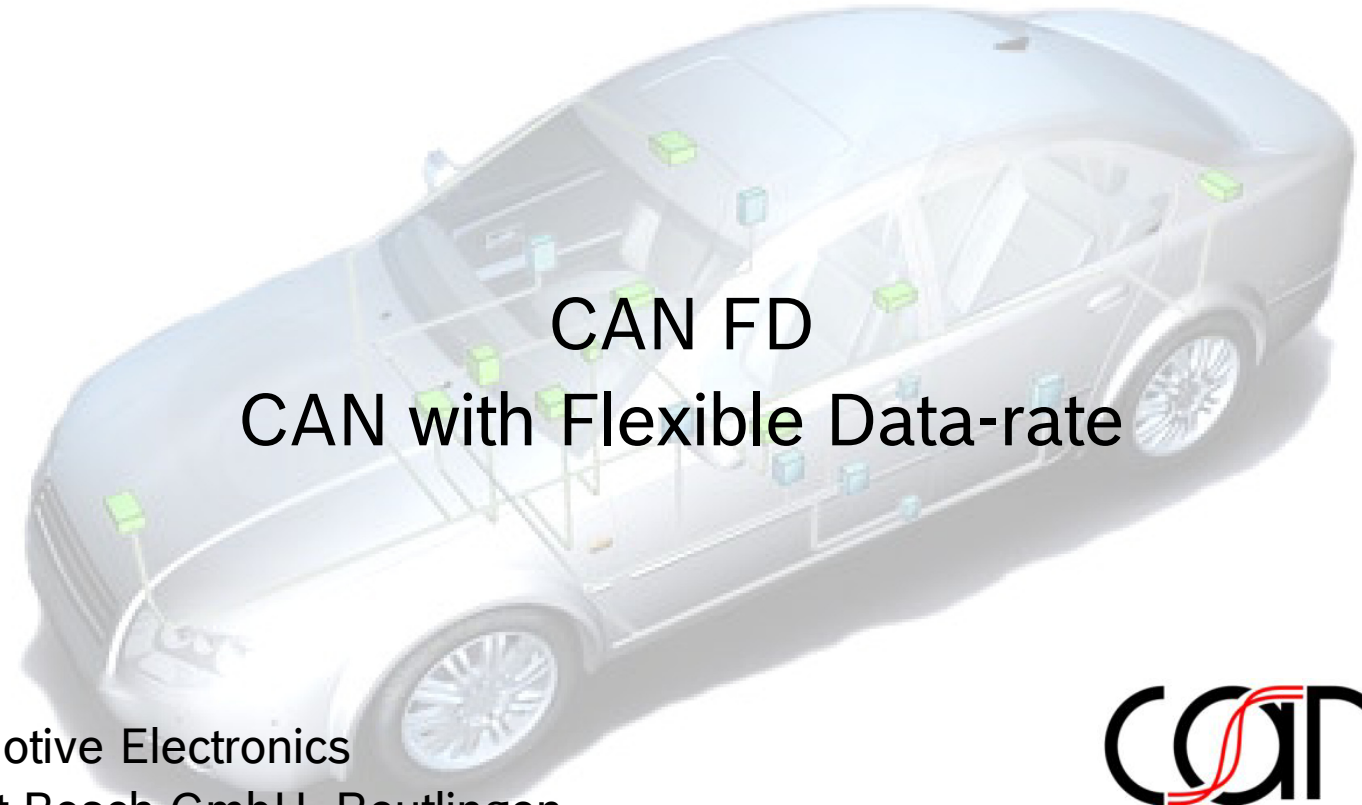
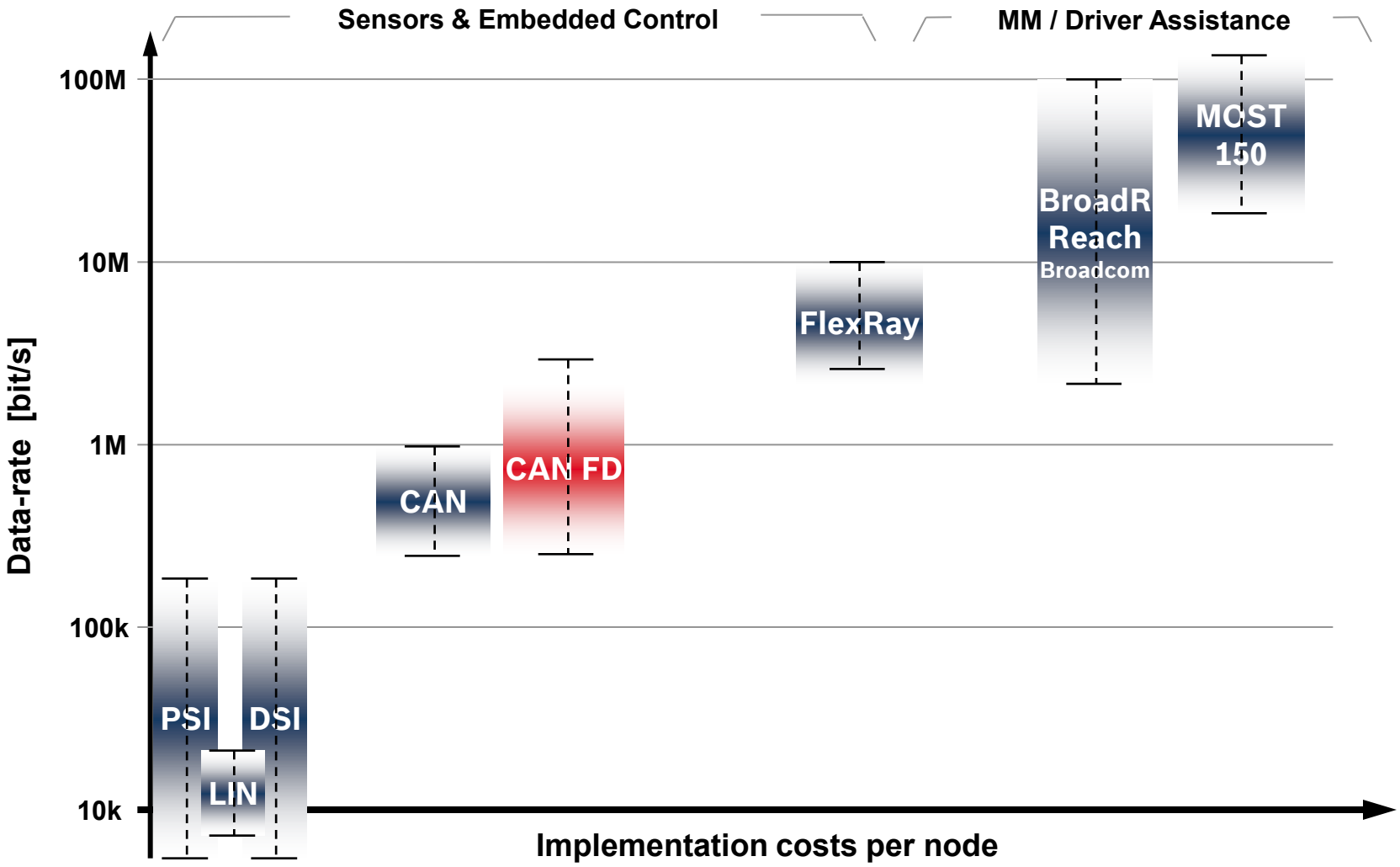


