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Testing of Automotive Systems (Part I)

Module 4 – CAN / LIN

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Schedule

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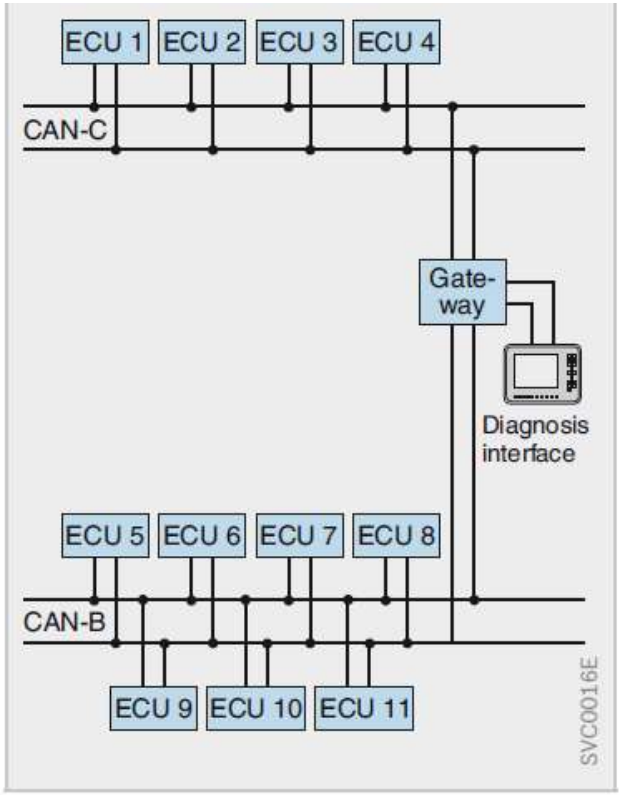
CAN-BUS

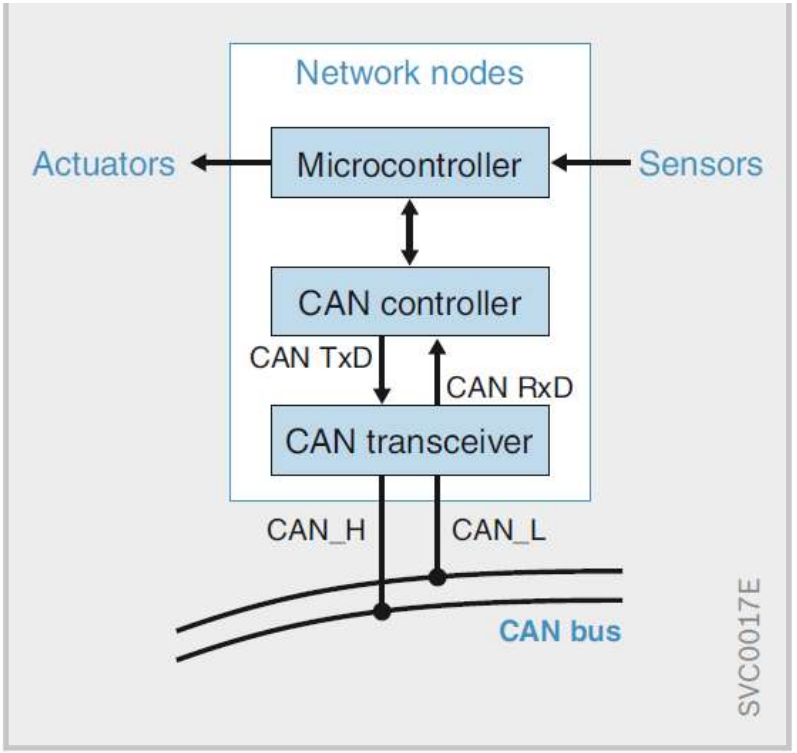
CAN-Bus

- Firstly introduced 1991, still standard in automotive
- Used in various domains in vehicles
- Different data rates are used
  - CAN-C 125kbit-1Mbit/sec
    - „high-speed CAN“ 500 kbit/sec
    - Still in almost every vehicle
  - CAN-B 5-125kbit/sec
    - „low-speed CAN“ 125 kbit/sec
    - More fault-tolerant
    - less used



Network nodes

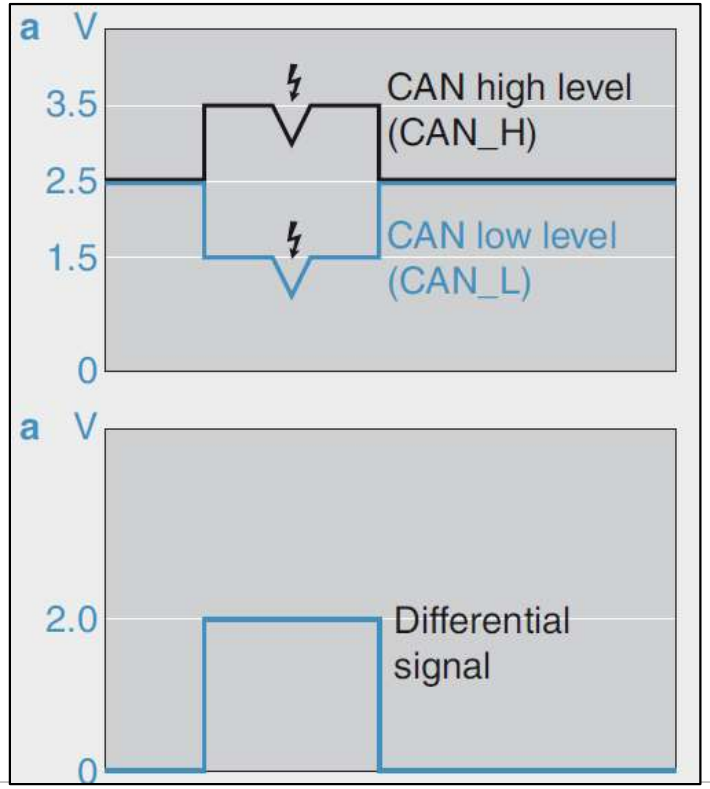
- All network nodes are connected to a bus and each node is able to receive all information sent on the bus
- The two bus lines are designated CAN_H and CAN_L
- A network node comprises of
  - Microcontroller
    - runs the application program
    - controls the CAN controller
    - prepares the sent data and evaluates received data
  - CAN Controller
    - responsible for the transmit and receive modes
    - generates the data communication bit stream
    - forwards it to the transceiver on the TxD line
  - CAN Tranceiver
    - Signal amplification, generates voltage levels
    - transmits the processed bit stream serially



Logical bus states

- Two states created by CAN controller
  - dominant binary “0”
  - recessive “1”
  - NRZ = non-return-to-zero
- Unshielded twisted pair cables (UTP, diameter between 0,34 and 0,6 mm²)
- Disturbance pulses have effect on both lines
- Differential amplifier subtracts CAN_L from CAN_H level
- Additional shielding reduce self emissions

CAN great benefit -> it is extremly robust because of twisted pairs.



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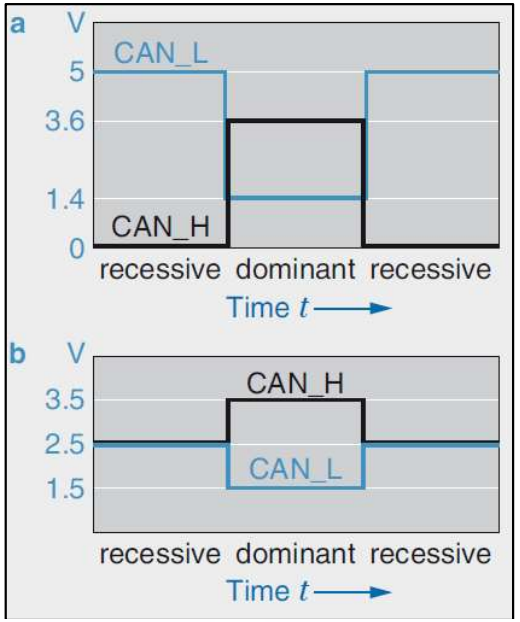
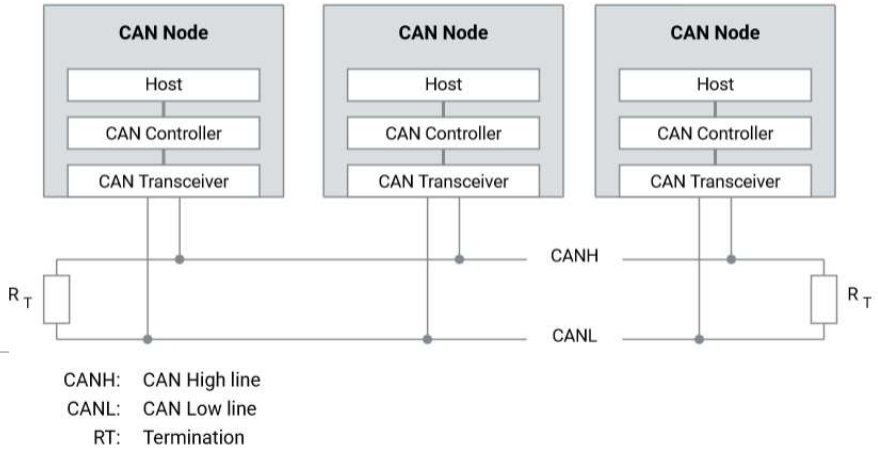
Electrical bus states

