTC) – 0x006016

15 – 11	10	9 – 8	7	6 – 3	2 – 0
reserved	SBG	SJW	SAM	TSEG1	TSEG2

Synchronisation Jump Width (SJW)

$$\mathbf{sjw = TQ * (SJW + 1)}$$

Time Segment 1(tseg1)

$$\mathbf{tseg1 = TQ * (TSEG1 + 1)}$$

Synchronisation Edge Select (SBG)
0 = re synchronisation with falling edge only
1 = re-sync. with rising & falling edge

Time Segment 2(tseg2)

$$\mathbf{tseg2 = TQ * (TSEG2 + 1)}$$

Sample Points (SAM)
0 = one sample at sample point
1 = 3 samples at sample point – majority vote

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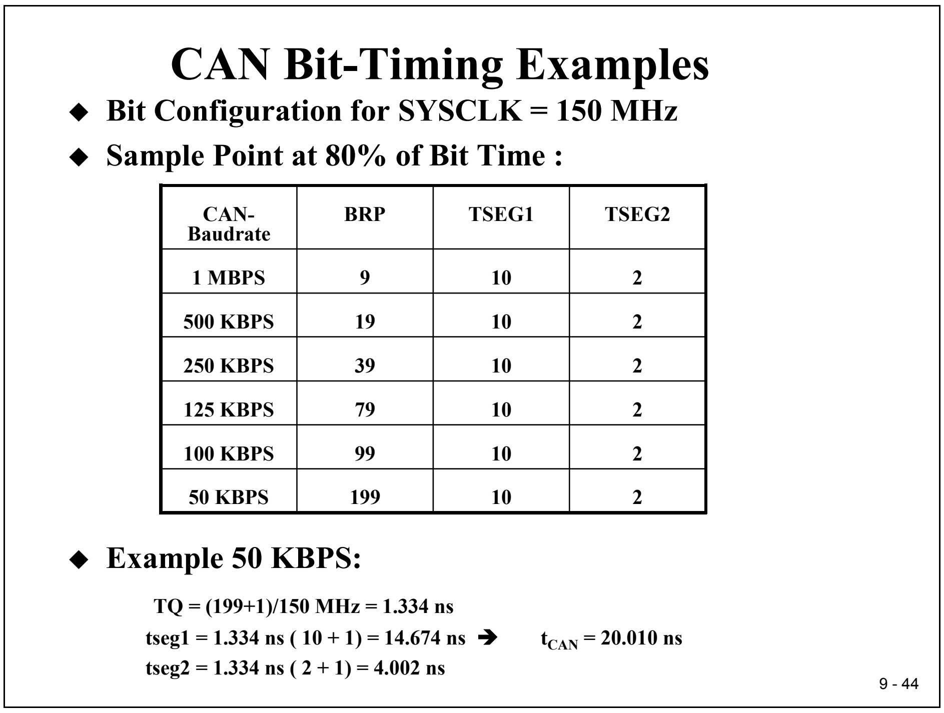

CAN Bit-Timing Examples

- **Bit Configuration for SYSCLK = 150 MHz**
- **Sample Point at 80% of Bit Time :**

CAN-Baudrate	BRP	TSEG1	TSEG2
1 MBPS	9	10	2
500 KBPS	19	10	2
250 KBPS	39	10	2
125 KBPS	79	10	2
100 KBPS	99	10	2
50 KBPS	199	10	2

- **Example 50 KBPS:**

TQ = (199+1)/150 MHz = 1.334 ns
tseg1 = 1.334 ns (10 + 1) = 14.674 ns ➔ t_{CAN} **= 20.010 ns**
tseg2 = 1.334 ns (2 + 1) = 4.002 ns

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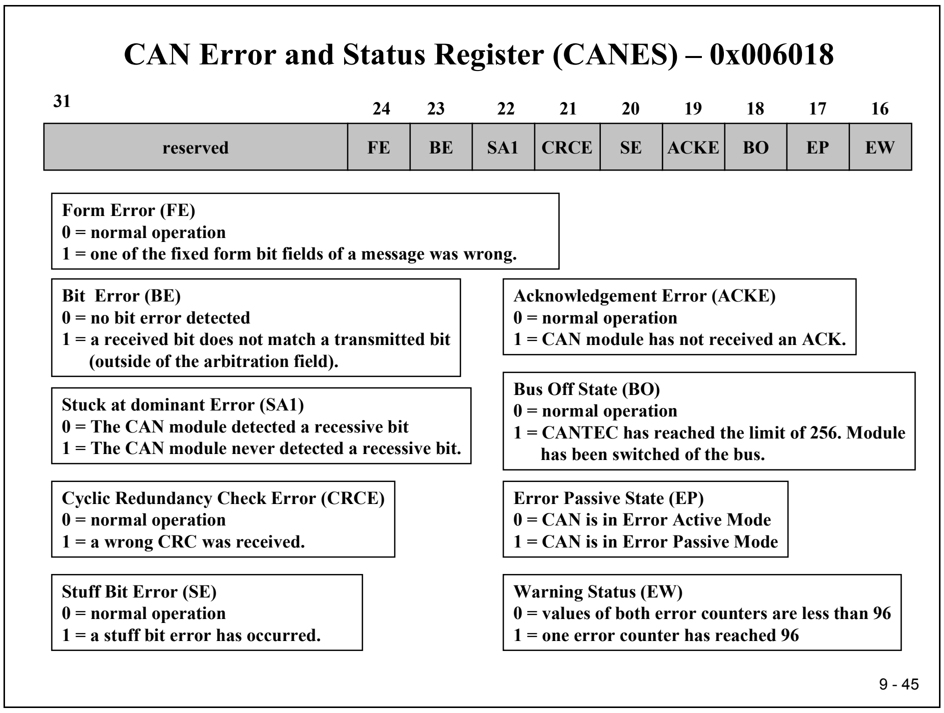
CAN Error Register

Error and Status - CANES



CAN Error and Status Register (CANES) – 0x006018

31 … 24	24	23	22	21	20	19	18	17	16
reserved	FE	BE	SA1	CRCE	SE	ACKE	BO	EP	EW

Form Error (FE)
0 = normal operation
1 = one of the fixed form bit fields of a message was wrong.

Bit Error (BE)
0 = no bit error detected
1 = a received bit does not match a transmitted bit (outside of the arbitration field).

Stuck at dominant Error (SA1)
0 = The CAN module detected a recessive bit
1 = The CAN module never detected a recessive bit.

Cyclic Redundancy Check Error (CRCE)
0 = normal operation
1 = a wrong CRC was received.

Stuff Bit Error (SE)
0 = normal operation
1 = a stuff bit error has occurred.

Acknowledgement Error (ACKE)
0 = normal operation
1 = CAN module has not received an ACK.

Bus Off State (BO)
0 = normal operation
1 = CANTEC has reached the limit of 256. Module has been switched of the bus.

Error Passive State (EP)
0 = CAN is in Error Active Mode
1 = CAN is in Error Passive Mode

Warning Status (EW)
0 = values of both error counters are less than 96
1 = one error counter has reached 96

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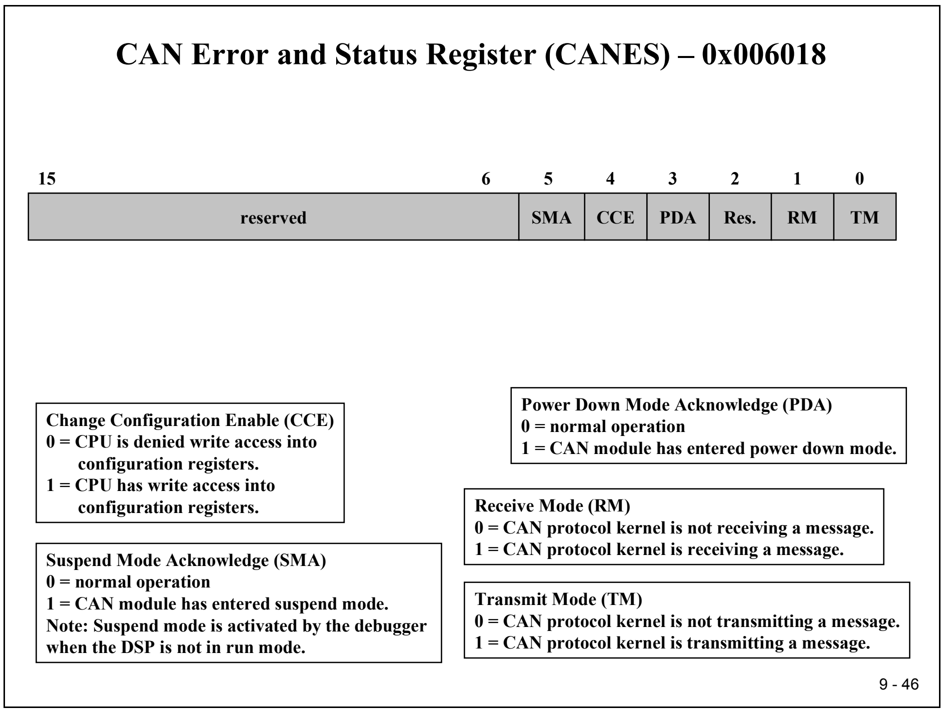

CAN Error and Status Register (CANES) – 0x006018

15 … 6	5	4	3	2	1	0
reserved	SMA	CCE	PDA	Res.	RM	TM

Change Configuration Enable (CCE)
0 = CPU is denied write access into configuration registers.
1 = CPU has write access into configuration registers.

Suspend Mode Acknowledge (SMA)
0 = normal operation
1 = CAN module has entered suspend mode.
Note: Suspend mode is activated by the debugger when the DSP is not in run mode.

Power Down Mode Acknowledge (PDA)
0 = normal operation
1 = CAN module has entered power down mode.

Receive Mode (RM)
0 = CAN protocol kernel is not receiving a message.
1 = CAN protocol kernel is receiving a message.

Transmit Mode (TM)
0 = CAN protocol kernel is not transmitting a message.
1 = CAN protocol kernel is transmitting a message.

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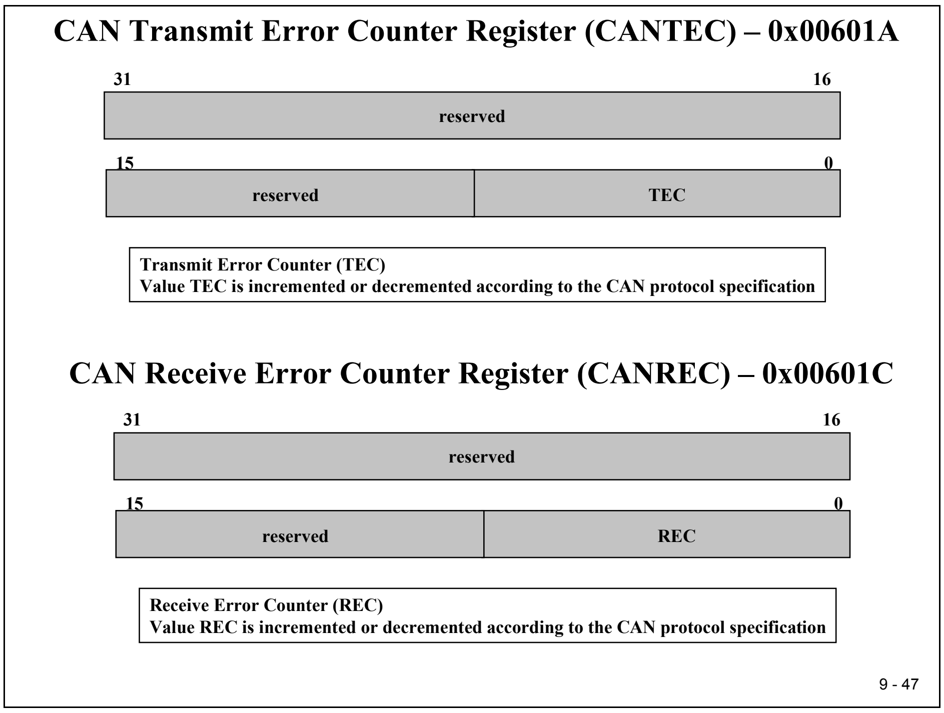
Transmit & Receive Error Counter - CANTEC / CANREC