CAN FD
CAN with Flexible Data-rate

Automotive Electronics
Robert Bosch GmbH, Reutlingen

CAN FD - CAN with Flexible Data-rate



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Motivation

- Increasing demand for bandwidth in automotive communication
- Close gap between CAN (max. 1 MBit/s) and FlexRay (10 MBit/s)
- Time-triggered communication not flexible enough
- High effort for migration to FlexRay / Ethernet
  - Hardware costs
  - Software changes

→ Make CAN faster !

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Speeding up CAN

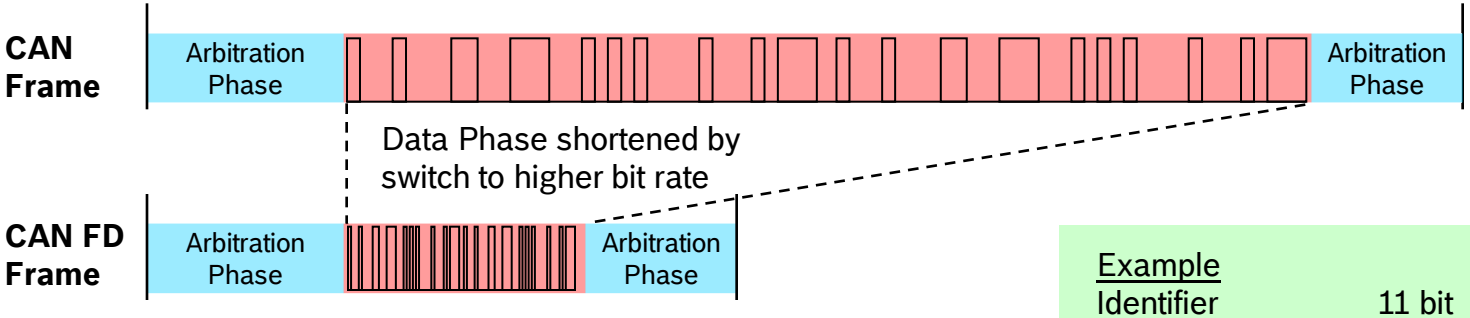
Unchanged

- CAN arbitration
- CAN acknowledge mechanism

New

- switch to higher bit rate for transmission of
  - Data Length Code
  - Data Field
  - Frame CRC
- data fields with more than eight bytes possible
  - configured by unused DLC codes “1001” to “1111”
  - 12, 16, 20, 24, 32, 48, 64 bytes
- new CRC polynomials for longer data fields, HD=6
  - 17 bit: up to 16 byte data fields, 21 bit: up to 64 byte data fields