- CAN transceiver converts digital to voltage signals
  - Low-Speed CAN (a)
    - dominant CAN_H 3.6V / CAN_L 1.4V
    - recessive CAN_H 0V / CAN_L 5V
  - High-Speed CAN (b)
    - dominant CAN_H 3.5V / CAN_L 1.5V
    - recessive CAN_H 2.5V / CAN_L 2.5V
- Terminal resistor RT= 120Ω to dampen reflections (b)
- Maximum number of nodes 32 according ISO11898
- Maximum bus length (recommendation)
  - 500kbaud 100m
  - 125kbaud 500m





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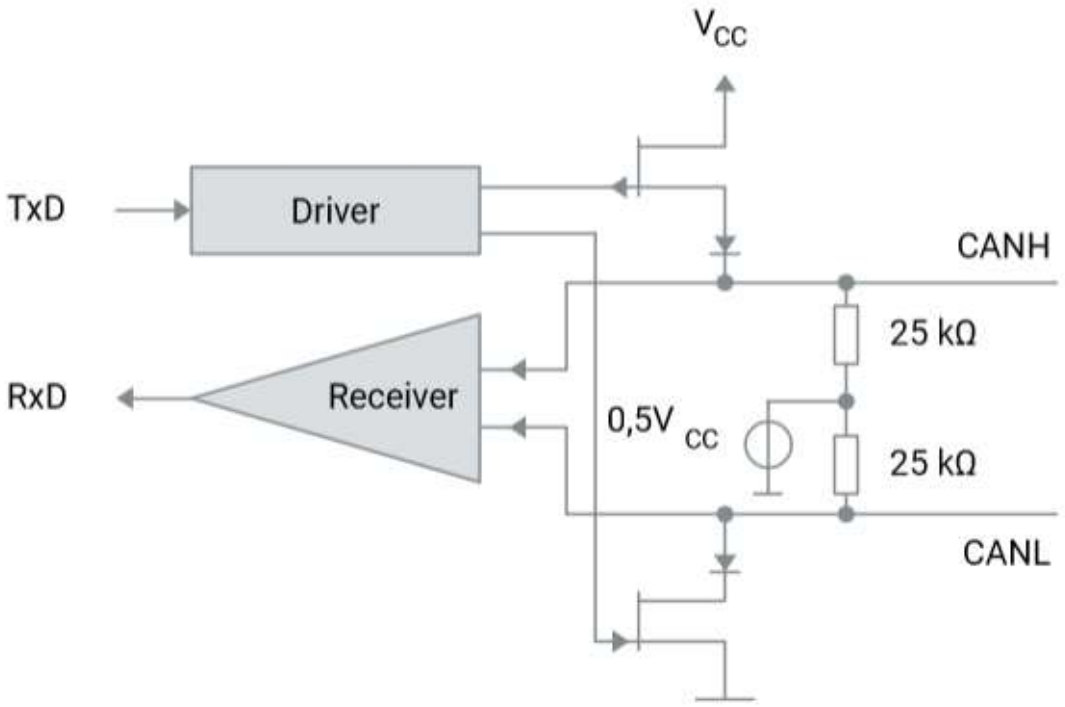
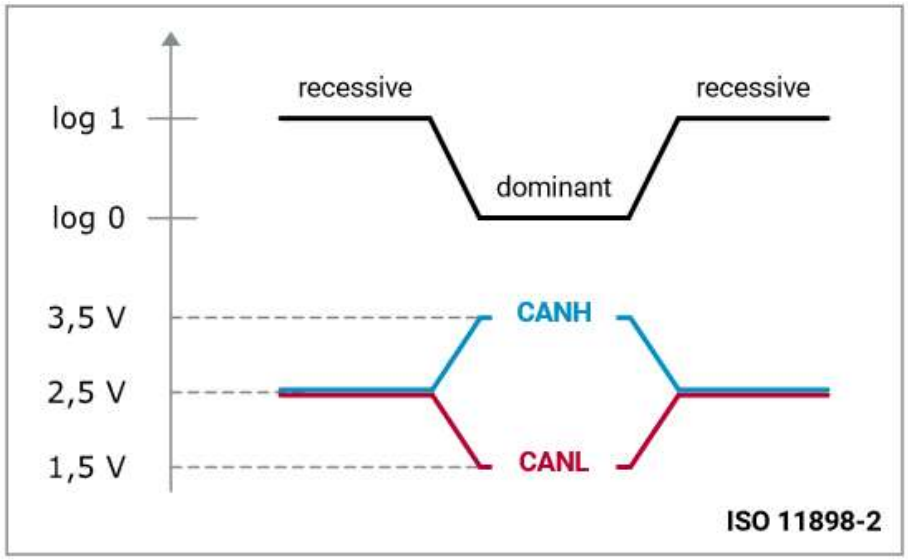
CAN Tranceiver





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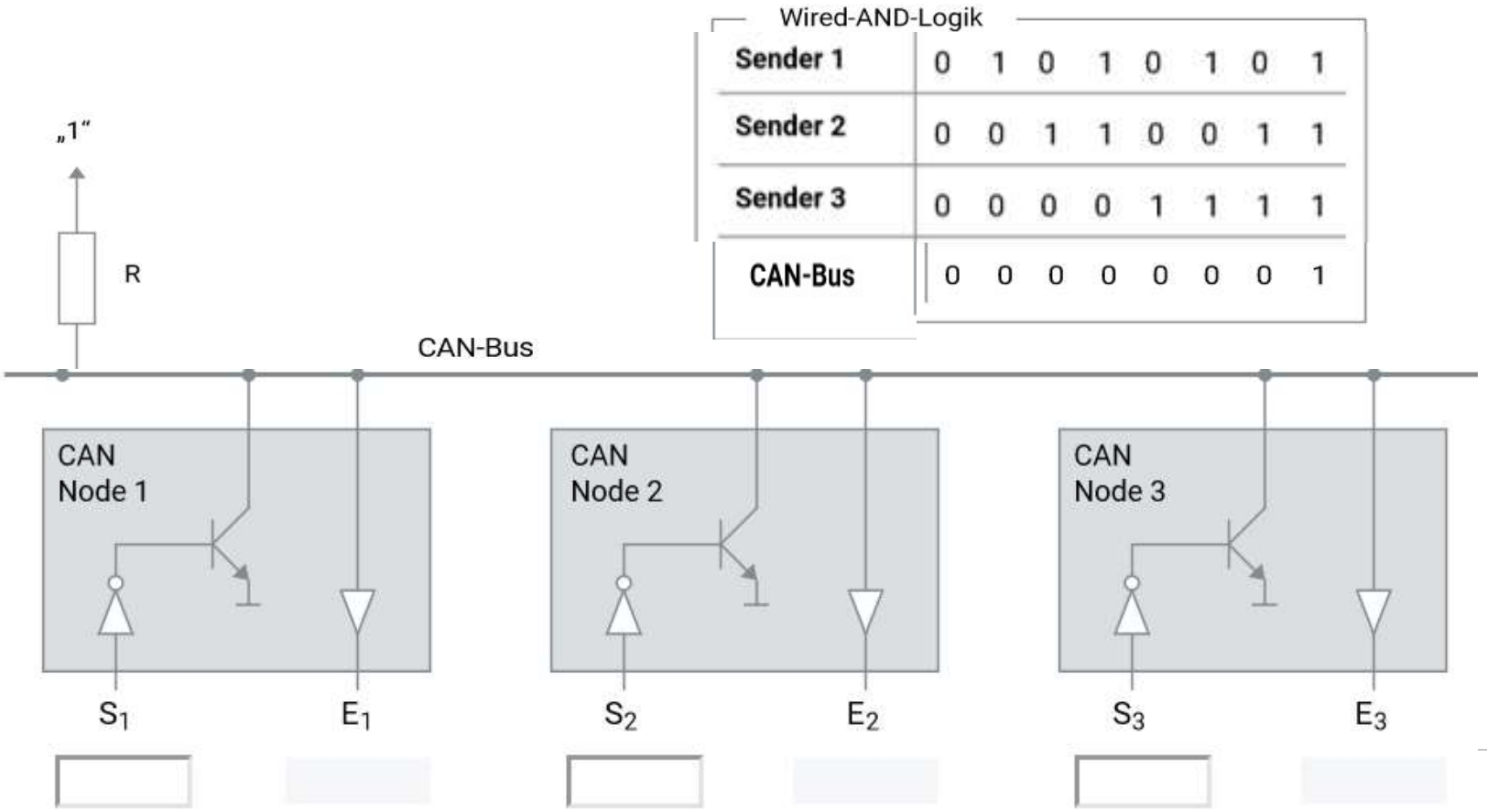
Exercise: Open Collector Buslogic