CAN Transmit Error Counter Register (CANTEC) – 0x00601A

31	16
reserved	

15	0
reserved	TEC

Transmit Error Counter (TEC)
Value TEC is incremented or decremented according to the CAN protocol specification

CAN Receive Error Counter Register (CANREC) – 0x00601C

31	16
reserved	

15	0
reserved	REC

Receive Error Counter (REC)
Value REC is incremented or decremented according to the CAN protocol specification

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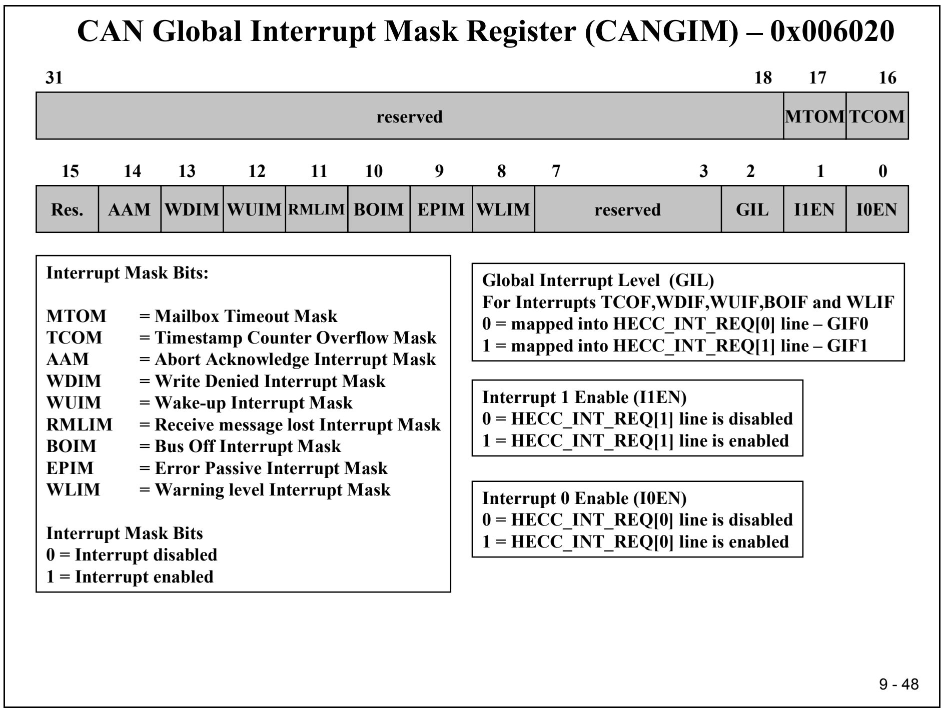
CAN Interrupt Register

Global Interrupt Mask - CANGIM



CAN Global Interrupt Mask Register (CANGIM) – 0x006020

31–18	17	16
reserved	MTOM	TCOM

15	14	13	12	11	10	9	8	7–3	2	1	0
Res.	AAM	WDIM	WUIM	RMLIM	BOIM	EPIM	WLIM	reserved	GIL	I1EN	I0EN

Interrupt Mask Bits:

MTOM	= Mailbox Timeout Mask
TCOM	= Timestamp Counter Overflow Mask
AAM	= Abort Acknowledge Interrupt Mask
WDIM	= Write Denied Interrupt Mask
WUIM	= Wake-up Interrupt Mask
RMLIM	= Receive message lost Interrupt Mask
BOIM	= Bus Off Interrupt Mask
EPIM	= Error Passive Interrupt Mask
WLIM	= Warning level Interrupt Mask

Interrupt Mask Bits
0 = Interrupt disabled
1 = Interrupt enabled

Global Interrupt Level (GIL)
For Interrupts TCOF,WDIF,WUIF,BOIF and WLIF
0 = mapped into HECC_INT_REQ[0] line – GIF0
1 = mapped into HECC_INT_REQ[1] line – GIF1

Interrupt 1 Enable (I1EN)
0 = HECC_INT_REQ[1] line is disabled
1 = HECC_INT_REQ[1] line is enabled

Interrupt 0 Enable (I0EN)
0 = HECC_INT_REQ[0] line is disabled
1 = HECC_INT_REQ[0] line is enabled

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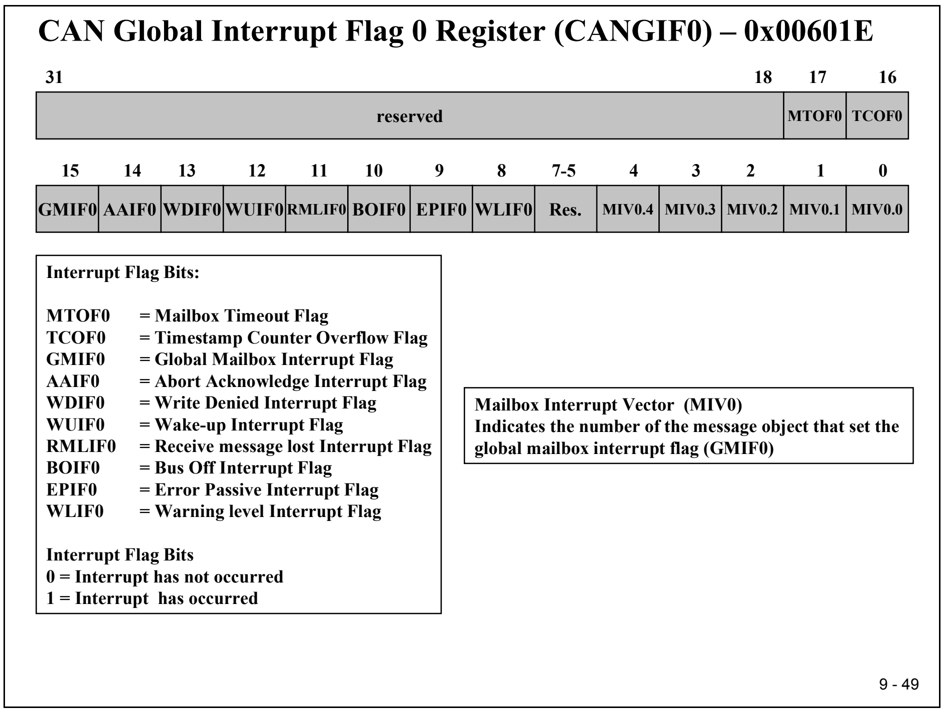
Global Interrupt 0 Flag – CANGIF0



CAN Global Interrupt Flag 0 Register (CANGIF0) – 0x00601E

31 … 18	17	16
reserved	MTOF0	TCOF0

15	14	13	12	11	10	9	8	7-5	4	3	2	1	0
GMIF0	AAIF0	WDIF0	WUIF0	RMLIF0	BOIF0	EPIF0	WLIF0	Res.	MIV0.4	MIV0.3	MIV0.2	MIV0.1	MIV0.0

Interrupt Flag Bits:

MTOF0	= Mailbox Timeout Flag
TCOF0	= Timestamp Counter Overflow Flag
GMIF0	= Global Mailbox Interrupt Flag
AAIF0	= Abort Acknowledge Interrupt Flag
WDIF0	= Write Denied Interrupt Flag
WUIF0	= Wake-up Interrupt Flag
RMLIF0	= Receive message lost Interrupt Flag
BOIF0	= Bus Off Interrupt Flag
EPIF0	= Error Passive Interrupt Flag
WLIF0	= Warning level Interrupt Flag

Interrupt Flag Bits
0 = Interrupt has not occurred
1 = Interrupt has occurred

Mailbox Interrupt Vector (MIV0)
Indicates the number of the message object that set the global mailbox interrupt flag (GMIF0)

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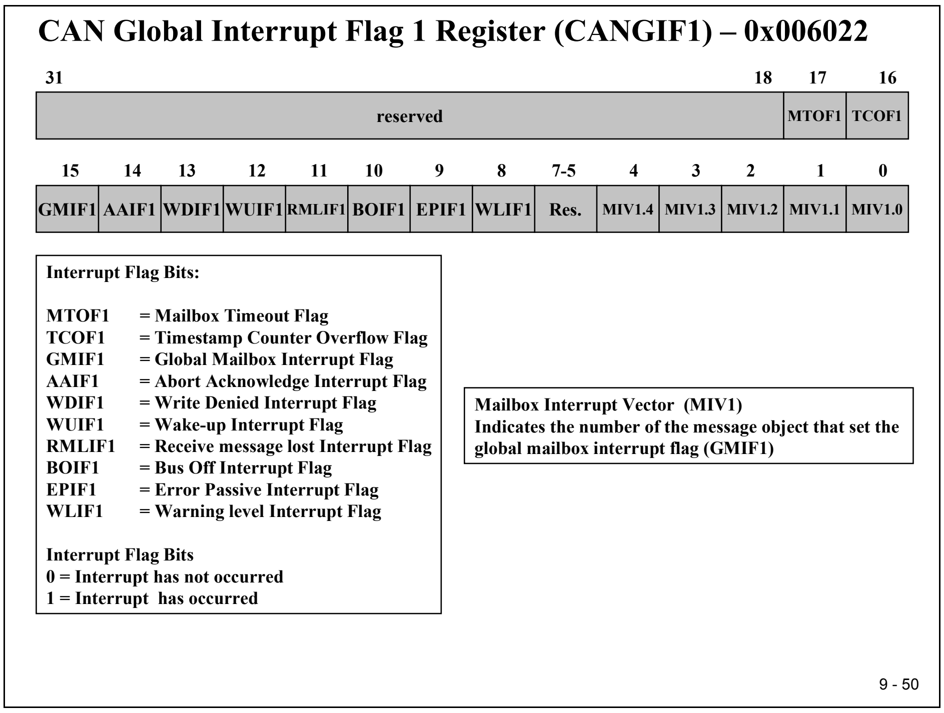
Global Interrupt 1 Flag – CANGIF1



CAN Global Interrupt Flag 1 Register (CANGIF1) – 0x006022

31 … 18	17	16
reserved	MTOF1	TCOF1

15	14	13	12	11	10	9	8	7-5	4	3	2	1	0
GMIF1	AAIF1	WDIF1	WUIF1	RMLIF1	BOIF1	EPIF1	WLIF1	Res.	MIV1.4	MIV1.3	MIV1.2	MIV1.1	MIV1.0

Interrupt Flag Bits:

MTOF1	= Mailbox Timeout Flag
TCOF1	= Timestamp Counter Overflow Flag
GMIF1	= Global Mailbox Interrupt Flag
AAIF1	= Abort Acknowledge Interrupt Flag
WDIF1	= Write Denied Interrupt Flag
WUIF1	= Wake-up Interrupt Flag
RMLIF1	= Receive message lost Interrupt Flag
BOIF1	= Bus Off Interrupt Flag
EPIF1	= Error Passive Interrupt Flag
WLIF1	= Warning level Interrupt Flag

Interrupt Flag Bits
0 = Interrupt has not occurred
1 = Interrupt has occurred

Mailbox Interrupt Vector (MIV1)
Indicates the number of the message object that set the global mailbox interrupt flag (GMIF1)

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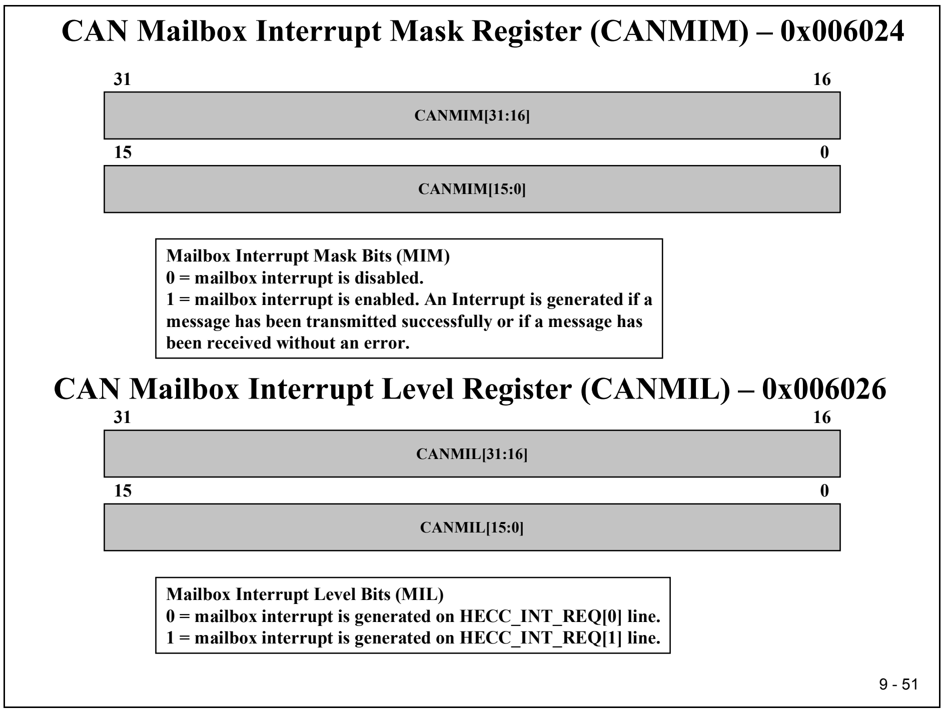
Mailbox Interrupt Mask - CANMIM



CAN Mailbox Interrupt Mask Register (CANMIM) – 0x006024

31	16
CANMIM[31:16]	
15	**0**
CANMIM[15:0]	

Mailbox Interrupt Mask Bits (MIM)
0 = mailbox interrupt is disabled.
1 = mailbox interrupt is enabled. An Interrupt is generated if a message has been transmitted successfully or if a message has been received without an error.