Speeding up CAN



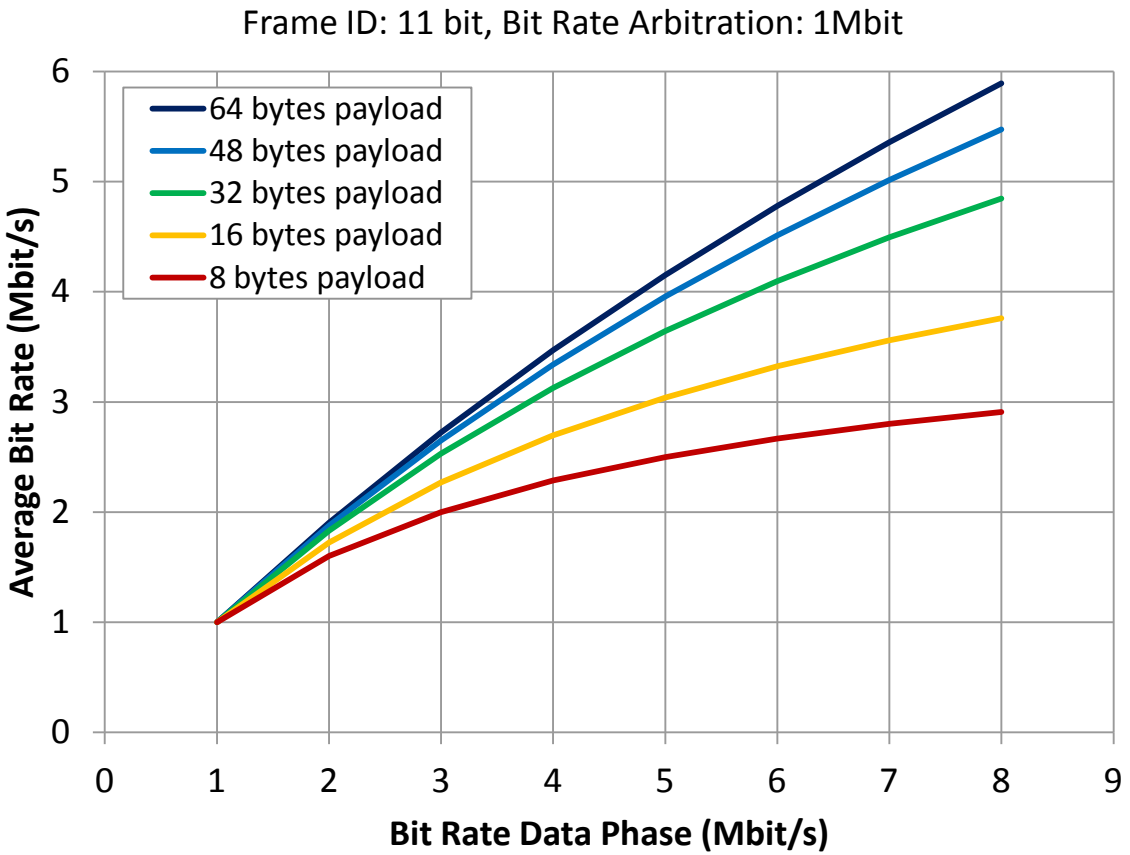
Example

Identifier	11 bit
Data Field	32 byte
Arbitration Phase	1 Mbit/s
Data Phase	4 Mbit/s

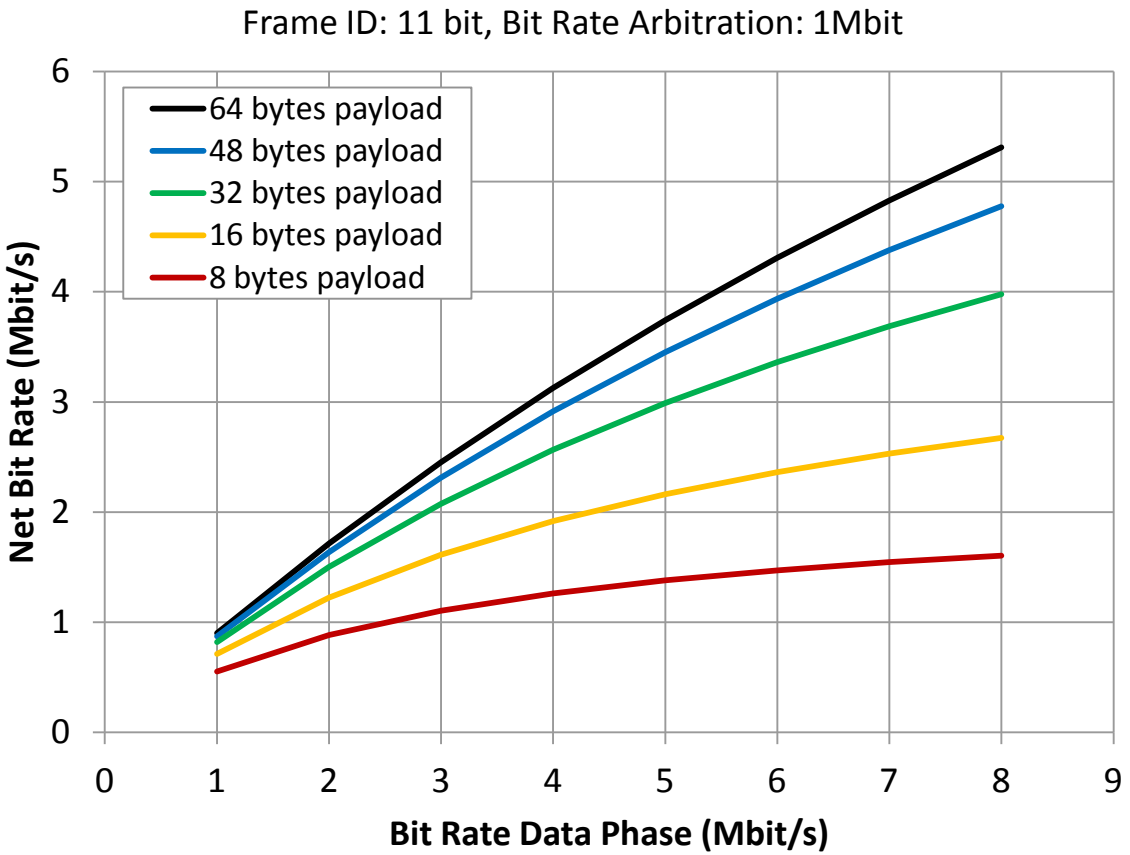
→ average bit rate 3.1 Mbit/s

- → Based on existing CAN
  - well known technology, minimized risk
  - **changes limited to HW:** protocol controller
    - for bit rates up 1 Mbit/s standard CAN transceivers usable
  - **no changes to SW:** with 8 bytes data field (legacy SW fully compatible)
    - even higher data rate possible by data fields >8 bytes and SW change
- → Costs similar to CAN

Average CAN FD Bit Rate

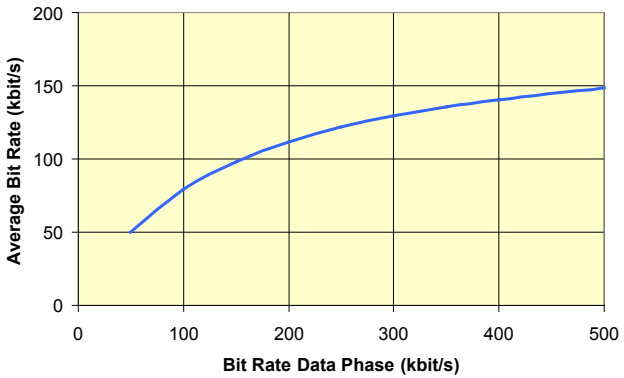


Net CAN FD Bit Rate



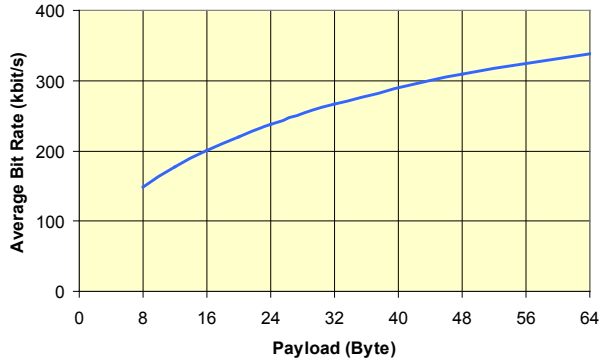
CAN FD with Bit Rates below 1 MBit/s

- Application:
- Long bus line limits bit rate for arbitration
- Arbitrate with e.g. 125 kbit/s
- Transmission of data field with e.g 500 kbit/s