12 V
~ 0,7 V
~ 50 mA
~ 4 Ω
~ 0 V
~ 12 V
leitet
geschlossen

As long as we have a zero on one it will be pulled to zero.

There is no master, kind of democracy with no refree.

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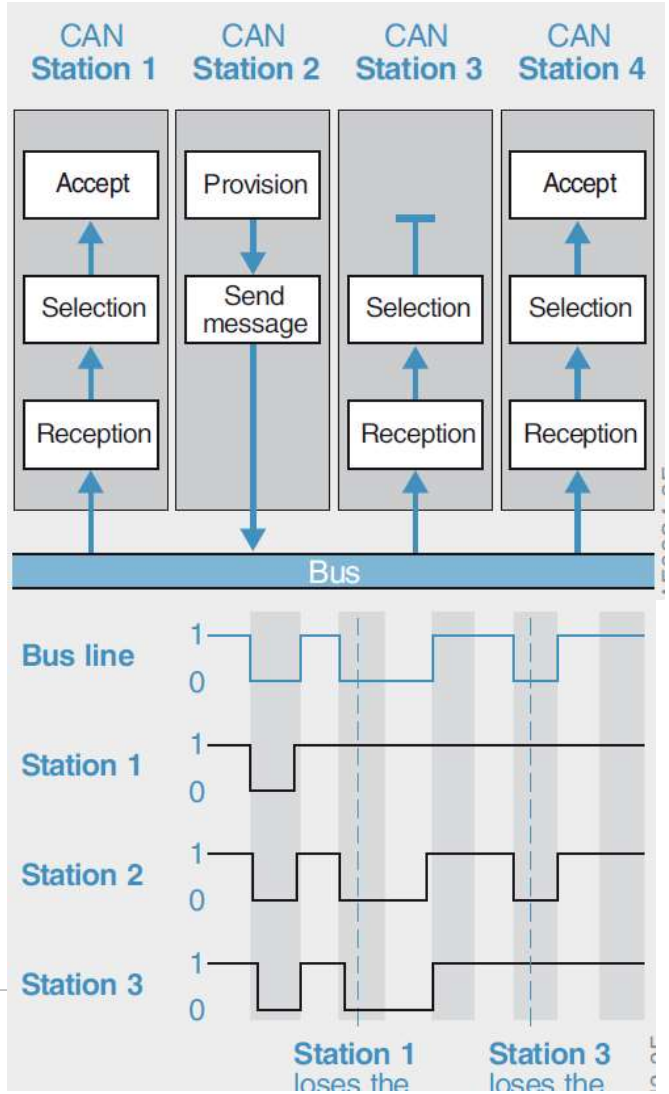
CAN Communication

- Multi-Master Principle
  - Each node may send messages any time
  - If bus is free and arbitration has been passed
- Content-based addressing
  - No addressing of nodes but of messages
  - Identifier classifies message content
  - Messages are broadcasted to all stations
  - Read only those messages which are stored in acceptance list
- Arbitration
  - Message begins with a dominant bit (start-of-frame bit), followed by the identifier
  - Message with highest priority is assigned first access
  - With highest priority bus access ~300µs
  - The higher the busload the bigger the latency



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Arbitration and priorisation

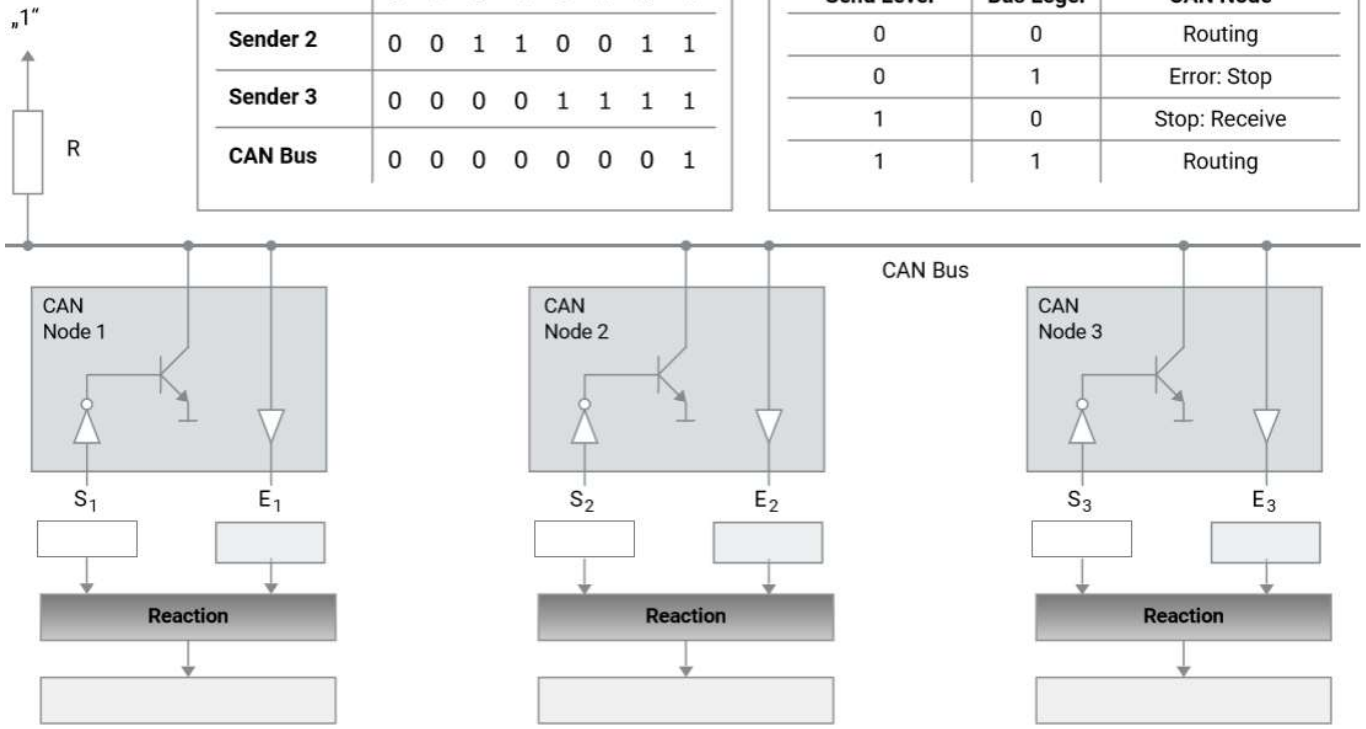
- Bitwise arbitration, wired-AND logic
- To get access to the bus a node needs message with the highest priority
- The smaller the Identifier value the higher the priority

Wired-AND-Logik

Sender 1	0	1	0	1	0	1	0	1
Sender 2	0	0	1	1	0	0	1	1
Sender 3	0	0	0	0	1	1	1	1
CAN Bus	0	0	0	0	0	0	0	1

Arbitration Logic

CAN Node/ Send Level	CAN Bus Legel	Reaction of CAN Node
0	0	Routing
0	1	Error: Stop
1	0	Stop: Receive
1	1	Routing