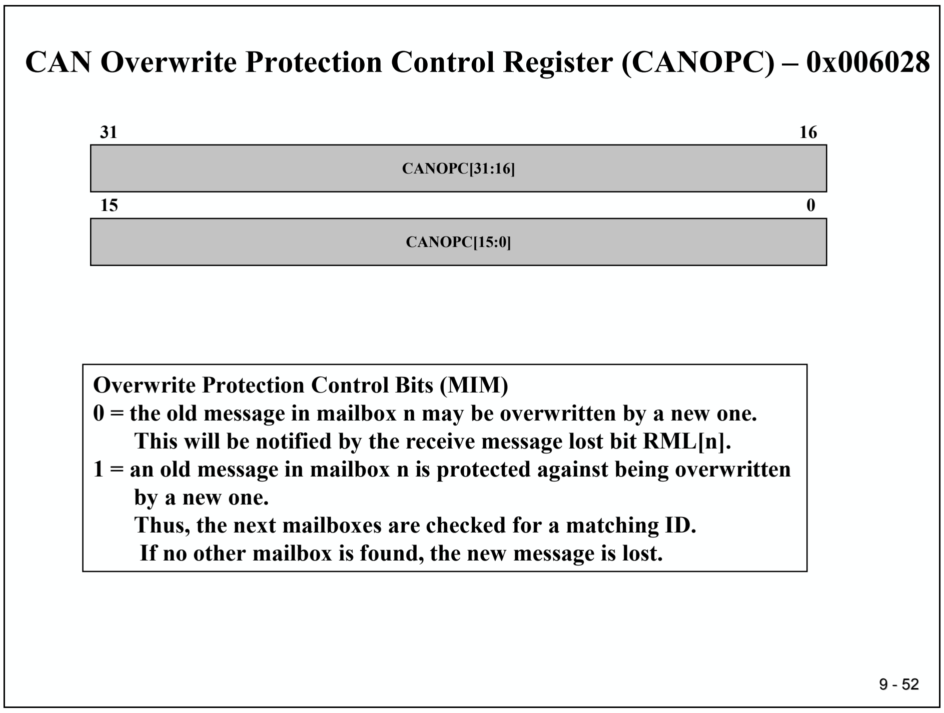
CAN Mailbox Interrupt Level Register (CANMIL) – 0x006026

31	16
CANMIL[31:16]	
15	**0**
CANMIL[15:0]	

Mailbox Interrupt Level Bits (MIL)
0 = mailbox interrupt is generated on HECC_INT_REQ[0] line.
1 = mailbox interrupt is generated on HECC_INT_REQ[1] line.

9 - 51

Overwrite Protection Control - CANOPC



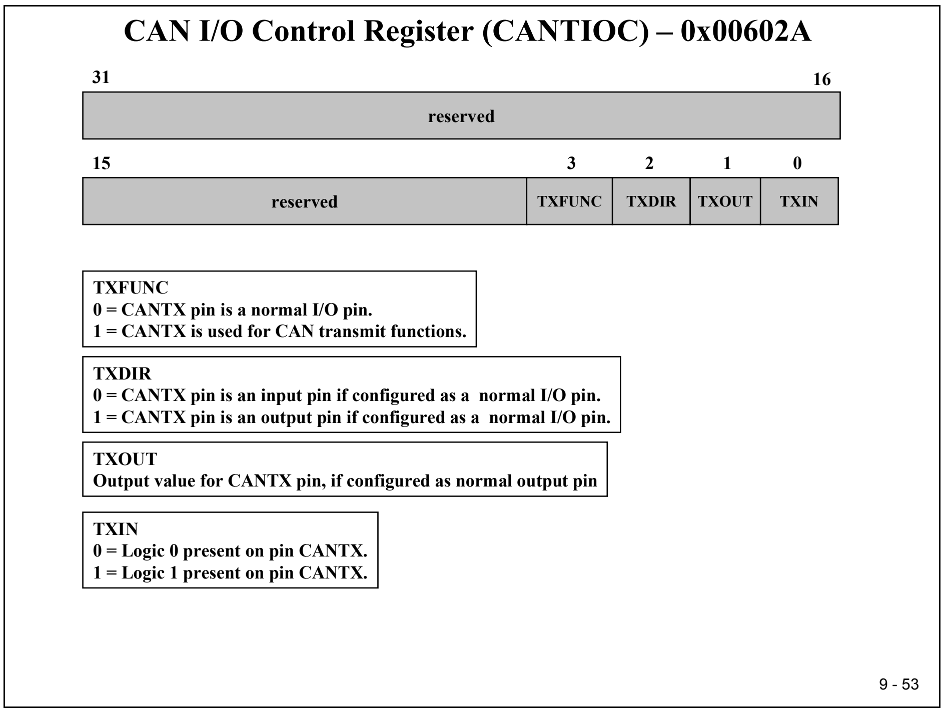
CAN Overwrite Protection Control Register (CANOPC) – 0x006028

31	16
CANOPC[31:16]	
15	**0**
CANOPC[15:0]	

Overwrite Protection Control Bits (MIM)
0 = the old message in mailbox n may be overwritten by a new one.
This will be notified by the receive message lost bit RML[n].
1 = an old message in mailbox n is protected against being overwritten by a new one.
Thus, the next mailboxes are checked for a matching ID.
If no other mailbox is found, the new message is lost.

9 - 52

Transmit I/O Control - CANTIOC



CAN I/O Control Register (CANTIOC) – 0x00602A

31 … 16
reserved

15 … 4	3	2	1	0
reserved	TXFUNC	TXDIR	TXOUT	TXIN

TXFUNC
0 = CANTX pin is a normal I/O pin.
1 = CANTX is used for CAN transmit functions.

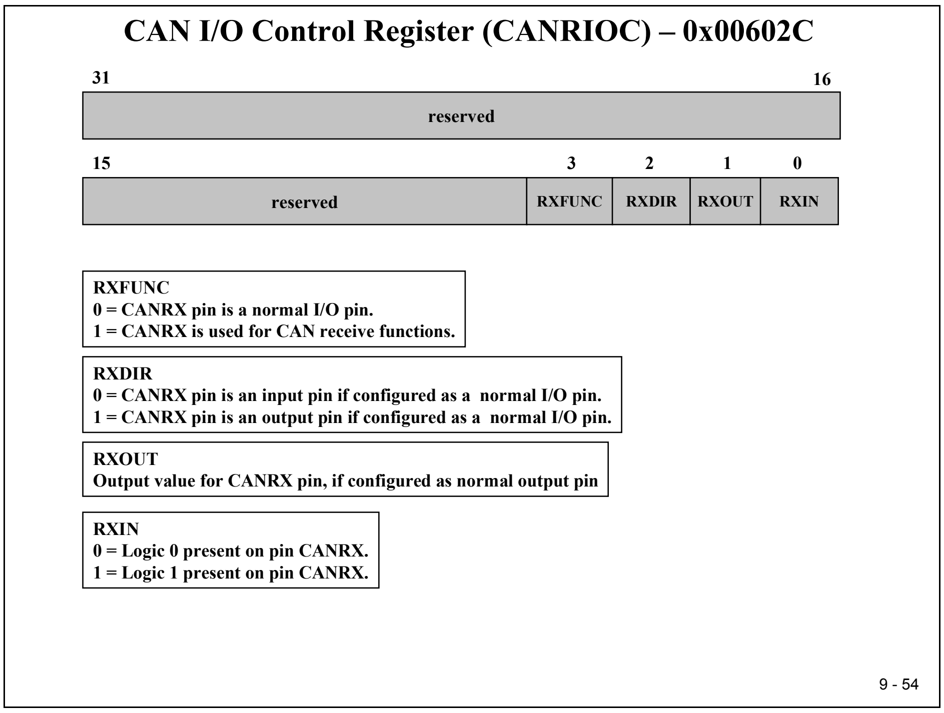
TXDIR
0 = CANTX pin is an input pin if configured as a normal I/O pin.
1 = CANTX pin is an output pin if configured as a normal I/O pin.

TXOUT
Output value for CANTX pin, if configured as normal output pin

TXIN
0 = Logic 0 present on pin CANTX.
1 = Logic 1 present on pin CANTX.

9 - 53

Receive I/O Control - CANRIOC



CAN I/O Control Register (CANRIOC) – 0x00602C

31 … 16
reserved

15 … 4	3	2	1	0
reserved	RXFUNC	RXDIR	RXOUT	RXIN

RXFUNC
0 = CANRX pin is a normal I/O pin.
1 = CANRX is used for CAN receive functions.

RXDIR
0 = CANRX pin is an input pin if configured as a normal I/O pin.
1 = CANRX pin is an output pin if configured as a normal I/O pin.

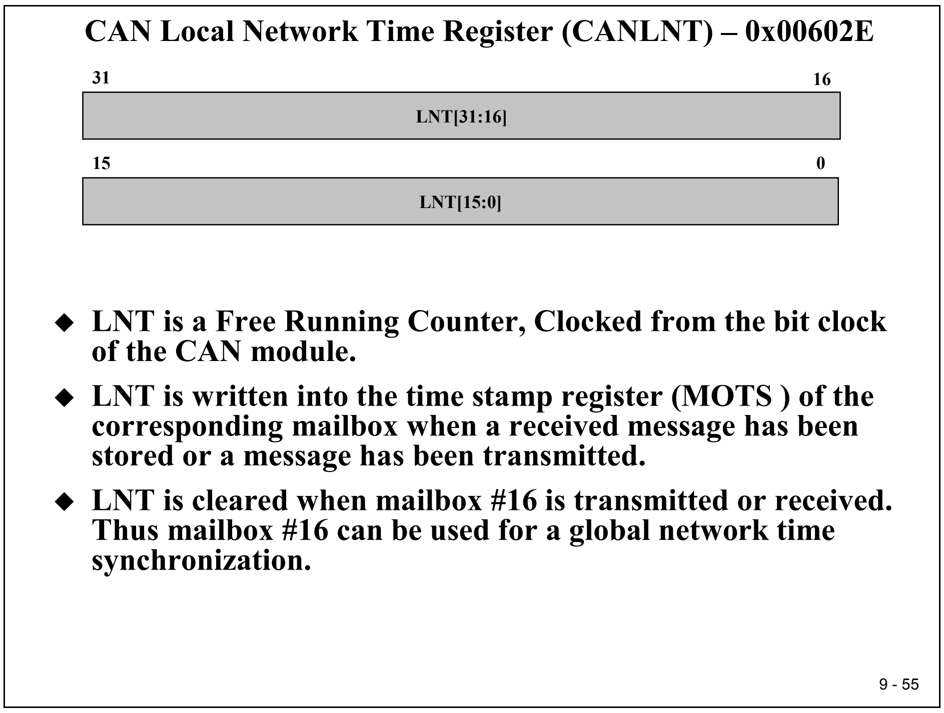
RXOUT
Output value for CANRX pin, if configured as normal output pin

RXIN
0 = Logic 0 present on pin CANRX.
1 = Logic 1 present on pin CANRX.