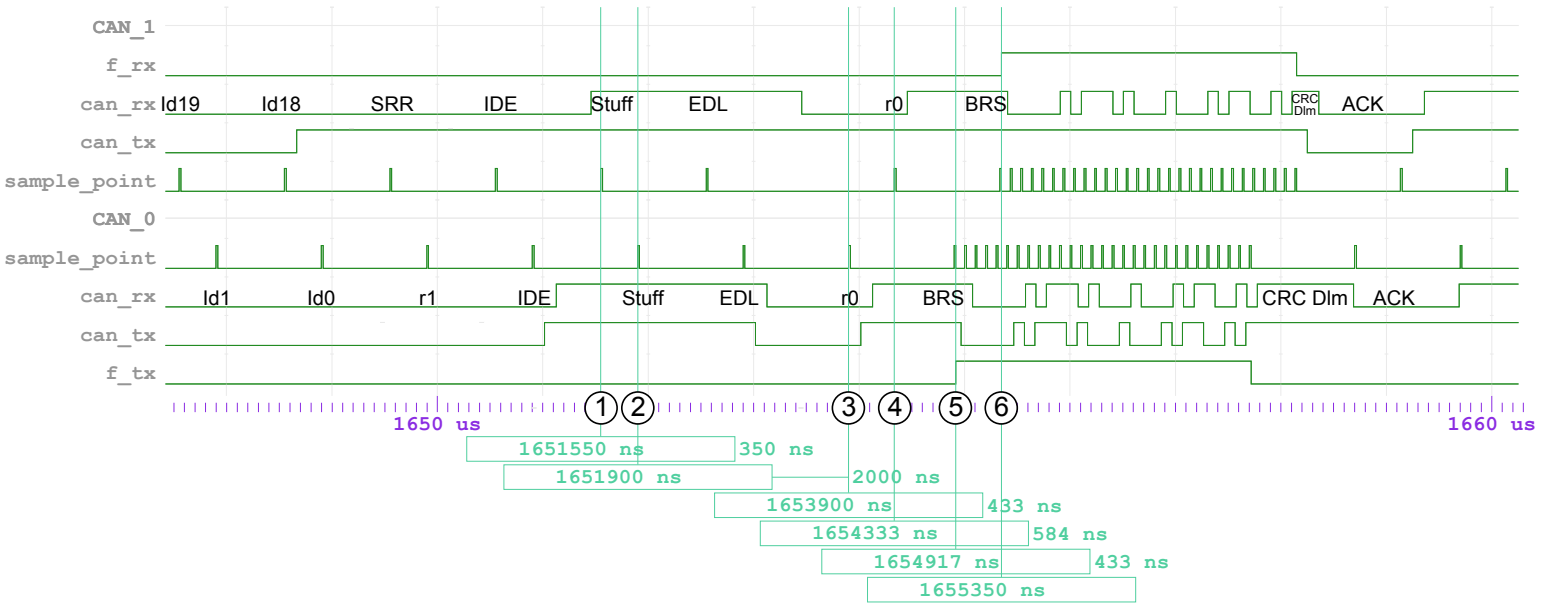


No requalification or redesign of transceivers necessary !

- Option:
- Transmission of long frames with up 64 bytes payload
- Increase of net data rate
- Handling of large data packets w/o segmentation



Synchronous Switching of Bit Rate



Example: CAN_0 wins arbitration at reserved/SRR bit

- Phase-shift before synchronization: ①←② – 350 ns
- Phase-shift after synchronization: ③→④ + 433 ns
- Phase-shift at beginning of Data Phase: ⑤→⑥ + 433 ns

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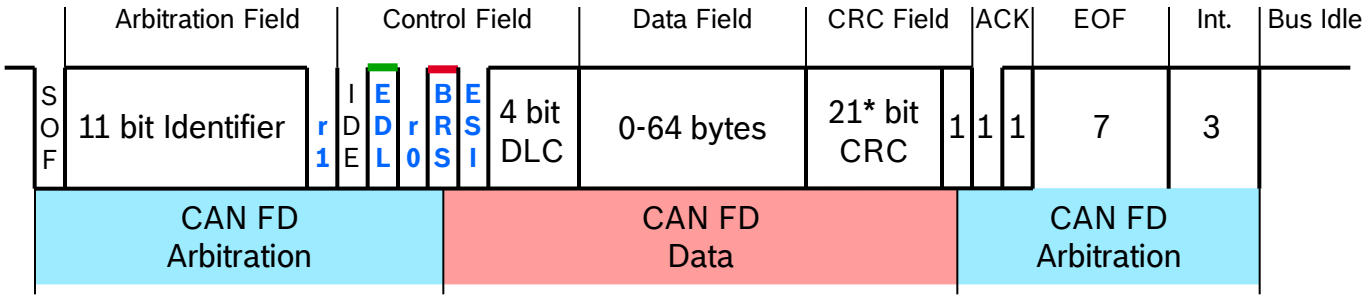
CAN FD Standard Frame



* 17 bit CRC for data fields with up to 16 bytes

- CAN FD Arbitration Phase
  - length: 30 bit times*
  - data rate: max. 1 MBit/s
- CAN FD Data Phase
  - length: 86 bit times* (8 data bytes)
  - data rate: > 1 MBit/s
- Remote Frames always in CAN Format
  - RTR bit replaced by reserved bit r1
  - r1 takes part in CAN arbitration
  - reserved for protocol expansion