CAN Message Format

- Data Frame
  - Transmitted message contains data (e.g. current engine speed) that is provided by transmitting station (data source)
- Remote Frame
  - Stations can call-in data they need from the data source
  - Example: windshield wiper requests how wet windshield is from rain sensor
- Error Frame
  - If station detects a fault or error
- Overload Frame
  - create a delay between preceding and subsequent data or remote frame

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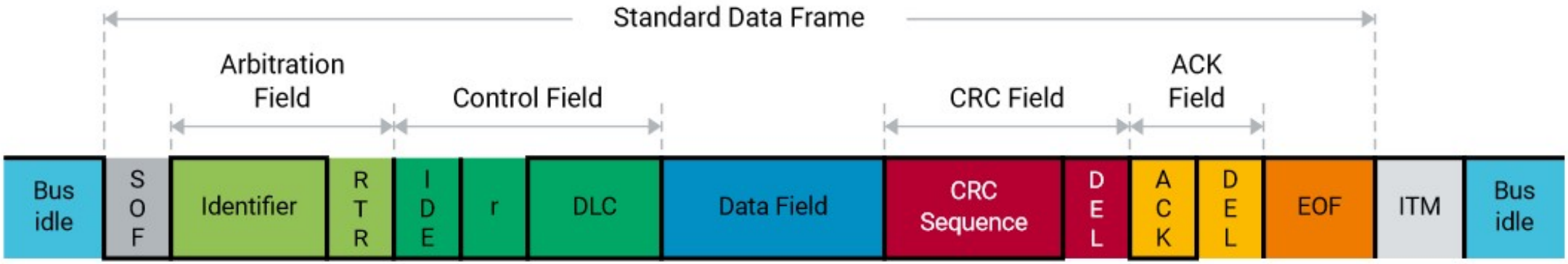
CAN Message Format

- SOF → start of frame represented by a dominant bit
- Arbitration field → 11-bit or 29-bit (extended) identifier and remote transmission request
- Control field → Identifier extension and number of data length code (DLC) in data field
- Data field → Actual message information 0…8 byte
- CRC field → 15-bit cyclic redundancy checksum (Generator polynom G(x))
- ACK field → Divison frame/polynom →acknowledge receipt by the **receiver**
- EOF → End of frame with 7 recessive bits
- ITM → Interframe space, separate successive messages



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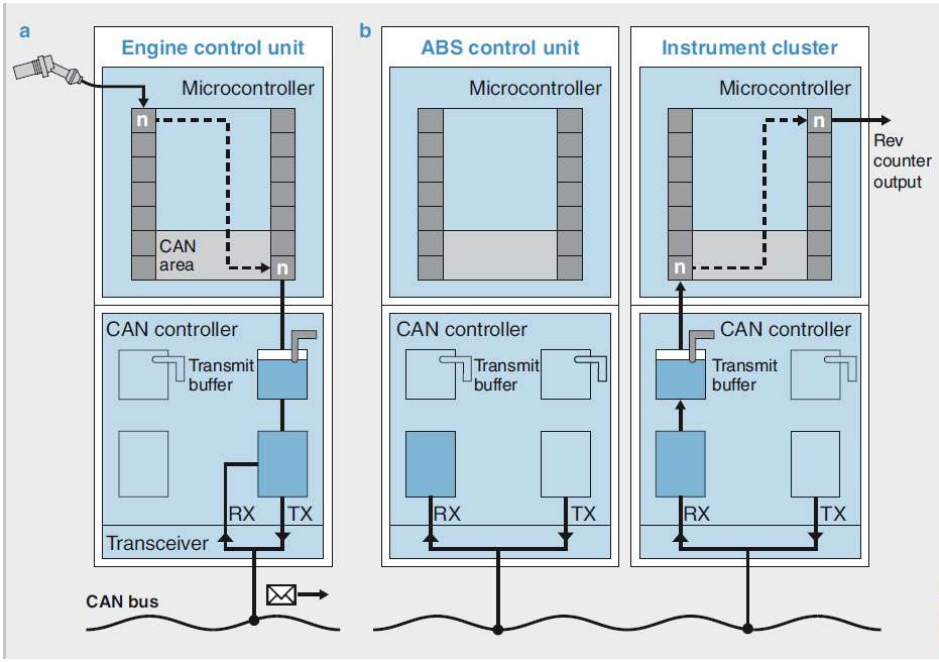
Data transfer sequence

- Engine ECU calculates engine speed from sensor on microcontroller level
- CAN Controller compiles CAN frame and generates bitstream if bus is free
- Bus availability check via CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance)
- Tranceiver generates electrical signal and puts it on the bus
- Signal is received by all stations
- CAN controller of receiving node checks message for errors and acceptance, reject or receives message



All transmitter/receiver relationships including the meaning of the messages are described in the **communication matrix**

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Now it is getting stressful, because the messages are higher and it happens that a lot of messages wait too long.

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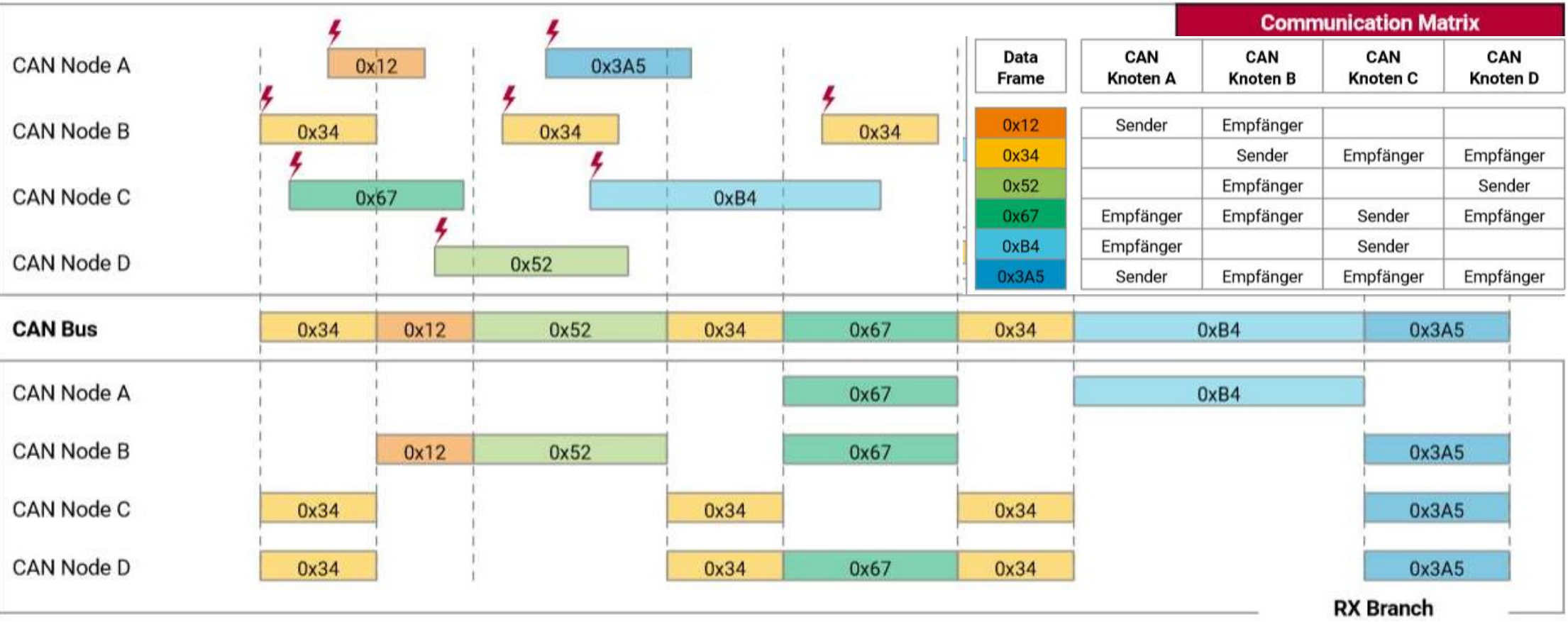
Exercise: Typical CAN-Communication