9 - 54

Alarm / Time Out Register

Local Network Time - CANLNT



CAN Local Network Time Register (CANLNT) – 0x00602E

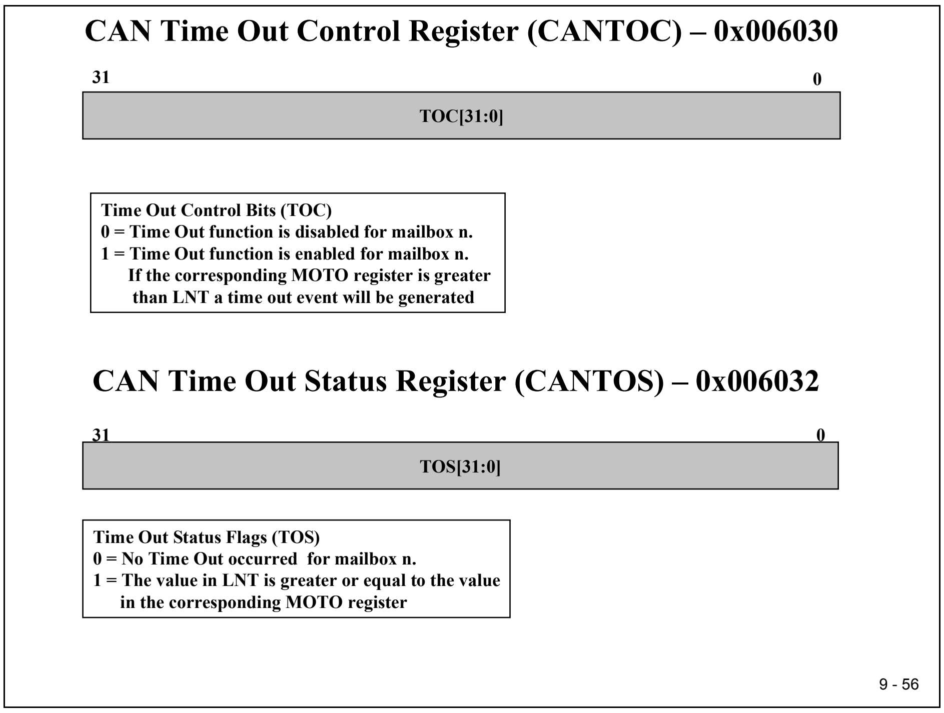
31	16
LNT[31:16]	

15	0
LNT[15:0]	

- **LNT is a Free Running Counter, Clocked from the bit clock of the CAN module.**
- **LNT is written into the time stamp register (MOTS) of the corresponding mailbox when a received message has been stored or a message has been transmitted.**
- **LNT is cleared when mailbox #16 is transmitted or received. Thus mailbox #16 can be used for a global network time synchronization.**

9 - 55

Time Out Control - CANTIOC



CAN Time Out Control Register (CANTOC) – 0x006030

31 … 0
TOC[31:0]

Time Out Control Bits (TOC)
0 = Time Out function is disabled for mailbox n.
1 = Time Out function is enabled for mailbox n.
If the corresponding MOTO register is greater than LNT a time out event will be generated

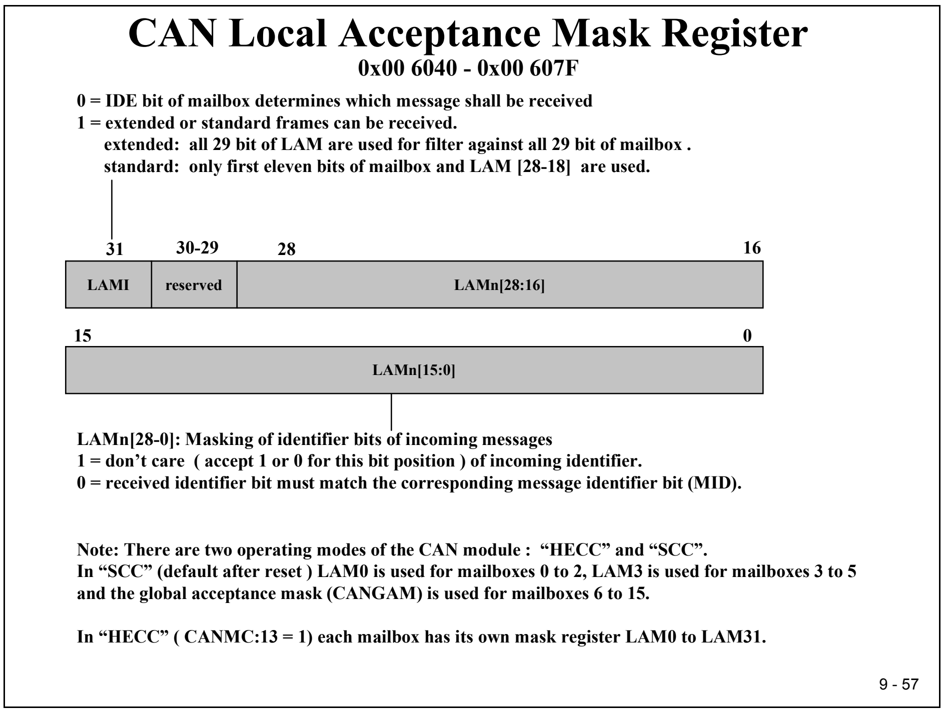
CAN Time Out Status Register (CANTOS) – 0x006032

31 … 0
TOS[31:0]

Time Out Status Flags (TOS)
0 = No Time Out occurred for mailbox n.
1 = The value in LNT is greater or equal to the value in the corresponding MOTO register

9 - 56

Local Acceptance Mask - LAMn



CAN Local Acceptance Mask Register

0x00 6040 - 0x00 607F

0 = IDE bit of mailbox determines which message shall be received
1 = extended or standard frames can be received.
extended: all 29 bit of LAM are used for filter against all 29 bit of mailbox .
standard: only first eleven bits of mailbox and LAM [28-18] are used.

31	30-29	28 … 16
LAMI	reserved	LAMn[28:16]

15 … 0
LAMn[15:0]

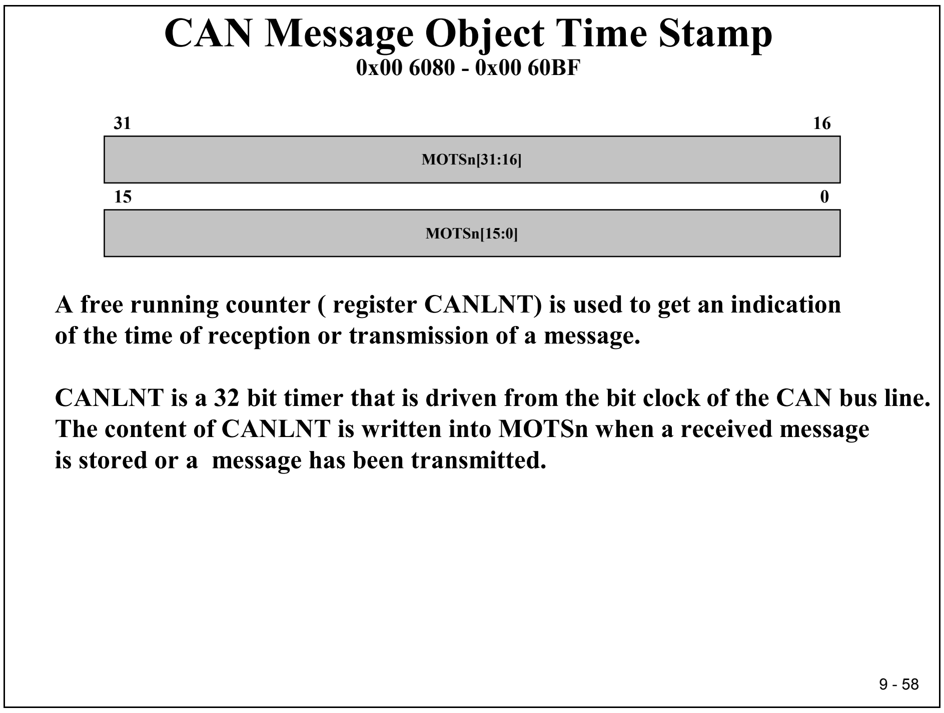
LAMn[28-0]: Masking of identifier bits of incoming messages
1 = don’t care (accept 1 or 0 for this bit position) of incoming identifier.
0 = received identifier bit must match the corresponding message identifier bit (MID).

Note: There are two operating modes of the CAN module : “HECC” and “SCC”.
In “SCC” (default after reset) LAM0 is used for mailboxes 0 to 2, LAM3 is used for mailboxes 3 to 5 and the global acceptance mask (CANGAM) is used for mailboxes 6 to 15.

In “HECC” (CANMC:13 = 1) each mailbox has its own mask register LAM0 to LAM31.

9 - 57

Message Object Time Stamp - MOTSn



CAN Message Object Time Stamp

0x00 6080 - 0x00 60BF

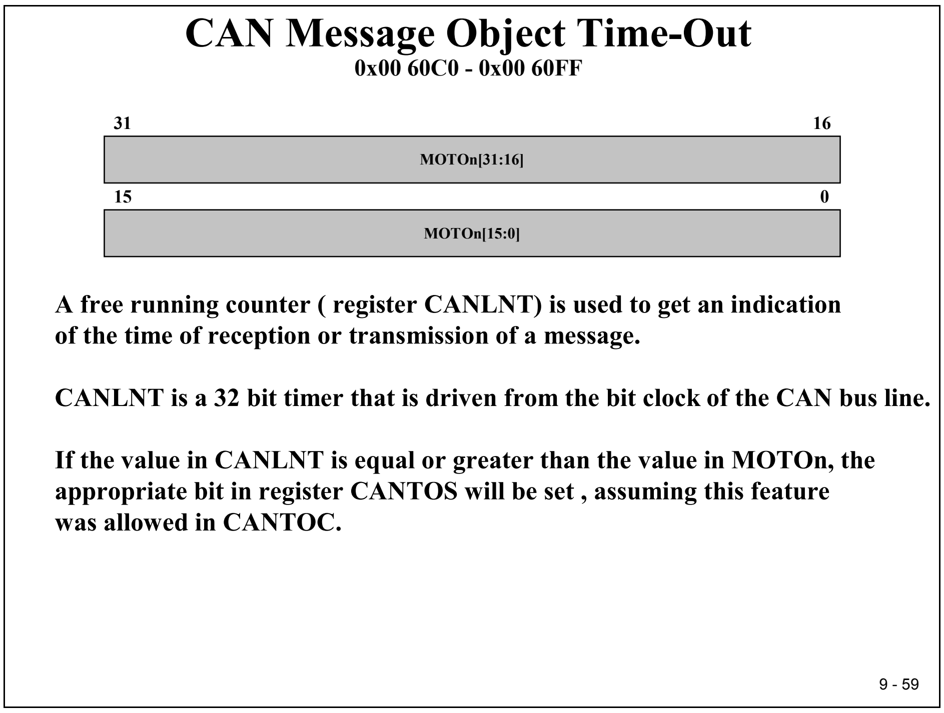
31	16
MOTSn[31:16]	
15	**0**
MOTSn[15:0]	

A free running counter (register CANLNT) is used to get an indication of the time of reception or transmission of a message.

CANLNT is a 32 bit timer that is driven from the bit clock of the CAN bus line. The content of CANLNT is written into MOTSn when a received message is stored or a message has been transmitted.

9 - 58

Message Object Time Out - MOTOn



CAN Message Object Time-Out

0x00 60C0 - 0x00 60FF

31	16
MOTOn[31:16]	
15	**0**
MOTOn[15:0]	

A free running counter (register CANLNT) is used to get an indication of the time of reception or transmission of a message.

