Lecture 5. CAN with Flexible Data-Rate – CAN-FD

Why the need for CAN-FD?

CAN has reached practical limits in current applications

- CAN buses exceed recommended busloads (>50%)
- High overhead for sending CAN messages (≥50% overhead) →
  Only around 40-50$% of the bandwidth is used for actual data
- CAN bus speeds are limited to 1Mbit/s – lower speeds used in actual
  implementation due to vehicle wiring limitations:
    - Up to 500Kbit/s used in most cases
    - 250Kbit/s used in J1939 networks (500Kbit/s allowed by spec)
    - Maximum achievable bus speed limitied by the In-Frame
      Response mechanism, i.e. Error frames, ACK field
   - ACK generation delays = transceiver delay + wire propagation
      delay

What does CAN-FD bring?

Improvements on the CAN protocol

- CAN-FD is based on the CAN 2.0 specification
- Adds new features on top:
  - Support for variable bitrates for the two main message segments:
    - Arbitration phase – same as standard CAN
    - Data phase – bitrates higher than 1Mbit/s possible (up to ~8Mbit/s)
  - Support for larger data payloads – up to 64 bytes/message

Migrating from CAN to CAN-FD

- Differences limited to the CAN controller, i.e. Data Link layer
- Physical layer not changed – existing CAN transceivers can be used up to 2-8Mbit/s
- Legacy SW implementations still usable (≤ 8 byte fields)
- System cost is similar to standard CAN
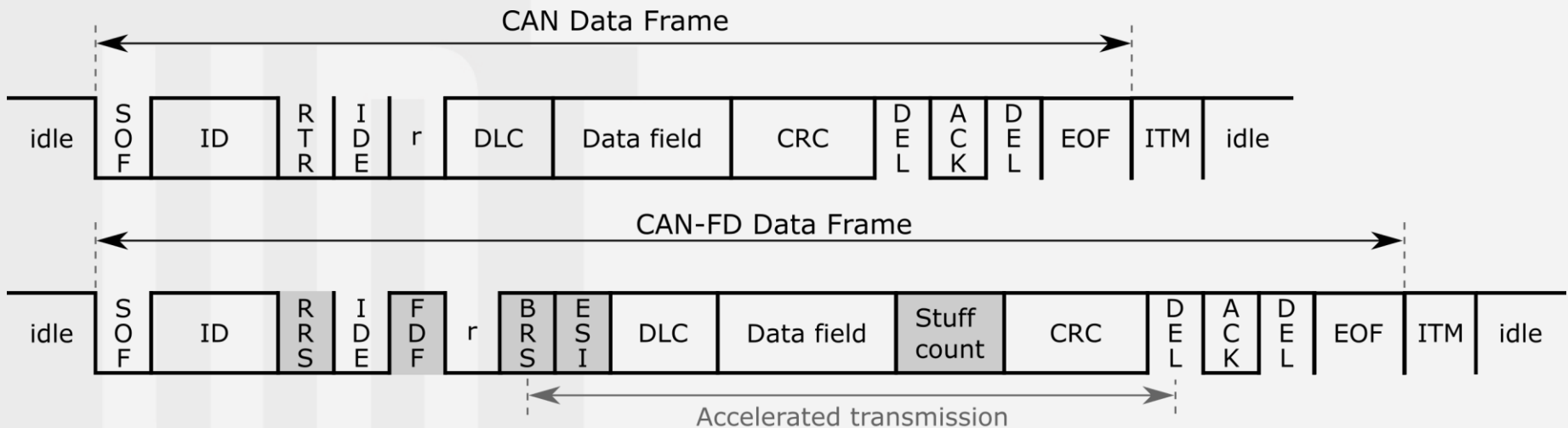
SOF - Start Of Frame
ID - Identifier
IDE - Identifier Extension
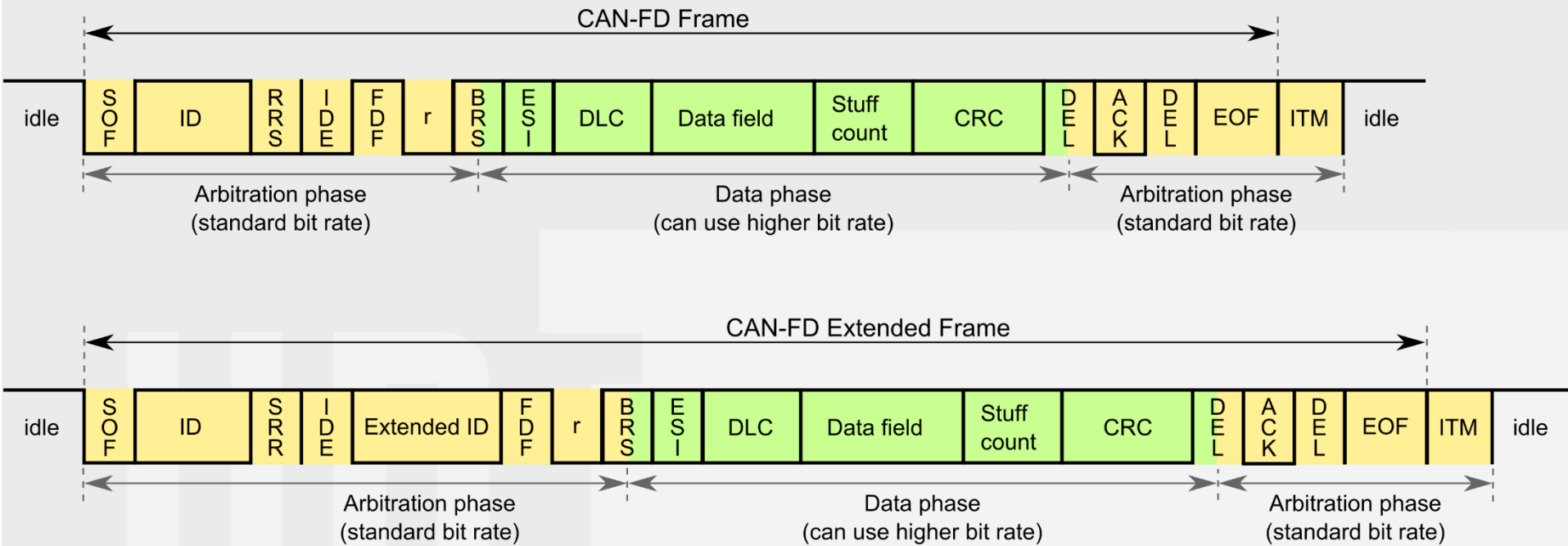CRC - Cyclic Redundancy Check