* bit stuffing not considered

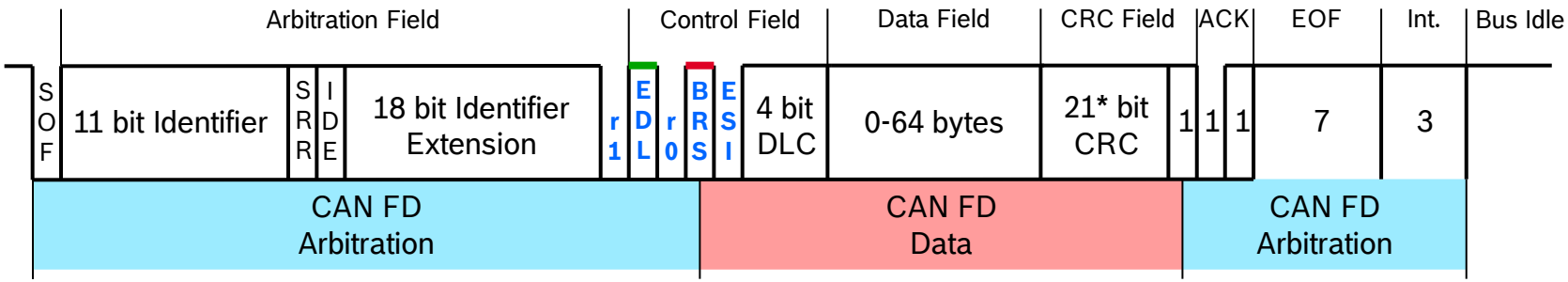
EDL – Extended Data Length
Substitutes first reserved bit in standard frames
EDL = recessive indicates CAN FD frame format
(new DLC-coding and CRC)
EDL = dominant indicates standard CAN frame format

r1, r0 – reserved bits
Transmitted dominant, reserved for future protocol variants

BRS – Bit Rate Switch
BRS = recessive: switch to alternate bit rate
BRS = dominant: do not switch bit rate

ESI – Error State Indicator
ESI = recessive: transmitting node is error passive
ESI = dominant: transmitting node is error active

CAN FD Extended Frame



* 17 bit CRC for data fields with up to 16 bytes

- CAN FD Arbitration Phase
  - length: 49 bit times*
  - data rate: max. 1 MBit/s
- CAN FD Data Phase
  - length: 86 bit times* (8 data bytes)
  - data rate: > 1 MBit/s
- Remote Frames always in CAN Format
  - RTR bit replaced by reserved bit r1
  - r1 takes part in CAN arbitration
  - reserved for protocol expansion

* bit stuffing not considered

EDL – Extended Data Length
Substitutes first reserved bit in standard frames
EDL = recessive indicates CAN FD frame format
(new DLC-coding and CRC)
EDL = dominant indicates standard CAN frame format

r1, r0 – reserved bits
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BRS = recessive: switch to alternate bit rate
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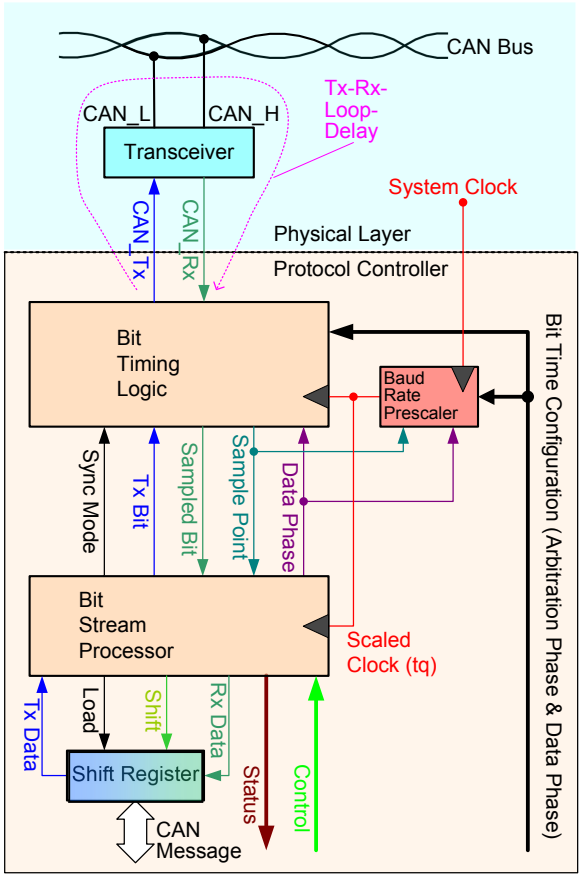
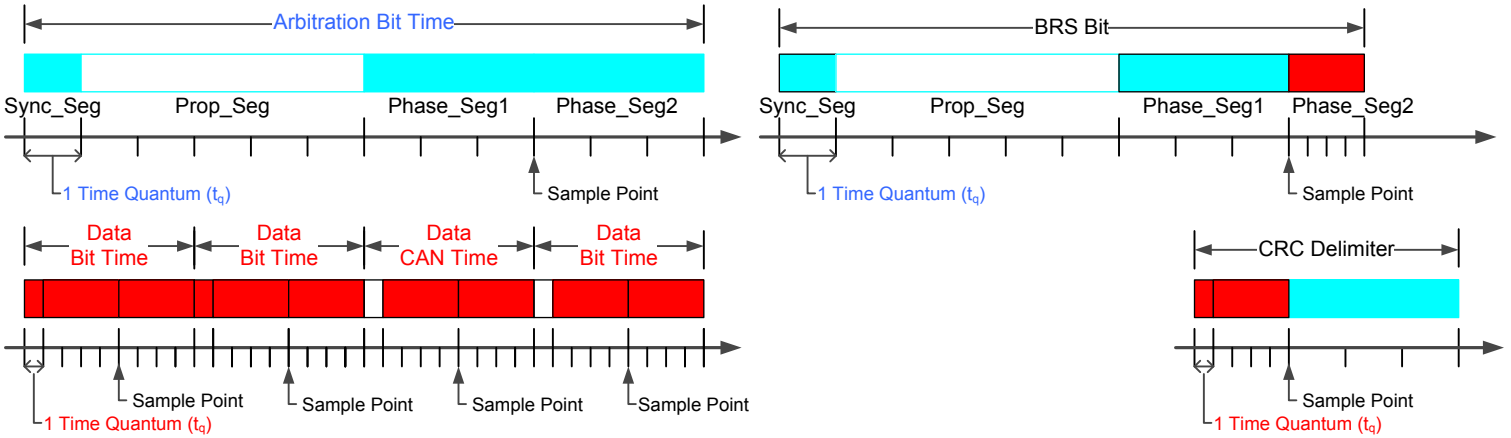
ESI = recessive: transmitting node is error passive
ESI = dominant: transmitting node is error active