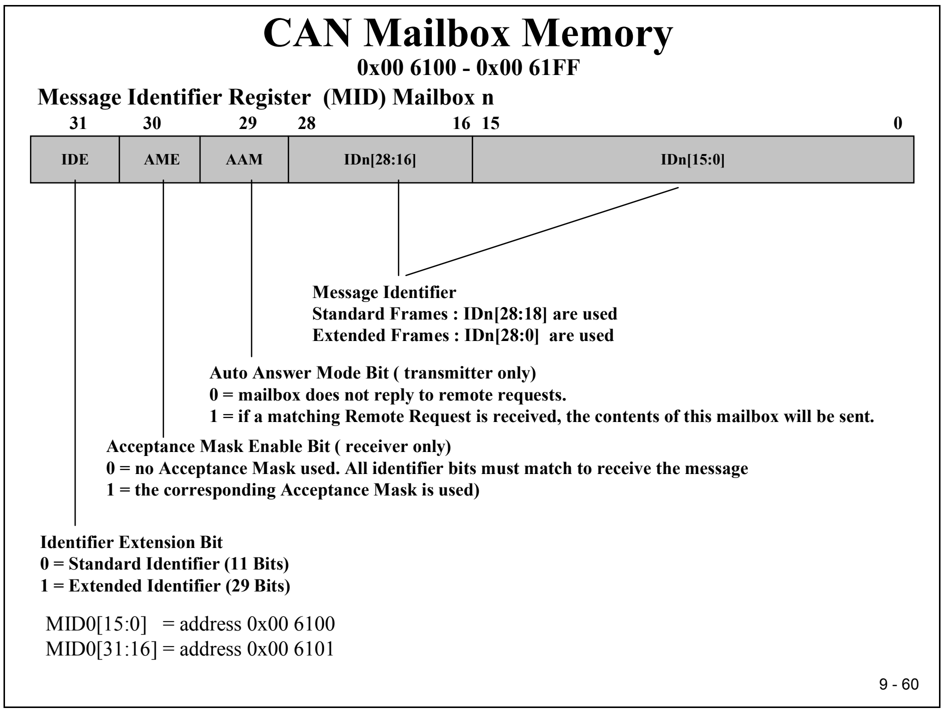
CANLNT is a 32 bit timer that is driven from the bit clock of the CAN bus line.

If the value in CANLNT is equal or greater than the value in MOTOn, the appropriate bit in register CANTOS will be set , assuming this feature was allowed in CANTOC.

9 - 59

Mailbox Memory

Message Identifier - CANMID



CAN Mailbox Memory

0x00 6100 - 0x00 61FF

Message Identifier Register (MID) Mailbox n

Message Identifier
Standard Frames : IDn[28:18] are used
Extended Frames : IDn[28:0] are used

Auto Answer Mode Bit (transmitter only)
0 = mailbox does not reply to remote requests.
1 = if a matching Remote Request is received, the contents of this mailbox will be sent.

Acceptance Mask Enable Bit (receiver only)
0 = no Acceptance Mask used. All identifier bits must match to receive the message
1 = the corresponding Acceptance Mask is used)

Identifier Extension Bit
0 = Standard Identifier (11 Bits)
1 = Extended Identifier (29 Bits)

MID0[15:0] = address 0x00 6100
MID0[31:16] = address 0x00 6101

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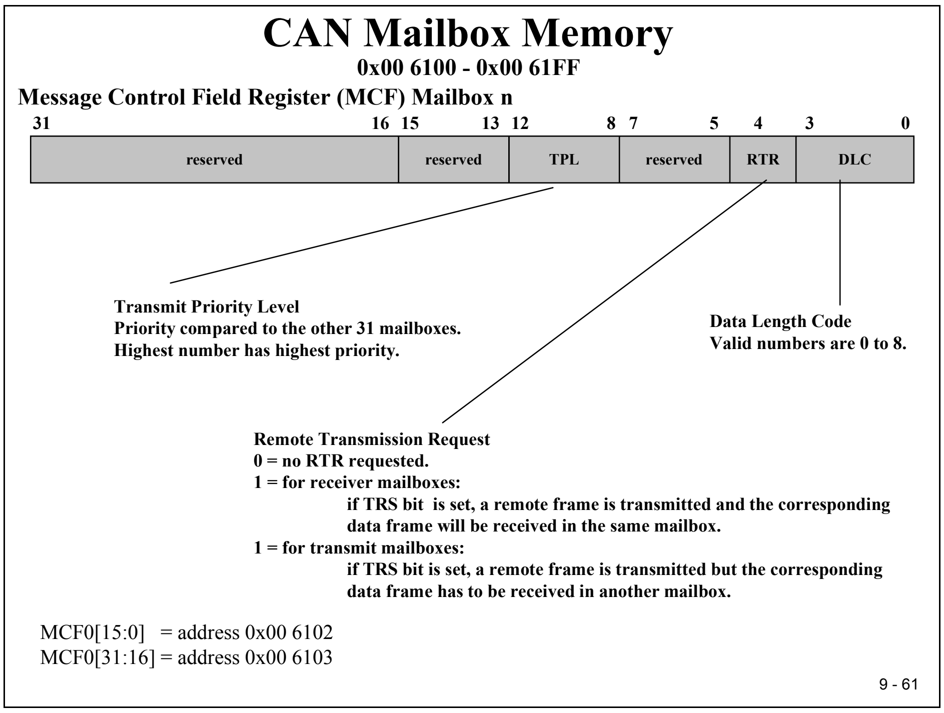
Message Control Field - CANMCF



CAN Mailbox Memory

0x00 6100 - 0x00 61FF

Message Control Field Register (MCF) Mailbox n

Transmit Priority Level
Priority compared to the other 31 mailboxes.
Highest number has highest priority.

Data Length Code
Valid numbers are 0 to 8.

Remote Transmission Request
0 = no RTR requested.
1 = for receiver mailboxes:
if TRS bit is set, a remote frame is transmitted and the corresponding data frame will be received in the same mailbox.
1 = for transmit mailboxes:
if TRS bit is set, a remote frame is transmitted but the corresponding data frame has to be received in another mailbox.

MCF0[15:0] = address 0x00 6102
MCF0[31:16] = address 0x00 6103

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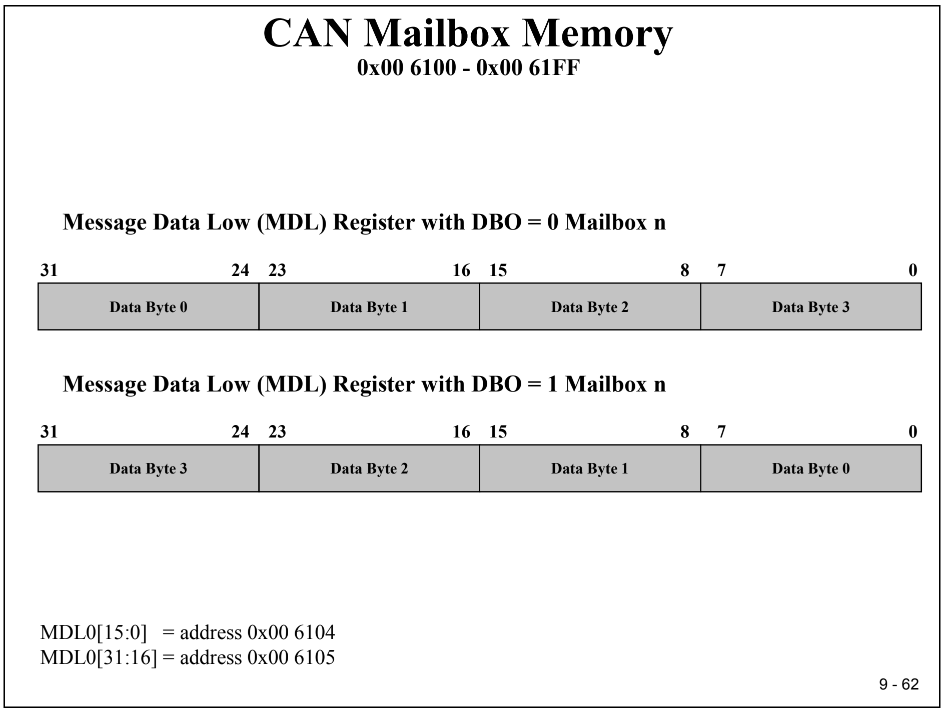
Message Data Field Low - CANMDL



CAN Mailbox Memory

0x00 6100 - 0x00 61FF

Message Data Low (MDL) Register with DBO = 0 Mailbox n

31 … 24	23 … 16	15 … 8	7 … 0
Data Byte 0	Data Byte 1	Data Byte 2	Data Byte 3

Message Data Low (MDL) Register with DBO = 1 Mailbox n

31 … 24	23 … 16	15 … 8	7 … 0
Data Byte 3	Data Byte 2	Data Byte 1	Data Byte 0

MDL0[15:0]   = address 0x00 6104
MDL0[31:16] = address 0x00 6105

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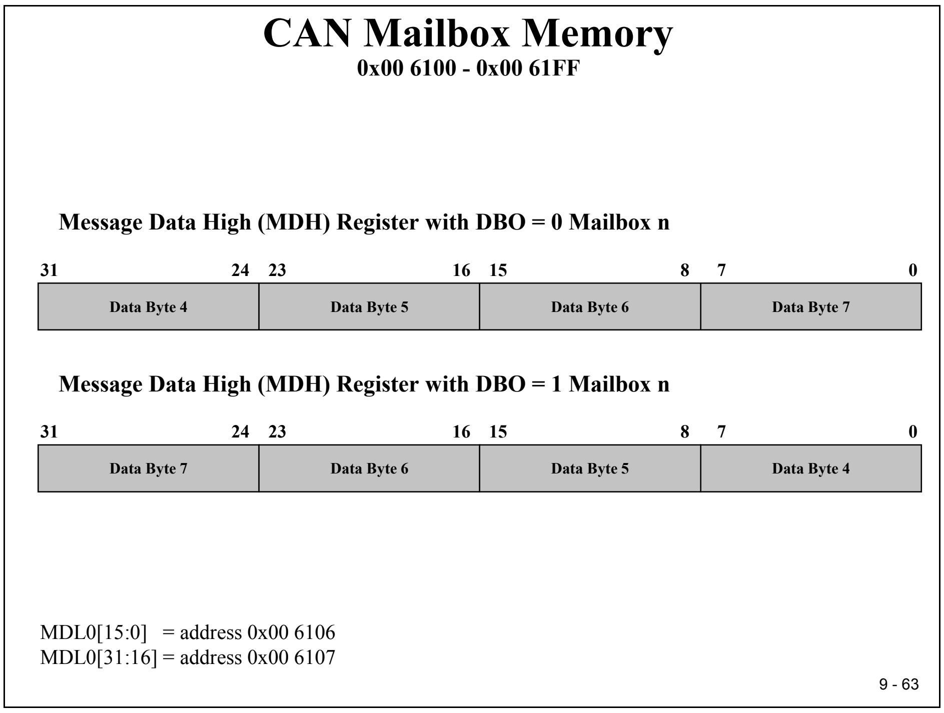
Message Data Field High - CANMDH



CAN Mailbox Memory

0x00 6100 - 0x00 61FF

Message Data High (MDH) Register with DBO = 0 Mailbox n

31 … 24	23 … 16	15 … 8	7 … 0
Data Byte 4	Data Byte 5	Data Byte 6	Data Byte 7

Message Data High (MDH) Register with DBO = 1 Mailbox n

31 … 24	23 … 16	15 … 8	7 … 0
Data Byte 7	Data Byte 6	Data Byte 5	Data Byte 4

MDL0[15:0]   = address 0x00 6106
MDL0[31:16] = address 0x00 6107

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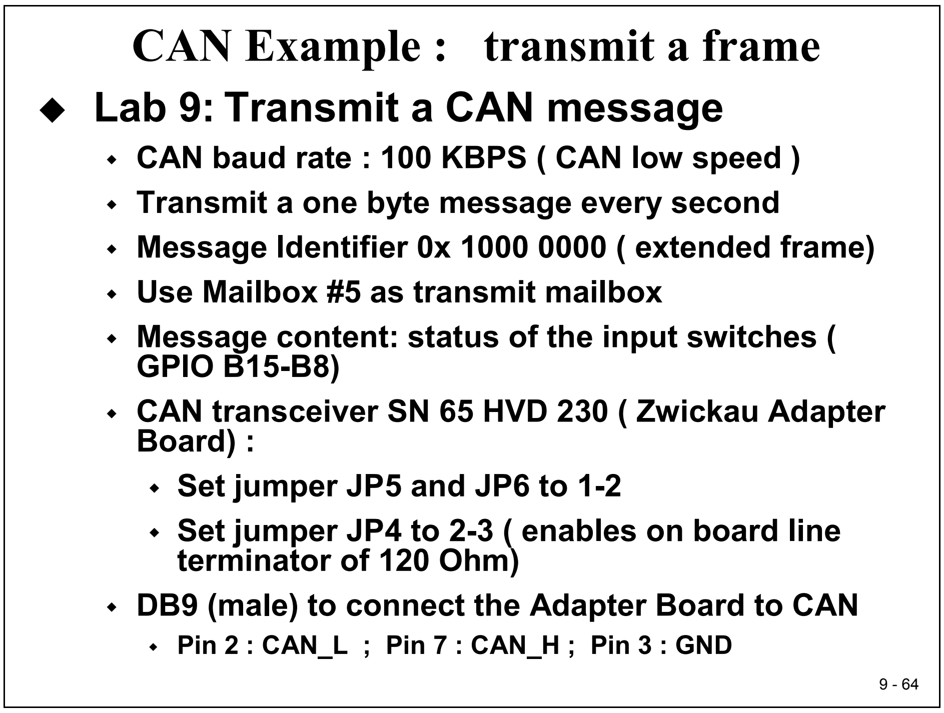
Lab Exercise 9