Communication Matrix

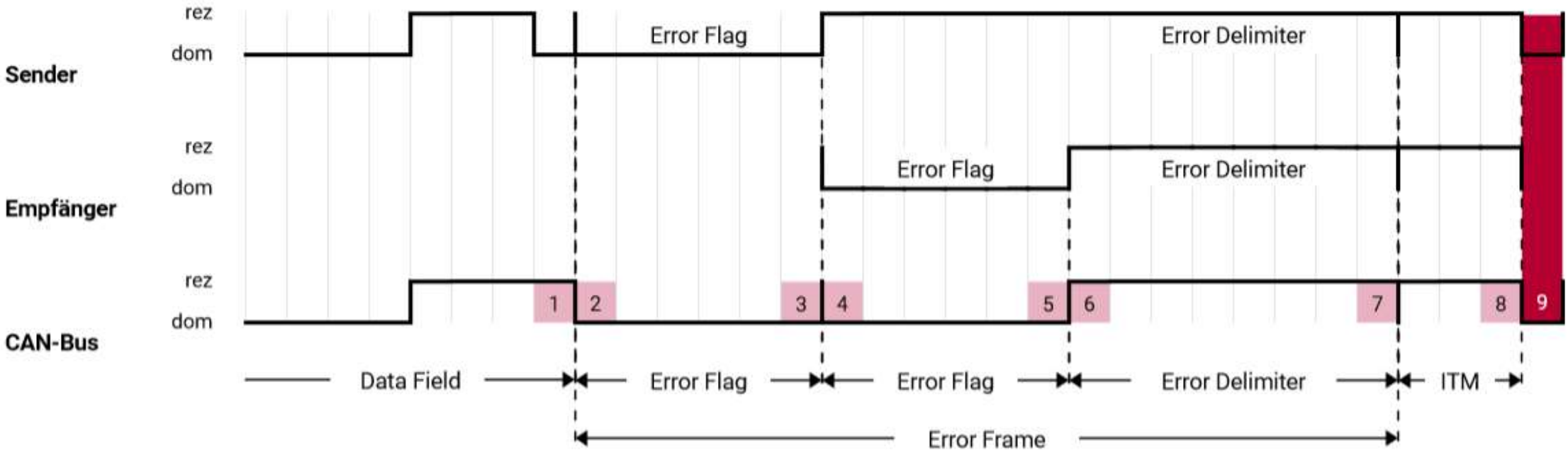
Data Frame	CAN Knoten A	CAN Knoten B	CAN Knoten C	CAN Knoten D
0x12	Sender	Empfänger		
0x34		Sender	Empfänger	Empfänger
0x52		Empfänger		Sender
0x67	Empfänger	Empfänger	Sender	Empfänger
0xB4	Empfänger		Sender	
0x3A5	Sender	Empfänger	Empfänger	Empfänger

CAN Error processing

- If an error is detected by a node , message transfer is aborted
- All nodes have to be informed by the node who has detected the error
- Error flag is put on the bus by six dominant bits
- This is a violation of the bitstuffing rule
  - Bitstuffing rule: after five bits of same kind transmission of one complementary bit
- Violation of bitstuffing rule causes error flag at all other nodes
- After error flag, delimiter and intermission data frame is send again (if allowed by arbitration)
- Error counters detect recurring errors, CAN-Controller will be cut from bus at counter overload

Error processing

- 1-2 Bus monitoring error detected by sender, error flag set and bit stuffing rule violated
- 3-4 Receiver detects bitstuffing rule violation and stets error flag, sender in delimiter state
- 5-6 Receiver has finished error flag, both sender and receiver go in delimiter mode
- 7-9 Delimiter and intermission finished, data frame starts again with SOF



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CAN-FD

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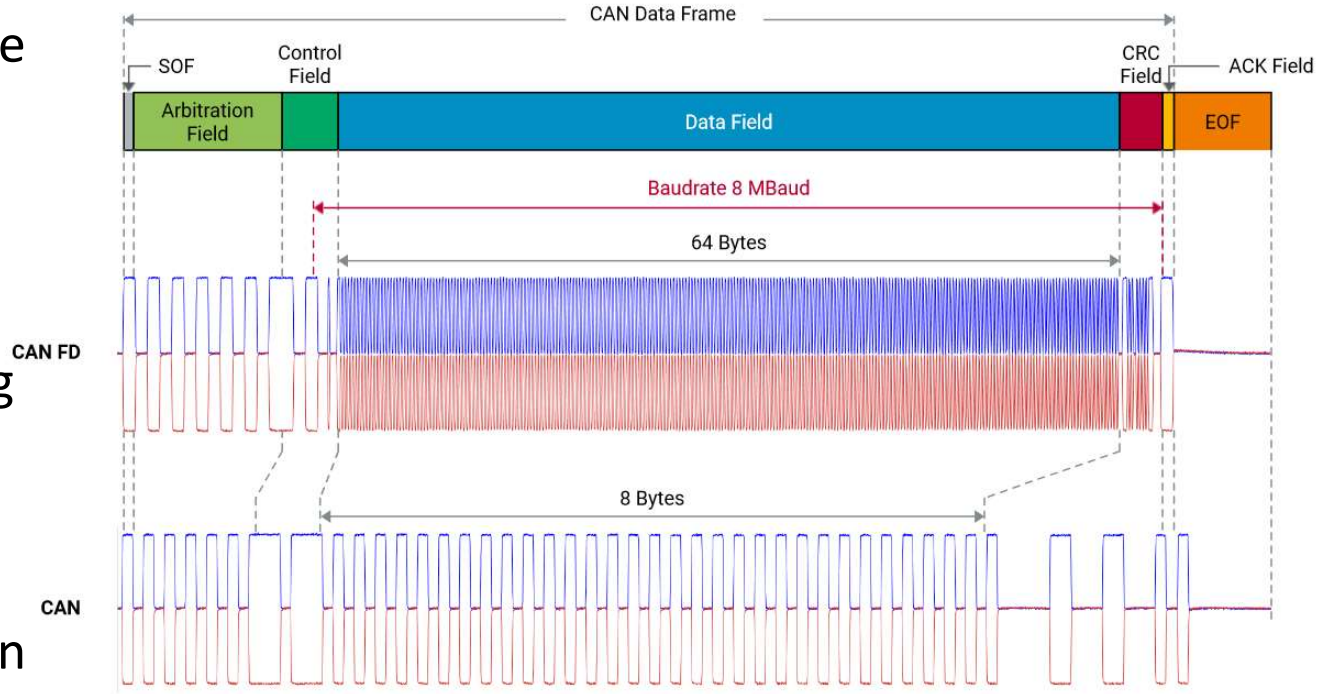
CAN FD Motivation and principle

- Bandwidth requirements increase due to additional vehicle functions
- General exchange CAN by other bus technologies with higher bandwidth not suitable regarding costs and development efforts
- Bandwidth limitating factor for CAN is parallel node communication during arbitration (and acknowledge ACK) period
- Idea: Increase the bandwidth only during data field



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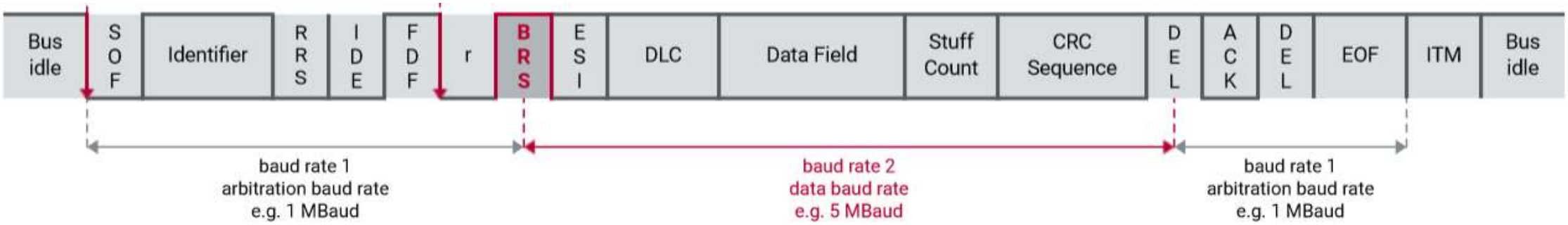
CAN FD Motivation and principle

- CAN Reserve bit is used as CAN FD indicator
- FDF (Flexible data rate format) indicates transmission of CAN or CAN FD frame
- Bit rate switch (BRS) announces increase of baud rate
- Switch back to baudrate 1 at CRC delimiter
- Backwards compatibility to CAN, but no upwards compatibility