Structure of CAN FD Nodes



- Physical Layer
  - unchanged for CAN FD
  - same CAN transceivers
- CAN FD Protocol Controller
  - two sets of timing configuration
- BTL and BRP control bit timing
  - BTL and BRP switch between two sets
- BSP controls frame (de)coding
  - BSP defines Arbitration and Data Phase
- CAN Message Handling
  - shift register as (de)serializer
  - BSP does not limit data field length

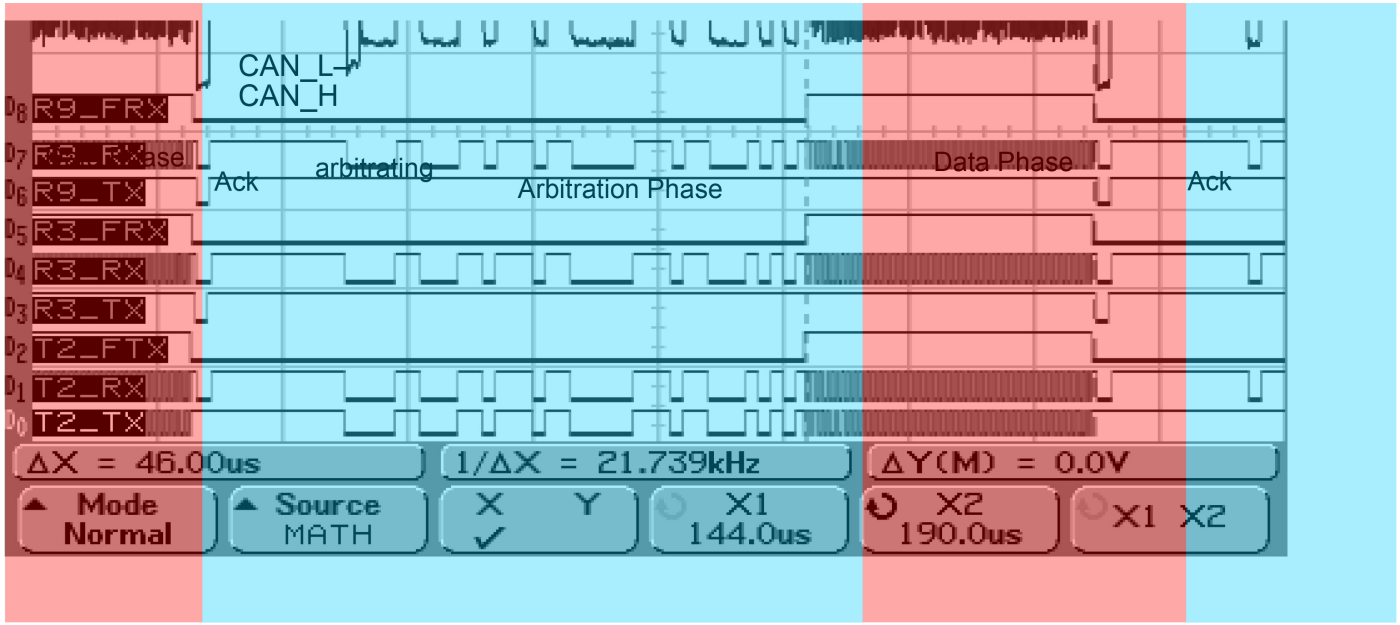
CAN FD Bit Rate Switching



Example: (Bit rate in Data Phase) = 4 · (Bit rate in Arbitration Phase)

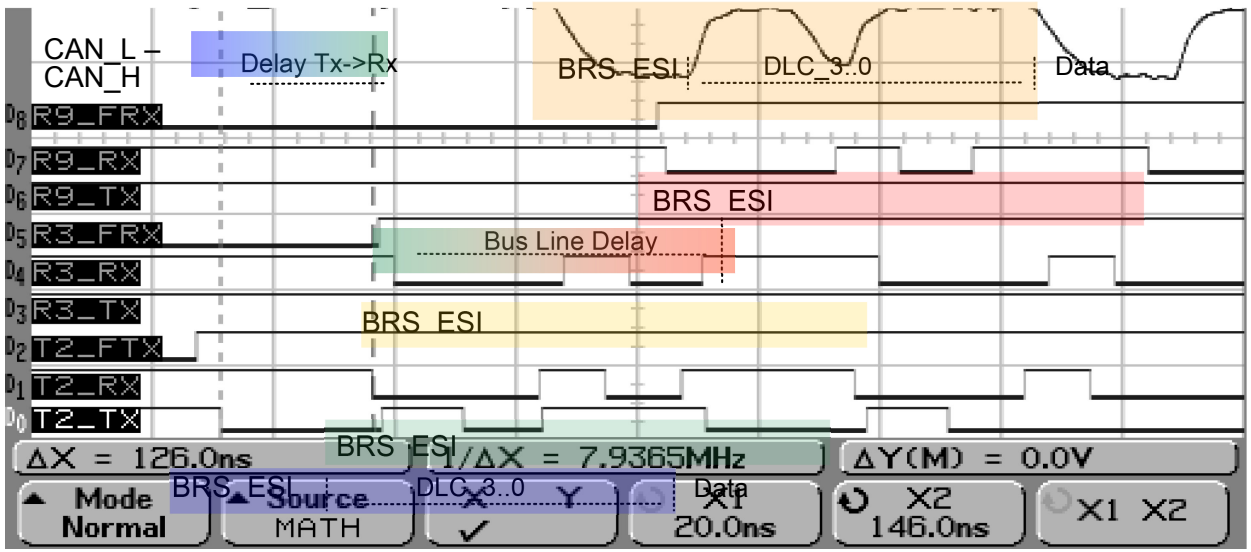
- Different length of time quanta, no Prop_Seg in Data Phase
- BRS bit with timing of Arbitration Phase until Sample Point
- CRC Delimiter with timing of Data Phase until Sample Point