CAN Example : transmit a frame

- **Lab 9: Transmit a CAN message**
  - **CAN baud rate : 100 KBPS (CAN low speed)**
  - **Transmit a one byte message every second**
  - **Message Identifier 0x 1000 0000 (extended frame)**
  - **Use Mailbox #5 as transmit mailbox**
  - **Message content: status of the input switches (GPIO B15-B8)**
  - **CAN transceiver SN 65 HVD 230 (Zwickau Adapter Board) :**
    - **Set jumper JP5 and JP6 to 1-2**
    - **Set jumper JP4 to 2-3 (enables on board line terminator of 120 Ohm)**
  - **DB9 (male) to connect the Adapter Board to CAN**
    - **Pin 2 : CAN_L ; Pin 7 : CAN_H ; Pin 3 : GND**

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Preface

After this extensive description of all CAN registers of the C28x, it is time to carry out an exercise. Again, it is a good idea to start with some simple experiments to get our hardware to work. Later, we can try to refine the projects by setting up enhanced operation modes such as “Remote Transmission Request”, “Auto Answer Mode”, „Pipelined Mailboxes” or “Wakeup Mode”. We will also refrain from using the powerful error recognition and error management, which of course would be an essential part of a real project. To keep it simple, we will also use a polling method instead of an interrupt driven communication between the core of the DSP and the CAN mailbox server. Once you have a working example, it is much simpler to improve the code in this project by adding more enhanced operating modes to it.

The CAN requires a transceiver circuit between the digital signals of the C28x and the bus lines to adjust the physical voltages. The Zwickau Adapter Board is equipped with two different types of CAN transceivers, a Texas Instruments SN65HVD230 for high speed ISO 11898 applications and a Phillips TJA1054, quite often used in the CAN for body electronics of a car. With the help of two jumpers (JP5, JP6), we can select the transceiver in use. For Lab 9 we will use the SN65HVD230.

The physical CAN lines for ISO 11898 require a correct line termination at the ends of the transmission lines by 120 Ohm terminator resistors. If the C28x is placed at one of the end positions in your CAN network, you can use the on board 120 Ohm terminator by setting jumper JP4 to position 2-3. If the physical structure of the CAN in your laboratory does not require the C28x to terminate the net, set JP4 to 1-2. Ask your teacher which set up is the correct one.

To test your code, you will need a partner team with a second C28x doing Lab 10. This lab is an experiment to receive a CAN message and display its data at GPIO B7-B0 (8 LED's on the Zwickau Adapter Board). If your laboratory does not provide any CAN infrastructure, it is quite simple to connect the two boards. Use two female DB9 connectors, a twisted pair cable to connect pins 2-2 (CAN_L), 7-7 (CAN_H) and eventually 3-3 (GND) and plug them into the DB9 connectors of the Zwickau Adapter Board.

Before you start the hard wiring, ask your teacher or a laboratory technician what exactly you are supposed to do to connect the boards!

Objective

- The objective of Lab 9 is to transmit a one byte data frame every second via CAN.
- The actual data byte should be taken from input lines GPIO-B15 to B8. In case of the Zwickau Adapter Board, these 8 lines are connected to 8 digital input switches.
- The baud rate for the CAN should be set to 100 kbps.
- The exercise should use extended identifier 0x1000 0000 for the transmit message. You can also use any other number as identifier, but please make sure that your partner team (Lab 10) knows about your change. If your classroom uses several eZdsp's at the same time, it could be an option to set-up pairs of teams sharing the CAN by using different identifiers. It is also possible that due to the structure of the laboratory set-up at your university, not all identifier combinations might be available to you. You surely don't want to start the ignition of a motor control unit that is also connected to the CAN for some other experiments. Before you use any other ID's ➔ ask your teacher!
- Use Mailbox #5 as your transmit mailbox
- Once you have started a CAN transmission wait for completion by polling the status bit. Doing so we can refrain from using CAN interrupts for this first CAN exercise.
- Use CPU core timer 0 to generate the one second interval

Procedure

Open Files, Create Project File

1. Create a new project, called **Lab9.pjt** in E:\C281x\Labs.

2. A good point to start with is the source code of Lab4, which produces a hardware based time period using CPU core timer 0. Open the file Lab4.c from E:\C281x\Labs\Lab4 and save it as Lab9.c in E:\C281x\Labs\Lab9.

3. Add the source code file to your project:
   - **Lab9.c**

4. From *C:\tidcs\c28\dsp281x\v100\DSP281x_headers\source* add:
   - **DSP281x_GlobalVariableDefs.c**

   From *C:\tidcs\c28\dsp281x\v100\DSP281x_common\source* add:
   - **DSP281x_PieCtrl.c**
   - **DSP281x_PieVect.c**
   - **DSP281x_DefaultIsr.c**
   - **DSP281x_CpuTimers.c**

   From *C:\tidcs\c28\dsp281x\v100\DSP281x_headers\cmd* add:
   - **F2812_Headers_nonBIOS.cmd**

   From *C:\tidcs\c28\dsp281x\v100\DSP281x_common\cmd* add:
   - **F2812_EzDSP_RAM_lnk.cmd**

   From *C:\ti\c2000\cgtoolslib* add:
   - **rts2800_ml.lib**

Project Build Options

5. Setup the search path to include the peripheral register header files. Click:

   Project → Build Options

   Select the Compiler tab. In the preprocessor Category, find the Include Search Path (-i) box and enter:

   C:\tidcs\C28\dsp281x\v100\DSP281x_headers\include;
   ..\include

6. Setup the stack size: Inside Build Options select the Linker tab and enter in the Stack Size (-stack) box:

   400

Close the Build Options Menu by Clicking <**OK**>.

Modify Source Code

7. Before we can start editing our own code we have to modify a portion of the Texas Instruments Header file "**DSP281x_ECan.h**", Version 1.0. This file has a bug inside the structures "CANMDL_BYTES" and "CANMDH_BYTES". The order of bytes is not correct.

   Search and edit struct CANMDL_BYTES and CANMDH_BYTES:

```
struct  CANMDL_BYTES {      // bits   description
            Uint16     BYTE3:8;     // 31:24
            Uint16     BYTE2:8;     // 23:16
            Uint16     BYTE1:8;     // 15:8
            Uint16     BYTE0:8;     // 7:0
            };
struct  CANMDH_BYTES {      // bits   description
            Uint16     BYTE7:8;     // 63:56
            Uint16     BYTE6:8;     // 55:48
            Uint16     BYTE5:8;     // 47:40
            Uint16     BYTE4:8;     // 39:32
            };
```

8. Open Lab9.c to edit. First, we have to adjust the while(1) loop of main to perform the next CAN transmission every 1 second. Recall that we initialized the CPU core timer 0 to interrupt every 50ms and to increment variable "CpuTimer0.InterruptCount" with every interrupt service. To generate a pause period of 1 second, we just have to wait until "CpuTimer0.InterruptCount" has reached 20. BUT, while we wait, we have to deal with the watchdog! One second without any watchdog service will be far too long; the watchdog will trigger a reset! Modify the code accordingly!

Build, Load and Run

9. Before we continue to modify our source code, let us try to compile the project and run a test. If everything goes as expected, the DSP should perform the LED Knight-Rider from Lab4, now with a pause interval of one second between the steps.

   Click the "Rebuild All" button or perform:

   Project → Build
   File → Load Program
   Debug → Reset CPU
   Debug ➔ Restart
   Debug → Go main
   Debug ➔ Run(F5)

Modify Source Code Cont.

10. Congratulations! Now the tougher part is waiting for you. You will have to add code to initialize the CAN module. Let's do it again using a step-by-step approach.

    First, delete the variables "i" and "LED[8]" of main. Next, add a new structure "ECanaShadow" as a local variable in main:

    struct ECAN_REGS ECanaShadow;

    This structure will be used as a local copy of the original CAN registers. A manipulation of individual bits is done inside the copy. At the end of the access, the whole copy is reloaded into the original CAN structures. This operation is necessary because of the inner structure of the CAN unit; some registers are only accessible by 32-bit accesses and by copying the whole structure, we make sure to generate 32 bit accesses only.

11. In function "InitSystem()" enable the clock unit for the CAN module.

12. Next, inside function "Gpio_select() enable the peripheral function of CANTxA and CANRxA:

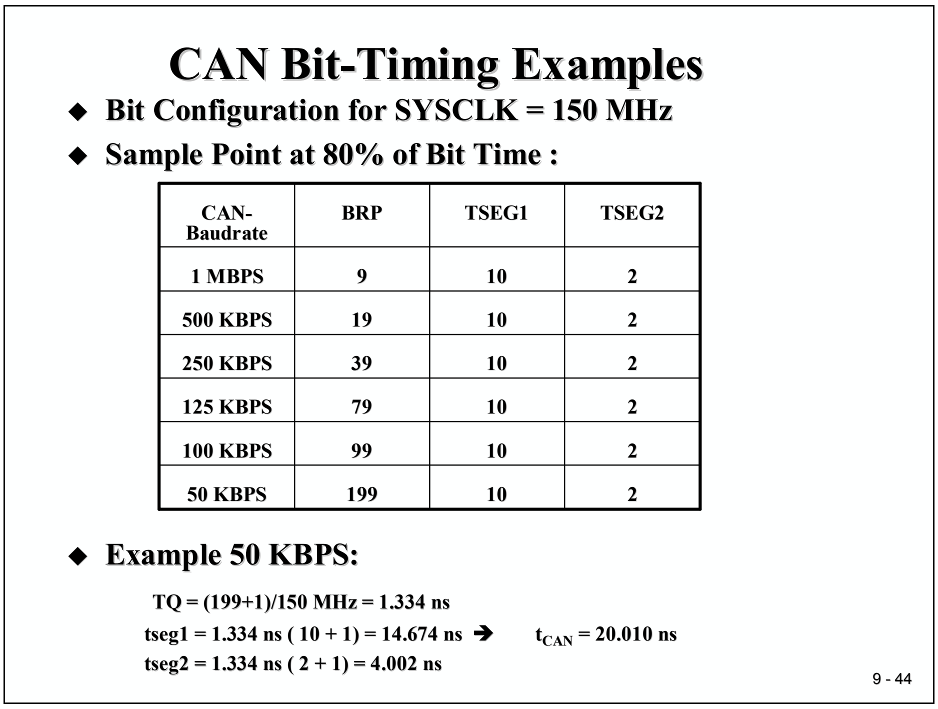
    GpioMuxRegs.GPFMUX.bit.CANTXA_GPIOF6 = 1;

    GpioMuxRegs.GPFMUX.bit.CANRXA_GPIOF7 = 1;

Add the CAN initialization code

13. Add a new function "InitCan()" at the end of your source code to initialize the CAN module. Inside "InitCan()" add the following steps:
    - In Register "ECanaRegs.CANTIOC" and "ECanaRegs.CANRIOC" configure the two pins "TXFUNC" and "RXFUNC"for CAN.