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LIN-BUS

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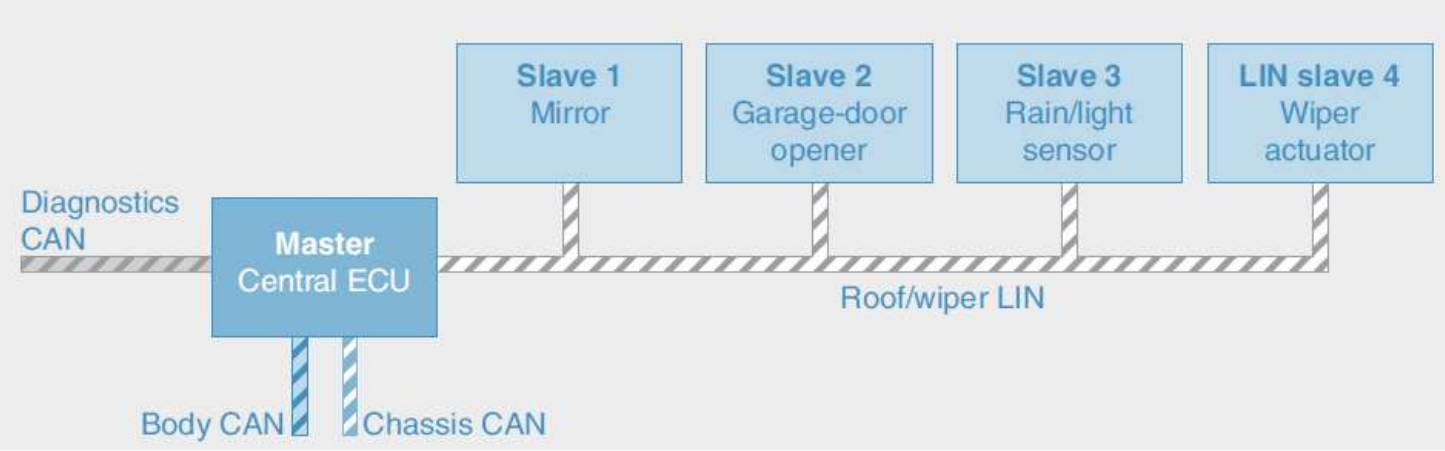
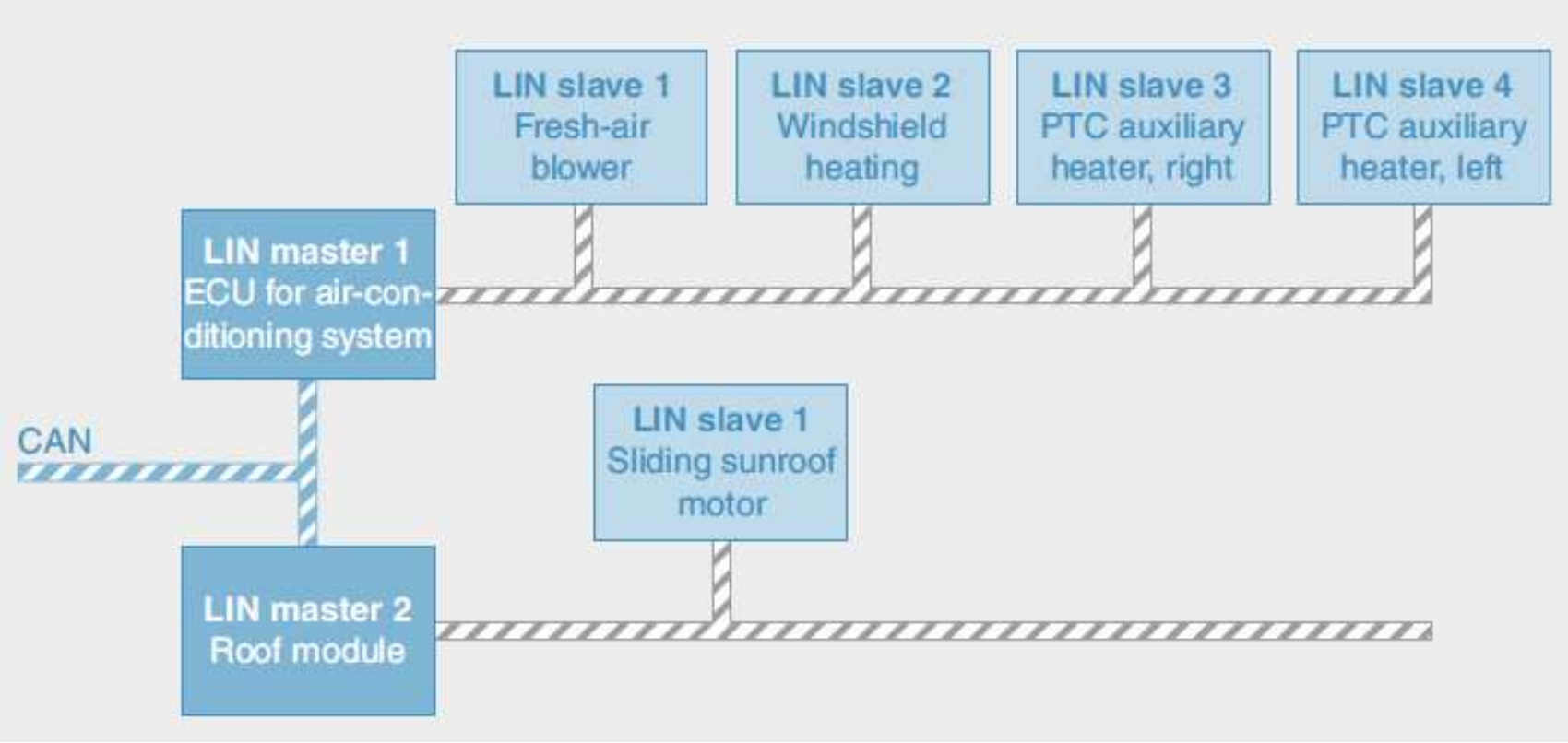
LIN (local interconnect network) – Bus

- Low-cost unshielded single-wire bus system
- Low data rates max 20kbit/sec and limited to 16 bus subscribers
- Local subsystem within demarcated installation space (e.g. door)
- Master/slave topology with connection to superordinate CAN
- Time-synchronous communication where master defines time grid
- Mainly comfort appications: Door modules, sunroof, seat adjustment etc.



LIN networking example – AC control



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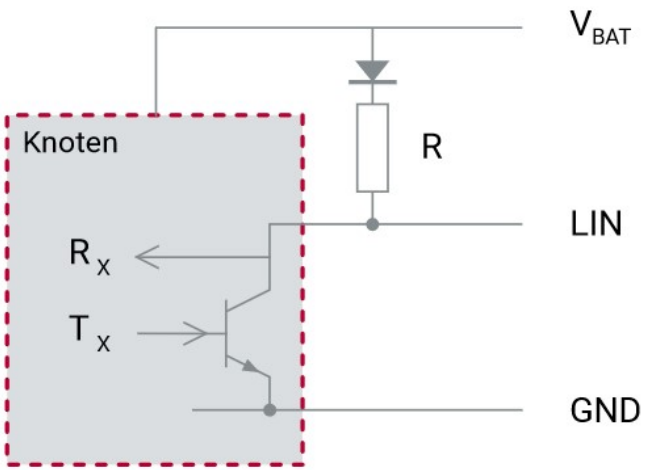
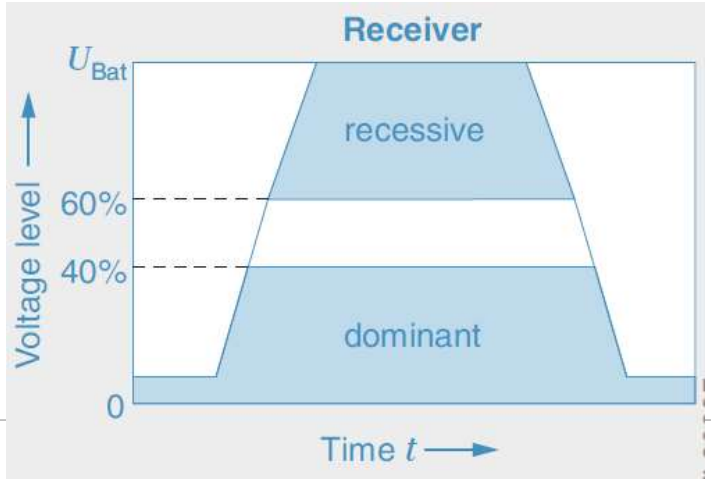
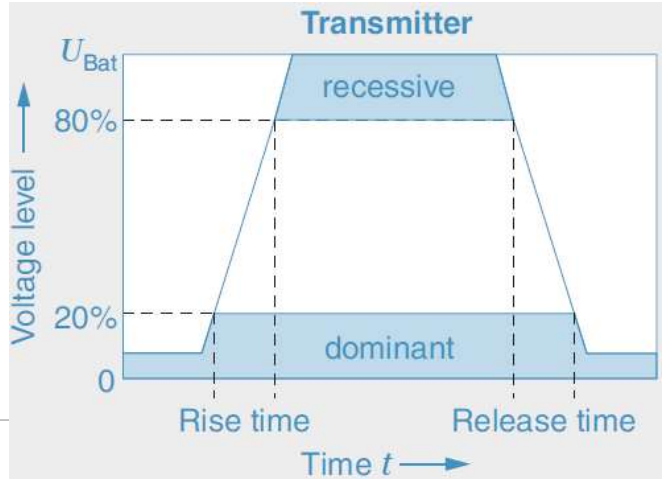
LIN data transmission system