CAN FD Demonstrator



CAN FD Communication		CAN FD Network	
Arbitration Phase	1 Mbit/s	Bus Line	42 m
Data Phase	12 Mbit/s	CAN FD nodes	7
Data Field	64 Byte	CAN Transceiver	NXP TJA 1040

Transceiver Delay and Bus Line Delay



CAN FD Communication

Arbitration Phase	1 Mbit/s
Data Phase	15 Mbit/s
Bus Line	42 m

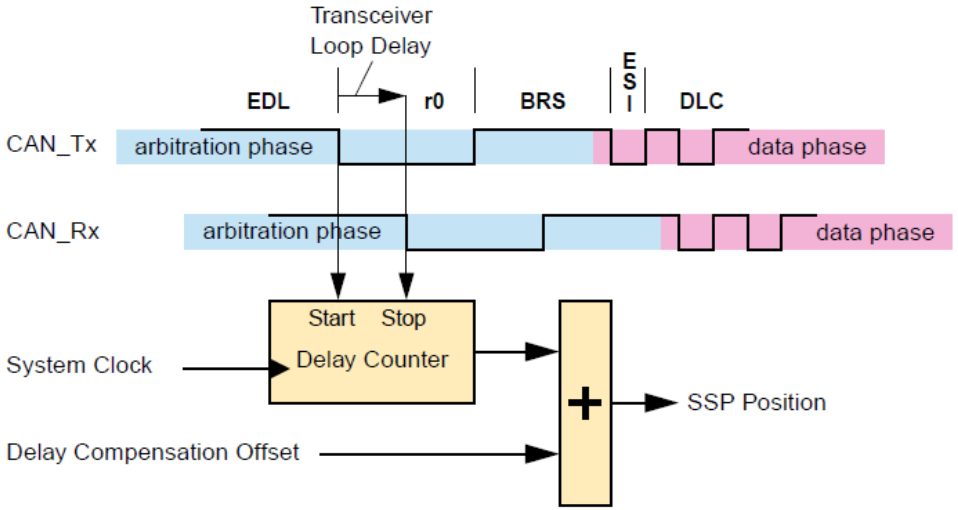
Delays in the CAN FD Network

measured at edge from BRS to ESI

Transceiver Loop Delay	126 ns
Bus Line Delay	163 ns

Transceiver Delay Compensation

- Transceiver Loop Delay is measured for each frame at the falling edge of bit EDL
  - Delay compensation independent of transceiver characteristics



- Transceiver delay measured in system clock periods
- Configurable offset added to adjust Secondary Sample Point SSP inside bit time
  - SSP position rounded down to next integer number of time quanta **tq**
- Delayed transmit data compared against received data at SSP
  - check for bit errors

Oscillator Tolerance – Rules

Rules Arbitration Phase		
Rule 1	Resynchronization	$df < \frac{sjw_A}{2 \cdot 10bt_A}$
Rule 2	Sampling of Bit after Error Flag	$df < \frac{\min(pb1_A, pb2_A)}{2 \cdot [13bt_A - pb2_A]}$
Rules Data Phase (when Bit Rate is switched)		
Rule 3	Resynchronization	$df < \frac{sjw_D}{2 \cdot 10bt_D}$
Rule 4	Sampling of Bit after Error Flag	$df < \frac{\min(pb1_A, pb2_A)}{2 \cdot \left[(6bt_D - pb2_D) \cdot \frac{BRP_D}{BRP_A} + 7bt_A \right]}$
Rule 5	Bit Rate Switch	$df < \frac{sjw_D - \left(\frac{BRP_A}{BRP_D} - 1 \right)}{2 \cdot \left[(2bt_A - pb2_A) \frac{BRP_A}{BRP_D} + pb2_D + 4bt_D \right]}$

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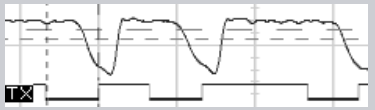
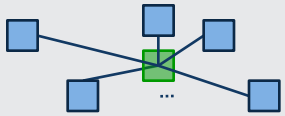
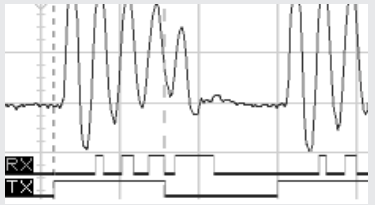
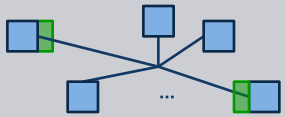
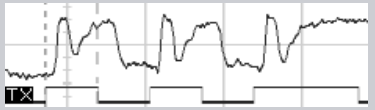
Lab Validation – Exemplary Results

Network Topology	Termin. Resist.	Bus Length	Max. Bit Rate*	Bus Signal (CANL–CANH)
ISO Bus Topology 	2x120Ω	42m	15,0 Mbit/s	
Passive Star 	1x 60Ω	16m	3,5 Mbit/s	
Passive Star 	2x120Ω	16m	7,5 Mbit/s	