- Enable the HECC mode of the CAN module (Register “ECanaRegs.CANMC”).
- To set-up the baud rate for the CAN transmission, we need to get access to the bit timing registers. This access is requested by setting bit “CCR” of register “ECanaRegs.CANMC to 1.
- Before we can continue with the initialisation, we have to wait until the CAN module has granted this request. In this case the flag “CCE” of register “ECanaRegs.CANES” will be set to 1 by the CAN module. Install a wait construct into your code.
- Now we are allowed to set-up the bit timing parameters “BRP”, “TSEG1” and “TSEG2” of register “ECanaRegs.CANBTC”. Use the 100 kbps set-up from the following table:



CAN Bit-Timing Examples

- **Bit Configuration for SYSCLK = 150 MHz**
- **Sample Point at 80% of Bit Time :**

CAN-Baudrate	BRP	TSEG1	TSEG2
1 MBPS	9	10	2
500 KBPS	19	10	2
250 KBPS	39	10	2
125 KBPS	79	10	2
100 KBPS	99	10	2
50 KBPS	199	10	2

- **Example 50 KBPS:**

TQ = (199+1)/150 MHz = 1.334 ns

tseg1 = 1.334 ns (10 + 1) = 14.674 ns ➔ t_{CAN} = 20.010 ns

tseg2 = 1.334 ns (2 + 1) = 4.002 ns

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- After the access to register “ECanaRegs.CANBTC”, we have to re-enable the CAN modules access to this register. This is done by clearing bit “Change Configuration Request (CCR)” of register “ECanaRegs.CANMC”. Again we have to apply a wait loop until this command is acknowledged by the CAN module (Flag “CCE” of register “ECanaRegs.CANES” will be cleared by the CAN module as acknowledgement).
- Finally, we have to disable all mailboxes to exclude them from data communication and to allow write accesses into the message identifier registers of the mailbox of our choice. To disable all mailboxes we have to write a ‘0’ into all bit fields of register “ECanaRegs.CANME”.

14. In main, just before the CpuCoreTimer0 is started, add the function call of “InitCan()”.
15. At the beginning of your code, add a function prototype for “InitCan()”

Prepare Transmit Mailbox #5

16. In main, after the function call to “InitCan()”, add code to prepare the transmit mailbox. In this exercise, we will use mailbox #5, an extended identifier of 0x10000000 and a data length code of 1. Add the following steps:
    - Write the identifier into register “EcanaMboxes.MBOX5.MSGID”.
    - To transmit with extended identifiers set bit “IDE” of register “EcanaMboxes.MBOX5.MSGID” to 1.
    - Configure Mailbox #5 as a transmit mailbox. This is done by setting bit MD5 of register “ECanaRegs.CANMD” to 0. Caution! Due to the internal structure of the CAN-unit, we can’t execute single bit accesses to the original CAN registers. A good principle is to copy the whole register into a shadow register, manipulate the shadow and copy the modified 32 bit shadow back into its origin:

      ECanaShadow.CANMD.all = ECanaRegs.CANMD.all;

      ECanaShadow.CANMD.bit.MD5 = 0;

      ECanaRegs.CANMD.all = ECanaShadow.CANMD.all;

    - Enable Mailbox #5:

      ECanaShadow.CANME.all = ECanaRegs.CANME.all;

      ECanaShadow.CANME.bit.ME5 = 1;

      ECanaRegs.CANME.all = ECanaShadow.CANME.all;

    - Set-up the Data Length Code Field (DLC) in Message Control Register “ECanaMboxes.MBOX5.MSGCTRL” to 1.

Add the Data Byte and Transmit

17. Now we are almost done. The only thing that’s missing is the periodical loading of the data byte into the mailbox and the transmit request command. This must be done inside the while(1)-loop of main. Locate the code where we wait until variable “CpuTimer0.InterruptCount” has reached 20. Here add:
    - Load the current status of the 8 input switches at GPIO-Port B (Bits 15 to 8) into register “ECanaMboxes.MBOX5.MDL.byte.BYTE0”
    - Request a transmission of mailbox #5. Init register “ECanaShadow.CANTRS”. Set bit TRS5=1 and all other 31 bits to 0. Next, load the whole register into “ECanaRegs.CANTRS”

- Wait until the CAN unit has acknowledged the transmit request. The flag “ECanaRegs.CANTA.bit.TA5” will be set to 1 if your request has been acknowledged.
- Clear bit “ECanaRegs.CANTA.bit.TA5”. Again the access must be made as a 32 bit access:

```
ECanaShadow.CANTA.all = 0;

        ECanaShadow.CANTA.bit.TA5 = 1;

        ECanaRegs.CANTA.all = ECanaShadow.CANTA.all;
```

Build, Load and Run

18. Click the “Rebuild All” button or perform:

    Project → Build
    File → Load Program
    Debug → Reset CPU
    Debug ➔ Restart
    Debug → Go main
    Debug ➔ Run(F5)

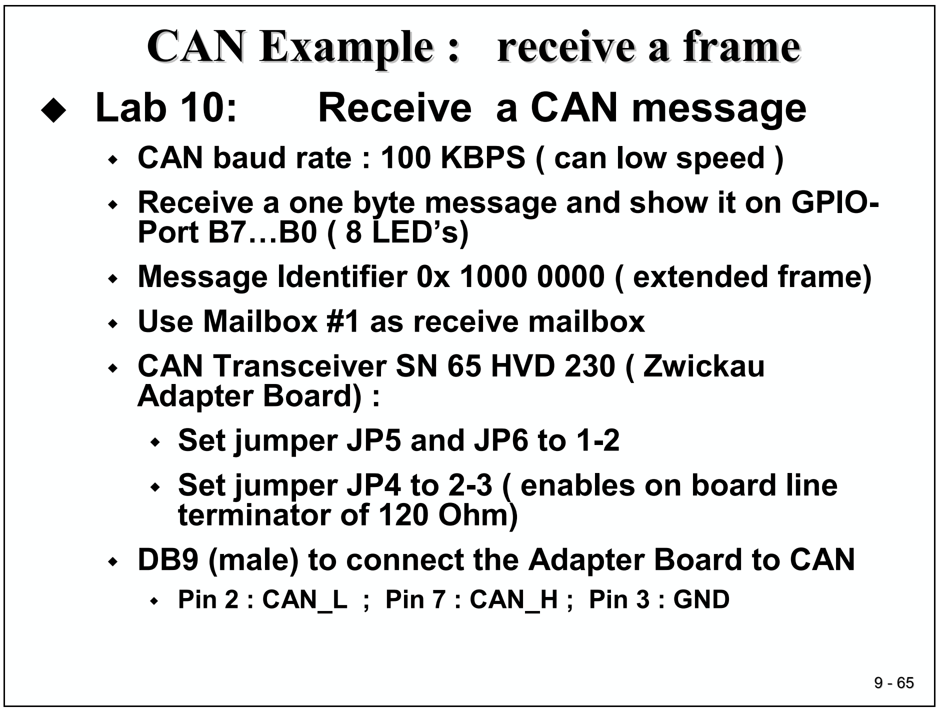
19. Providing you have found a partner team with another C28x connected to your laboratory CAN system and waiting for a one-byte data frame with identifier 0x10000000 you can do a real network test. Modify the status of your input switches. The current status should be transmitted every second via CAN.

    If your teacher can provide a CAN analyser you should be able to trace your data frames at the CAN. Your partner team should be able to receive your frames and use the information to update their LED’s.

    If you end up in a fight between the two teams about whose code might be wrong, ask your teacher to provide a working receiver node. Recommendation for teachers: Store a working receiver code version in the internal Flash of one node and start this node out of flash memory.

END of LAB 9

Lab Exercise 10



CAN Example : receive a frame

- **Lab 10: Receive a CAN message**
  - **CAN baud rate : 100 KBPS (can low speed)**
  - **Receive a one byte message and show it on GPIO-Port B7…B0 (8 LED's)**
  - **Message Identifier 0x 1000 0000 (extended frame)**
  - **Use Mailbox #1 as receive mailbox**
  - **CAN Transceiver SN 65 HVD 230 (Zwickau Adapter Board) :**
    - **Set jumper JP5 and JP6 to 1-2**
    - **Set jumper JP4 to 2-3 (enables on board line terminator of 120 Ohm)**
  - **DB9 (male) to connect the Adapter Board to CAN**
    - **Pin 2 : CAN_L ; Pin 7 : CAN_H ; Pin 3 : GND**

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Preface

This laboratory experiment is the second part of a CAN-Lab. Again we have to set up the physical CAN-layer according to the layout of your laboratory.

The CAN requires a transceiver circuit between the digital signals of the C28x and the bus lines to adjust the physical voltages. The Zwickau Adapter Board is equipped with two different types of CAN transceivers, a Texas Instruments SN65HVD230 for high speed ISO 11898 applications and a Phillips TJA1054, quite often used in the CAN for body electronics of a car. With the help of two jumpers (JP5, JP6), you can select the transceiver in use. For Lab 10 we will use the SN65HVD230.

The physical CAN lines for ISO 11898 require a correct line termination at the ends of the transmission lines by 120 Ohm terminator resistors. If the C28x is placed at one of the end positions in your CAN network, you can use the on-board terminator of 120 Ohms by setting jumper JP4 to position 2-3. If the physical structure of the CAN in your laboratory does not require the C28x to terminate the net, set JP4 to 1-2. Ask your teacher which set-up is the correct one.

To test your code you will need a partner team with a second C28x doing Lab 9. e.g. sending a one byte message with identifier 0x10 000 000 every second.

Before you start the hard wiring, ask your teacher or a laboratory technician what exactly you are supposed to do to connect the boards!

Objective

- The objective of Lab 10 is to receive a one byte data frame every time it is transmitted via CAN, and update the status of the 8 output lines GPIO-B7...B0 (8 LED's) with the data information..
- The baud rate for the CAN should be set to 100 KBPS.
- The exercise should use extended identifier 0x1000 0000 for the receive filter of mailbox 1. You can also use any other number as identifier, but please make sure that your partner team (Lab 9) knows about your change. If you classroom uses several eZdsp's at the same time, it could be an option to set up pairs of teams sharing the CAN by using different identifiers. It is also possible, that due to the structure of the laboratory set-up of your university, not all identifier combinations might be available to you. You surely don't want to start the ignition of a motor control unit that is also connected to the CAN for some other experiments. Before you use any other ID's ➔ ask your teacher!
- Use Mailbox #1 as your receiver mailbox
- Once you have initialized the CAN module wait for a reception of mailbox #1 by polling the status bit. Doing so we can refrain from using CAN interrupts for this first CAN exercise.

Procedure

Open Files, Create Project File

1. Create a new project, called **Lab10.pjt** in E:\C281x\Labs.
2. A good point to start with is the source code of Lab4, which produces a hardware based time period using CPU core timer 0. Open the file Lab4.c from E:\C281x\Labs\Lab4 and save it as Lab10.c in E:\C281x\Labs\Lab10.
3. Add the source code file to your project:
   - **Lab10.c**
4. From *C:\tidcs\c28\dsp281x\v100\DSP281x_headers\source* add:
   - **DSP281x_GlobalVariableDefs.c**

   From *C:\tidcs\c28\dsp281x\v100\DSP281x_headers\cmd* add:
   - **F2812_Headers_nonBIOS.cmd**

   From *C:\tidcs\c28\dsp281x\v100\DSP281x_common\cmd* add:
   - **F2812_EzDSP_RAM_lnk.cmd**

From *C:\ti\c2000\cgtoolslib* add:

- **rts2800_ml.lib**

Project Build Options

5. Setup the search path to include the peripheral register header files. Click:

   Project → Build Options

   Select the Compiler tab. In the preprocessor Category, find the Include Search Path (-i) box and enter:

   C:\tidcs\C28\dsp281x\v100\DSP281x_headers\include;
   ..\include

6. Setup the stack size: Inside Build Options select the Linker tab and enter in the Stack Size (-stack) box:

   400

   Close the Build Options Menu by Clicking <**OK**>.

Modify Source Code

7. Before we can start editing our own code we have to modify a portion of the Texas Instruments Header file "**DSP281x_ECan.h**", Version 1.0. This file has a bug inside the structures "CANMDL_BYTES" and "CANMDH_BYTES". The order of bytes is not correct.

   Search and edit struct CANMDL_BYTES and CANMDH_BYTES:

```
struct  CANMDL_BYTES {      // bits   description

            Uint16     BYTE3:8;     // 31:24

            Uint16     BYTE2:8;     // 23:16

            Uint16     BYTE1:8;     // 15:8

            Uint16     BYTE0:8;     // 7:0

            };

struct  CANMDH_BYTES {      // bits   description

            Uint16     BYTE7:8;     // 63:56

            Uint16     BYTE6:8;     // 55:48
Uint16    BYTE5:8;    // 47:40

Uint16    BYTE4:8;    // 39:32

};
```

8. Open Lab10.c to edit.

   Remove the function prototype and the definition of function "**cpu_timer0_isr()**." We do not use the CPU core timer in this lab exercise.