- Open collector circuit, wired-AND logic same as CAN
- Dominant level corresponds to ~ 0V (vehicle ground) and represents logical 0
- Recessive level corresponds to VBAT and represents logical 1
  - Pull-up Resistance 1kΩ (master) and 30kΩ (slaves)
- Stable data transfer by means of tolerance zones for transmitter and receiver
- Data rate limited to 20kbit/sec







LIN bus access – message format

- Master initiates slave(s) response with frame header
- Slaves answer with frame response
- Deterministic„Delegated token“ bus access → No collisions or arbitration
- Predictable data transfer, defined **schedule**
- LIN configuration in *.ldf-file
- LIN standard describes several types of frames
- Several types of frame, unconditional frame described here, unique header and response

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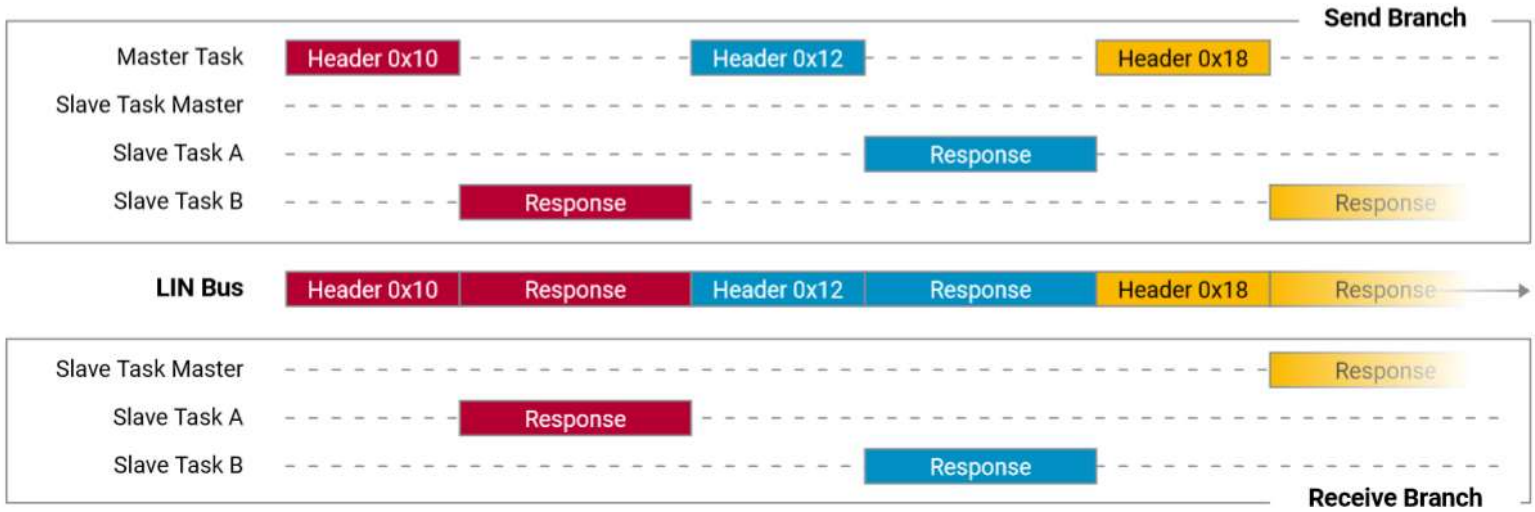
LIN Schedule

Communication Matrix

Schedule		Frame \ Slave Task	Slave Task Master	Slave Task A	Slave Task B
T_1	Frame Slot 1	Unconditional Frame ID=0x10		Receiver	Sender
T_2	Frame Slot 2	Unconditional Frame ID=0x12		Sender	Receiver
T_3	Frame Slot 3	Unconditional Frame ID=0x18	Receiver		Sender
T_4	Frame Slot 4	Unconditional Frame ID=0x1C	Receiver	Sender	Receiver
T_5	Frame Slot 5	Unconditional Frame ID=0x20	Receiver		Sender
T_6	Frame Slot 6	Unconditional Frame ID=0x24	Sender	Receiver	

Communication Cycle



These slides provide an overview of the LIN (Local Interconnect Network) protocol's data transmission system, message format, and communication schedule.

1. **LIN Data Transmission System:**
   - **Electrical Characteristics:** LIN uses an open collector/drain circuit, akin to CAN's differential signaling, allowing multiple devices to drive the line without conflict.
   - **Voltage Levels:** It signifies logical '0' (dominant) as battery voltage and logical '1' (recessive) as ground, similar to how low voltage corresponds to dominant level in CAN.
   - **Stable Data Transfer:** Ensured by the tolerance zones for signal voltage which accommodate variances in transmitter and receiver.
   - **Diagram:** Depicts a typical LIN communication setup, showing the master and slave, the LIN bus, and how the voltage levels correspond to logical states.

2. **LIN Bus Access – Message Format:**
   - **Frame Initiation:** The master starts communication with a frame header, signaling the slaves to listen.
   - **Slave Response:** Only the addressed slave responds with the appropriate frame as determined by the master.
   - **Bus Access:** It's deterministic and 'token-based,' meaning there are no collisions as communication timing is strictly controlled.
   - **Schedule-Based:** The data transmission is predetermined by a schedule set in the LDF (LIN Description File).
   - **Frame Types:** It mentions that LIN standard describes several frame types, with the 'unconditional frame' being the most basic, consisting of a unique header and response.

3. **LIN Schedule:**
   - **Tabular Format:** A schedule table is provided showing how data transmission is organized over time.
   - **Columns:** Indicate time slots, frame IDs, signal names, and data publishers, providing a clear overview of which node communicates, what data is sent, and when.
   - **Deterministic Sequence:** Ensures predictable communication with no conflicts or need for arbitration.
   - **Color Coding:** Appears to differentiate between various types of frames or signals, indicating a structured approach to network management.

The LIN schedule is essential for maintaining the order of messages on the bus, with the master node determining the sequence of message transmission. This prevents message collision, which is crucial for a single-wire network with multiple nodes. It also allows for lower-cost implementations suitable for the less demanding data rate requirements of LIN compared to the more robust CAN network.

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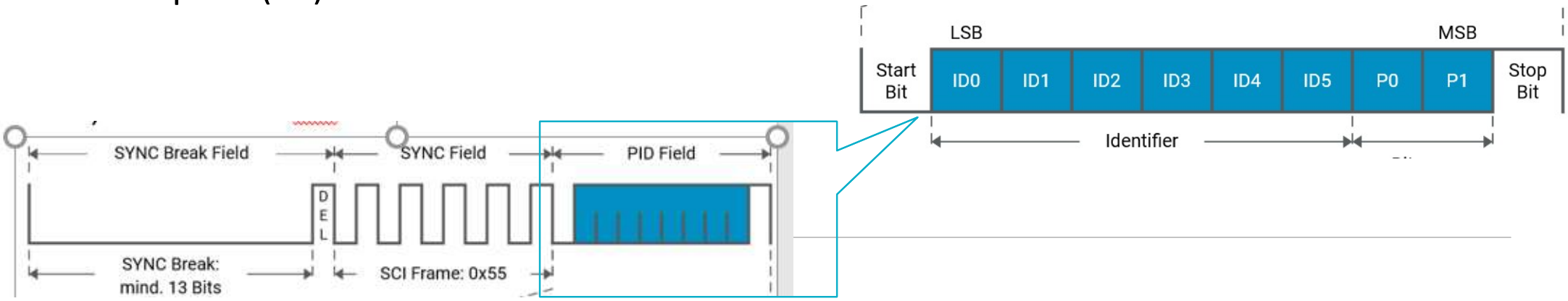
LIN Frame header