DEL - Delimiter
ACK - Acknowledge
EOF - End Of Frame
ITM - Intermission

RRS - Remote Request Substitution
FDF - Flexible Data-rate Format
BRS - Baudrate Switch
ESI - Error State Indicator

CAN-FD standardization

- CAN-FD specification is now included in ISO 11898-1 which previously contained only standard CAN specs

- Initial CAN-FD specification was slightly different than the current
  - CRC reliability issue discovered during the standardization process (CRC calculation vulnerable to bit sequence shortening or lengthening faults)
  - More details on the issue: *Mutter, A. "[CAN-FD and the CRC issue](#)" CAN Newsletter 1 (2015).*
  - Current specification solves this problem with a slight change in the CAN-FD frame format

- We next look at CAN-FD as specified in the latest ISO11898-1 version

CAN-FD data frame

SOF - Start Of Frame
ID - Identifier
Extended ID - Extended Identifier
RRS - Remote Request Substitution
SRR - Substitute Remote Request
IDE - Identifier Extension
FDF - Flexible Data-rate Format
BRS - Baudrate Switch

ESI - Error State Indicator
DLC - Data Length Code
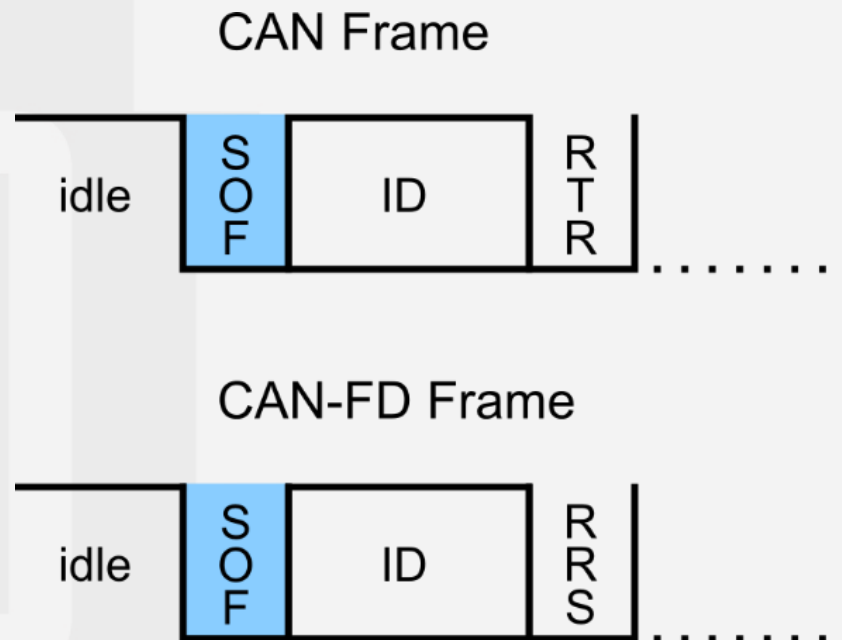CRC - Cyclic Redundancy Check
DEL - Delimiter
ACK - Acknowledge
EOF - End Of Frame
ITM - Intermission

CAN-FD Frame – Start of Frame

- CAN-FD Start of Frame field is identical to the CAN SOF – one dominant bit

CAN-FD Frame – Arbitration field

- A few differences in the arbitration field
  - The identifier field is the same as in CAN frames
  - The RTR (Remote transmission Request) bit in CAN frames becomes RRS (Remote Request Substitution) - always dominant since in CAN-FD there are no remote frames

CAN Frame

| S O F | ID | R T R | I D E | r | DLC | . . . . |

CAN-FD Frame

| S O F | ID | R R S | I D E | F D F | r | B R S | . . . . |
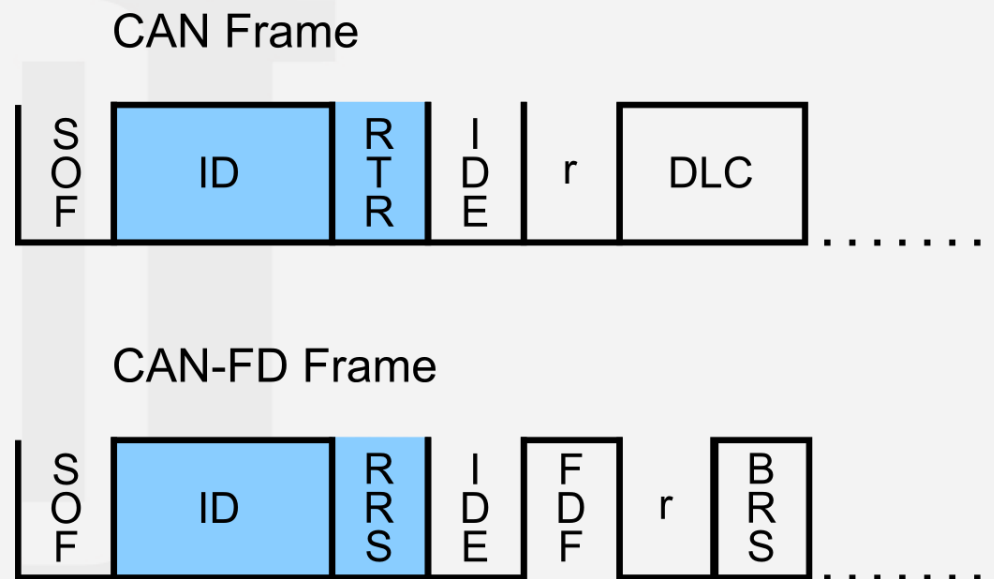
CAN-FD Frame – Control field

- IDE, r and DLC fields – same as in the standard CAN frame format
- CAN-FD features additional fields:
  - EDL – Extended data Length – determines the difference between standard CAN frames (dominant) and CAN-FD frames (recessive)
  - BRS – Bit Rate Switch – indicated a bit rate switch when recessive and marks the threshold between arbitration and data phase
  - ESI – Error State Indicator

| IDE | r | DLC | Data field | . . . . |

| IDE | FDF | r | BRS | ESI | DLC | Data field | . . . . |

CAN-FD Frame – Data Legth Code

- In addition to the standard CAN frame length encoding, the data length code in CAN-FD allows the usage of longer data fields up to 64 bytes