   In "main()", remove the local variables "**i**" and "**LED[8]**".

   Between the start of "main" and the "while(1)-loop of "main()", remove all function calls apart from "InitSystem()" and "Gpio_select()".

   Inside the while(1)-loop remove all old lines, just keep the service instructions for the watchdog:

```
EALLOW;
SysCtrlRegs.WDKEY = 0x55;
SysCtrlRegs.WDKEY = 0x55;
EDIS;
```

Build, Load and Run

9. Before we continue to modify our source code lets try to compile the project in this stage to find any syntax errors.

   Click the "Rebuild All" button or perform:

   Project → Build
   File → Load Program
   Debug → Reset CPU
   Debug → Restart
   Debug → Go main
   Debug → Run(F5)

   If everything went like expected you should end up with 0 errors, 0 warnings and 0 remarks.

Modify Source Code Cont.

10. Congratulations! Now let's install the CAN – receiver part.

    First, add a new structure "ECanaShadow" as a local variable in main:

    struct ECAN_REGS ECanaShadow;

This structure will be used as a local copy of the original CAN registers. A manipulation of individual bits is done inside the copy. At the end of the access the whole copy is reloaded into the original CAN structures. This principle of operation is necessary because of the inner structure of the CAN unit; some registers are only accessible by 32-bit accesses and by copying the whole structure, we make sure to generate 32-bit accesses only.

11. In function “InitSystem()” enable the clock unit for the CAN module.

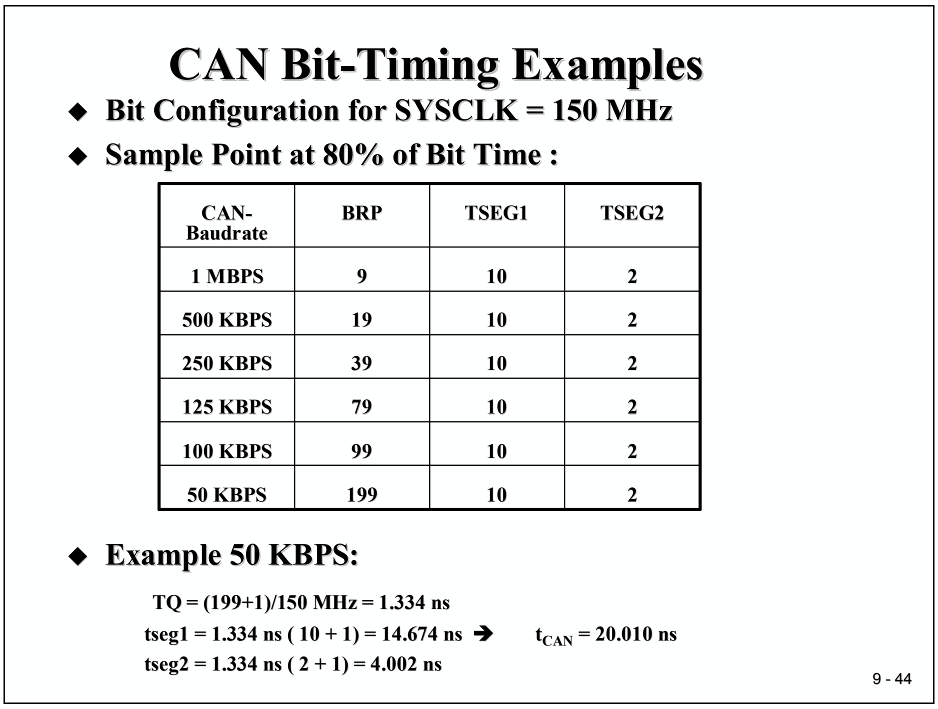
12. Next, inside function “Gpio_select()”, enable the peripheral function of CANTxA and CANRxA:

    GpioMuxRegs.GPFMUX.bit.CANTXA_GPIOF6 = 1;

    GpioMuxRegs.GPFMUX.bit.CANRXA_GPIOF7 = 1;

Add the CAN initialization code

13. Add a new function “InitCan()” at the end of your source code to initialize the CAN module. Inside “InitCan()”, add the following steps:
    - In Register “ECanaRegs.CANTIOC” and “ECanaRegs.CANRIOC” configure the two pins “TXFUNC” and “RXFUNC”for CAN.
    - Enable the HECC mode of the CAN module (Register “ECanaRegs.CANMC”).
    - To set-up the baud rate for the CAN transmission we need to get access to the bit timing registers. This access is requested by setting bit “CCR” of register “ECanaRegs.CANMC to 1.
    - Before we can continue with the initialization we have to wait until the CAN module has granted this request. In this case, the flag “CCE” of register “ECanaRegs.CANES” will be set to 1 by the CAN module. Install a wait construct into your code.
    - Now we are allowed to set-up the bit timing parameters “BRP”, “TSEG1” and “TSEG2” of register “ECanaRegs.CANBTC”. Use the 100 kbps set-up from the following table:



CAN Bit-Timing Examples

- **Bit Configuration for SYSCLK = 150 MHz**
- **Sample Point at 80% of Bit Time :**

CAN-Baudrate	BRP	TSEG1	TSEG2
1 MBPS	9	10	2
500 KBPS	19	10	2
250 KBPS	39	10	2
125 KBPS	79	10	2
100 KBPS	99	10	2
50 KBPS	199	10	2

- **Example 50 KBPS:**

TQ = (199+1)/150 MHz = 1.334 ns
tseg1 = 1.334 ns (10 + 1) = 14.674 ns ➔ t_{CAN} = 20.010 ns
tseg2 = 1.334 ns (2 + 1) = 4.002 ns

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- After the access to register “ECanaRegs.CANBTC” we have to re-enable the CAN modules access to this register. This is done by clearing bit “Change Configuration Request (CCR)” of register “ECanaRegs.CANMC”. Again, we have to apply a wait loop until this command is acknowledged by the CAN module (Flag “CCE” of register “ECanaRegs.CANES” will be cleared by the CAN module as acknowledgement).
- Finally, we have to disable all mailboxes to exclude them from data communication and to allow write accesses into the message identifier registers of the mailbox of our choice. To disable all mailboxes we have to write a ‘0’ into all bit fields of register “ECanaRegs.CANME”.

14. In main, just before we enter the while(1)-loop, add the function call to “InitCan()”.
15. At the beginning of your code, add a function prototype for “InitCan()”

Prepare Receiver Mailbox #1

16. In main, after the function call of “InitCan()” add code to prepare the receiver mailbox. In this exercise, we will use mailbox #1, an extended identifier of 0x10000000 and a data length code of 1. Add the following steps:
    - Write the identifier into register “EcanaMboxes.MBOX1.MSGID”.
    - To transmit with extended identifiers set bit “IDE” of register “EcanaMboxes.MBOX1.MSGID” to 1.
    - Configure Mailbox #1 as a receive mailbox. This is done by setting bit MD1 of register “ECanaRegs.CANMD” to 1. Caution! Due to the internal structure of the CAN-unit, we can’t execute single bit accesses to the original CAN registers. A

good principle is to copy the whole register into a shadow register, manipulate the shadow and copy the modified 32 bit shadow back into its origin:

ECanaShadow.CANMD.all = ECanaRegs.CANMD.all;

ECanaShadow.CANMD.bit.MD1 = 1;

ECanaRegs.CANMD.all = ECanaShadow.CANMD.all;

- Enable Mailbox #1:

ECanaShadow.CANME.all = ECanaRegs.CANME.all;

ECanaShadow.CANME.bit.ME1 = 1;

ECanaRegs.CANME.all = ECanaShadow.CANME.all;

Add a polling loop for a message in mailbox 1

17. Now we are almost done. The only thing that's missing is the final modification of the while(1)-loop of main. All we have to add is a polling loop to wait for a received message in mailbox #1. The register "ECanaRegs.CANRMP" – Bit field "RMP1" will be set to 1 if a valid message has been received. All we have to do is to wait for this event to happen in a sort of "do-while" loop.

    NOTE1: It is highly recommended to copy ECanaRegs.CANRMP into the local variable "ECanaShadow.CANRMP" before any logical test of bit RMP1 is made.

    NOTE2: Do not forget to include the watchdog-service code lines into your wait construct!

18. If Bit RMP1 was set to 1 by the CAN – Mailbox we can take the data byte 0 out of the mailbox and load it onto the GPIO-B7…B0 (8 LED')s:

    GpioDataRegs.GPBDAT.all = ECanaMboxes.MBOX1.MDL.byte.BYTE0;

19. Finally, we have to reset bit RMP1. This is done by writing a '1' into it:

    ECanaShadow.CANRMP.bit.RMP1 = 1;

    ECanaRegs.CANRMP.all = ECanaShadow.CANRMP.all;

Build, Load and Run again

20. Click the "Rebuild All" button or perform:

    Project → Build
    File → Load Program
    Debug → Reset CPU
    Debug ➔ Restart
    Debug → Go main
    Debug ➔ Run(F5)

21. Providing you have found a partner team with another C28x connected to your laboratory CAN system and transmitting a one-byte data frame with identifier 0x10000000 you can do a real network test. Ask your partner team to modify their input switches and transmit it every second via CAN.

    If your teacher can provide a CAN analyzer you can also generate a transmit message out of this CAN analyzer.

    If you end up in a fight between the two teams about whose code might be wrong, ask your teacher to provide a working transmitter node.

    Recommendation for teachers: Store a working transmitter code version in the internal Flash of one node and start this node out of flash memory.

END of LAB 10

What's next?

Congratulations! You've successfully finished your first two lab exercises using Controller Area Network. As mentioned earlier in this chapter these two labs were chosen as a sort of "getting started" with CAN. To learn more about CAN it is necessary to book additional classes at your university.

To experiment a little bit more with CAN, choose one of the following **optional exercises**:

Lab 10A :

Combine Lab9 (CAN – Transmit) and Lab10 (CAN-Receive) into a bi-directional solution. The task for your node is to transmit the status of the input switches (B15…B8) to CAN every second (or optional: every time the status has changed) with a one-byte frame and identifier 0x10 000 000. Simultaneously, your node is requested to receive CAN messages with identifier 0x11 000 000. Byte 1 of the received frame should be displayed at the GPIO-Port pins B7…B0, which in case of the Zwickau Adapter board are connected to 8 LED's.

Lab 10B:

Try to improve Lab9 and Lab10A by using the C28x Interrupt System for the receiver part of the exercises. Instead of polling the "CANRMP-Bit field" to wait for an incoming message your task is to use a mailbox interrupt request to read out the mailbox when necessary.

Lab 10C:

We did not consider any possible error situations on the CAN side so far. That's not a good solution for a practical project. Try to improve your previous CAN experiments by including the service of potential CAN error situations. Recall, the CAN error status register flags all possible error situations. A good solution would be to allow CAN error interrupts to request their individual service routines in case of a CAN failure. What should be done in the case of an error request? Answer: Try to use the PWM – loudspeaker at output line T1PWM to generate a sound. By using different frequencies, you can signal the type of failure.

Another option could be to monitor the status of the two CAN – error counters and show their current values with the help of the 8 LED's at GPIO-B7…B0.

If your laboratory is equipped with a CAN failure generator like "CANstress" (Vector Informatik GmbH, Germany) you can generate reproducible disturbance of the physical layer, you can destroy certain messages and manipulate certain bit fields with bit resolution. Ask your laboratory technician whether you are allowed to use this type of equipment to invoke CAN errors.

Lab 10D:

An enhanced experiment is to request a remote transmission from another CAN-node. An operating mode, that is quite often used is the so-called "automatic answer mode". A transmit mailbox, that receives a remote transmission request ("RTR") answers automatically by transmitting a predefined frame. Try to establish this operating mode for the transmitter node

(Lab9 or Lab10B). Wait for a RTR and send the current status of the input switches back to the requesting node. The node that has requested the remote transmission should be initialized to wait for the requested answer and display byte 1 of the received data frame at the 8 LED's (GPIO B7…B0).

There are a lot more options for RTR operations available. Again, look out for additional CAN classes at your university!