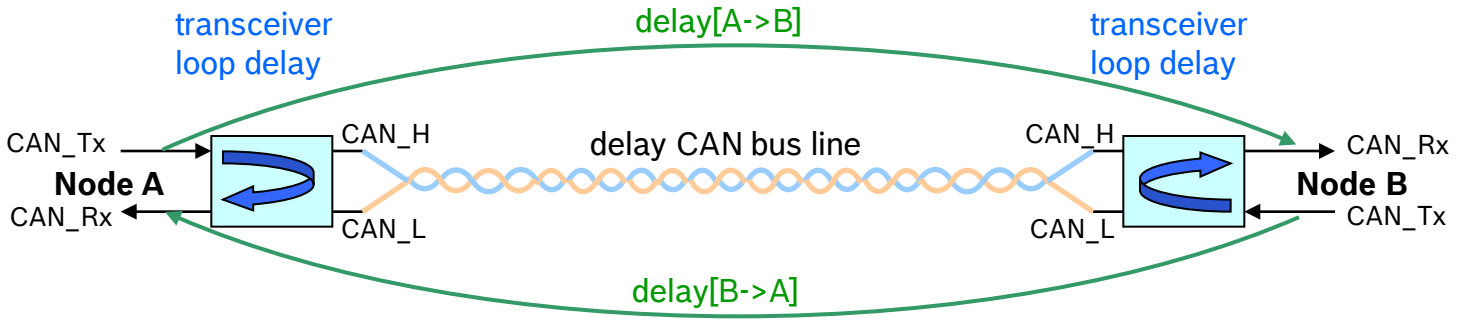
Term. resistor CAN FD node *CAN Transceiver: NXP TJA 1040

Conclusion

- Gradual introduction of CAN FD nodes into CAN networks possible
- Bosch CAN IPs currently upgraded to CAN FD (M_CAN, C_CAN)
  - will be integrated into µCs, first samples E2012
  - upgrade of Bosch VHDL Reference CAN Model to CAN FD
  - integration on µCs of other major manufacturers planned
- Tool support for CAN FD started
  - Vector and ETAS integrate CAN FD into their tool chain
- Development of vehicle demonstrator with CAN FD network
  - Joint project with automotive and semiconductor companies started
- Check EMC issues
  - Emission, Susceptibility / Immunity
- Impact on different network topologies under investigation
  - line, star, position of termination, different transceivers
- Standardization as ISO 11898-7
- Assure support in Higher Layer Protocols (e.g. AUTOSAR, CANopen)

Backup

Physical Layer



- CAN Physical Layer
  - Transceiver loop delay CAN_Tx → CAN_Rx: up to 240ns
  - delay on CAN bus line: ~5ns/m
- CAN FD Arbitration Phase: arbitrate with remote nodes
  - Limitation: delay[A→B] + delay[B→A] <TSEG1*
- CAN FD Data Phase: transceiver delay compensation for bit monitoring
  - Limitation: filter characteristics of input comparator and bus topology
  - independent of length of CAN bus line

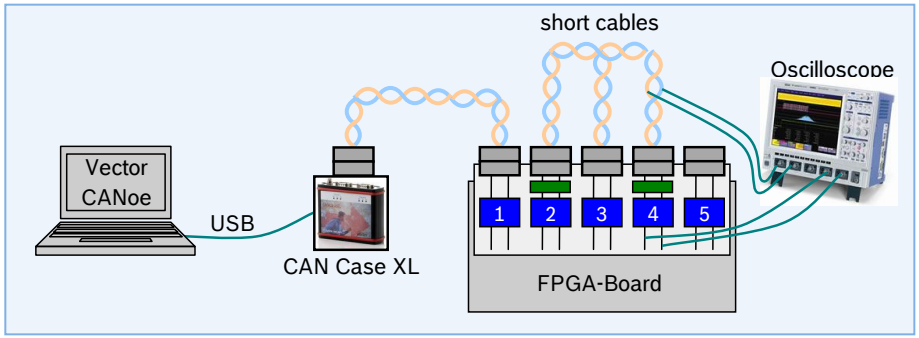
*TSEG1 = Time Segment before Sample Point

Remote Frames and CAN FD

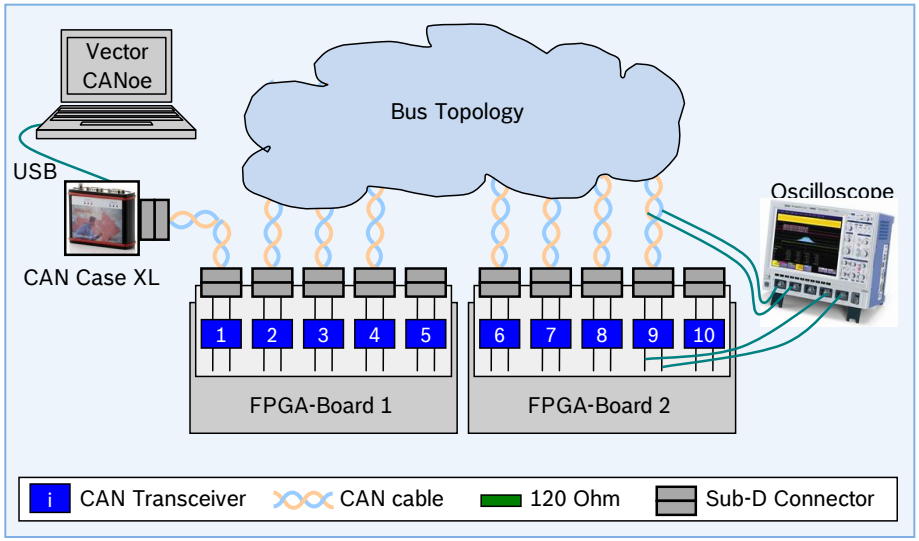
- There are no remote frames in CAN FD format
  - RTR bit is replaced by dominant reserved bit r1
  - The reserved bit r1 takes part in CAN bit arbitration
  - Bit r1 reserved for future protocol expansions,
    e.g. using r1 as additional identifier bit
  - Receivers ignore the actual value of bits r1, r0 in CAN FD frames
- CAN FD controllers are able to handle remote frames in standard CAN format

Lab Validation – Setup

Board Setup



Network Setup



Monitoring (CANoe)