- Master task
- Sync break field initiates begin of the header
- Sync Field includes clock frequency and is used for synchronization with slaves
- Protected identifier (PID) field
  - Unique identifier for slave communication, defined in *ldf
  - 6-bit identifier + 2 parity bits
- Between header and response frame there is a pause time called response space (RS)



In the LIN protocol, communication is always initiated by the master with a 'frame header,' and the 'response frame' is sent by the slave. Here's the sequence:

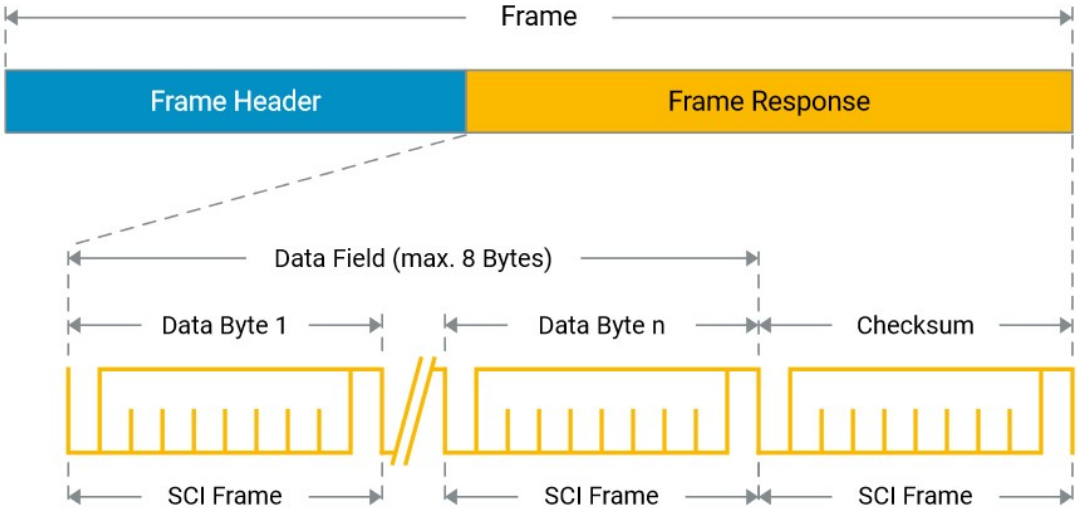
1. **Frame Header:**
   - The master node begins the transmission of a frame by sending the 'frame header,' which consists of two parts:
     - **Break Signal:** To alert all slave nodes that a new frame is starting.
     - **Sync Field:** To synchronize the timing of all slave nodes to the master.
     - **Identifier:** It tells which frame is being communicated and which slave node should respond.

2. **Response Frame:**
   - After the frame header, the intended slave node sends a 'response frame.'
   - The 'response frame' contains the actual payload data, which could be sensor readings, actuator commands, or other information.
   - No other nodes will send a response to this frame header except the addressed slave node, preventing any collision.

To summarize, the 'frame header' is always sent by the master to start communication and direct a specific slave node to respond, and the 'response frame' is the reply from the slave containing the data payload.

LIN Frame response

- Slave task
- Slaves answer with max. 8 byte response to the frame header (data field)
- Also slave task of the master can be accessed
- Bytes are transferred from LSB to MSB



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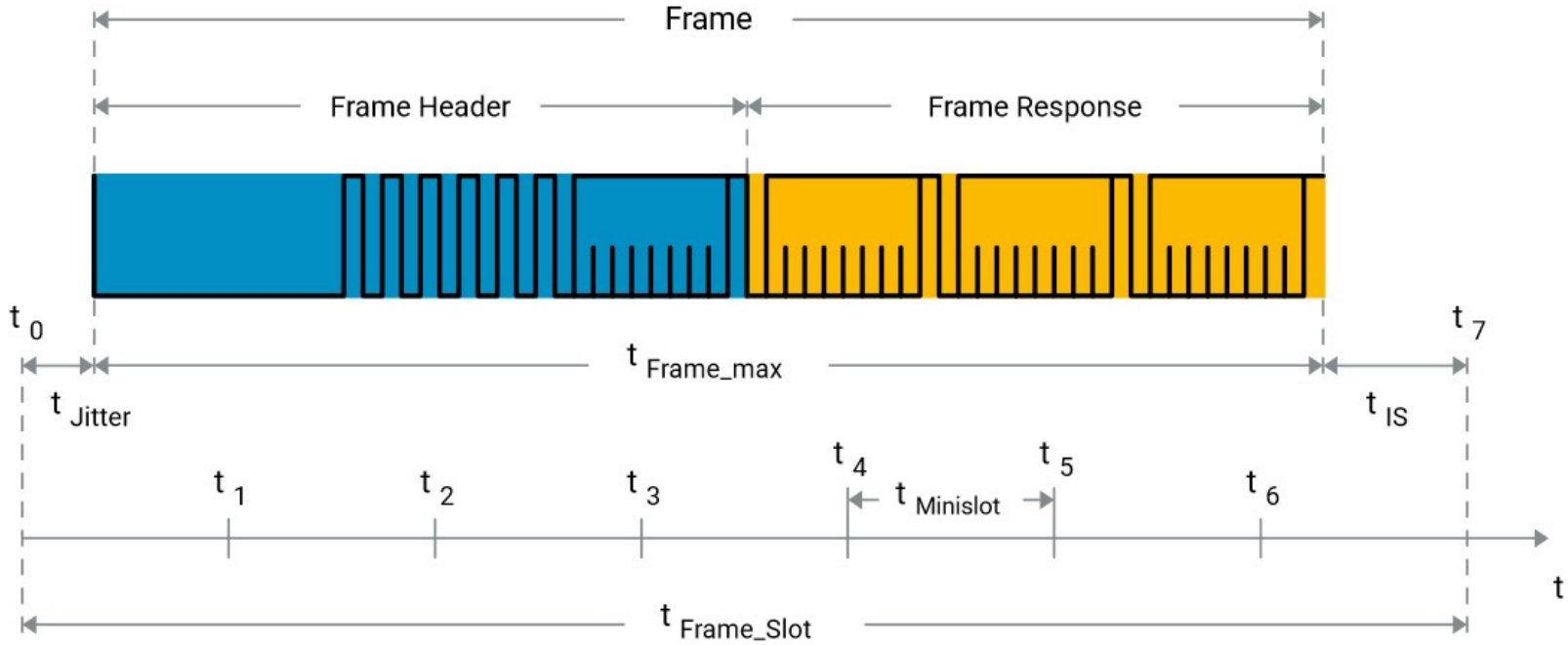
LIN Frame – time base

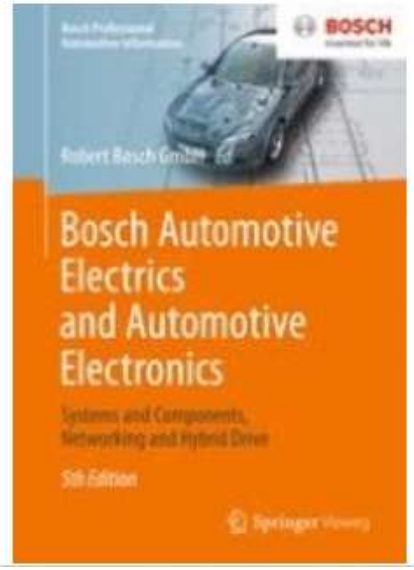
- The LIN schedule is organized in time slots to transfer one frame
- Size of the slots is defined by minislots as communication time base
- Time reserve to ensure communication (Jitter before and Interframe Space after frame) up to 40%



LIN Error Detection

- Bitmonitoring (sender task)
  - Compare each bit on the bus with bus level
- Checksum (Receiver task)
  - Check of incoming data bytes w/o PID (classic/enhanced checksum)
  - Sum of received data and received checksum has to 0xFF
- Parity check (receiver task)
  - Check of P0 and P1
- Slave responding check (receiver task)
  - Check whether frame response after header is transferred
- Sync field check (receiver task)
  - Check whether master sync rate is in between tolerance range
- Reaction to errors part of individual design, not described in the standard

References and quotations



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Herausgeber: Robert Bosch GmbH

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Print ISBN: 978-3-658-01783-5
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