DLC value	Data length
0000	0 bytes
0001	1 bytes
0010	2 bytes
0011	3 bytes
0100	4 bytes
0101	5 bytes
0110	6 bytes
0111	7 bytes
1000	8 bytes

Standard CAN

DLC value	Data length
1001	12 bytes
1010	16 bytes
1011	20 bytes
1100	24 bytes
1101	32 bytes
1110	48 bytes
1111	64 bytes

CAN-FD extension

CAN-FD Frame – Data field

- The data field can be
  - 0-8 bytes long in standard CAN frames
  - 0-8, 12, 16, 20, 24, 32, 48, 64 bytes in CAN-FD

| idle | SOF | ID | RRS | IDE | FDF | r | BRS | ESI | DLC | Data field | Stuff count | CRC | DEL | ACK | DEL | EOF | ITM | idle |
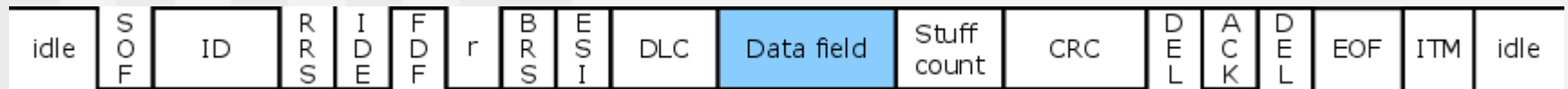
CAN-FD Frame – Stuff count

- Stuff count field added to CAN-FD frames to solve the CRC fail issue
- The number of stuff bits has to be known for verifying the correct transmission of a frame
- The stuff bit count itself has to be safeguarded with a parity bit and gray coding

| Stuff bit count modulo 8	Bits added to CAN-FD frame		
	Gray-coded value	Parity bit	Fixed stuff bit
0	000	0	1
1	001	1	0
2	010	0	1
3	011	1	0
4	100	0	1
5	101	1	0
6	110	0	1
7	111	1	0

CAN-FD Frame – CRC field

- Different size depending on data field length
  - 15 bits for CAN
  - 17 bits for CAN-FD if data field <= 16 bytes
  - 21 bits for CAN-FD if data field > 16 bytes
- Stuff bits are included in the CRC calculation for CAN-FD (this is not done in standard CAN)
- CRC delimiter transmitted as 1 bit, however receiver can accept up to 2 bit times (due to phase shift)
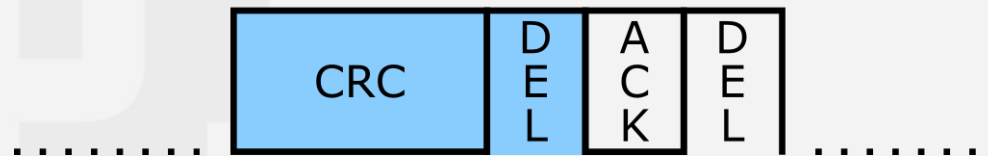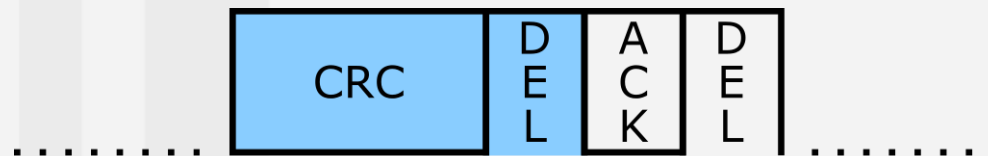
CAN-FD Frame – ACK and EOF

- ACK field is similar with the standard CAN format
- Difference in interpretation – CAN-FD can accept up to 2 bit times as a valid ACK (the additional bit time is allowed to compensate for transceiver phase shifts and propagation delays)

- EOF – 7 recessive bits like in standard CAN frames
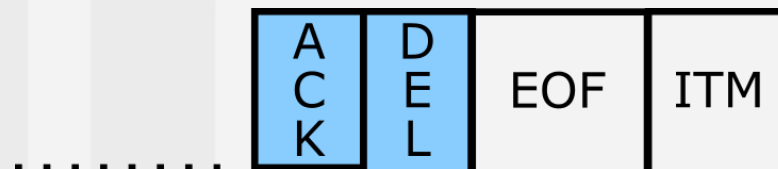
CAN-FD Frame formats

- Four data frame formats:
    - Standard CAN – 11 bit ID and fixed bit rate
    - Extended CAN – 29 bit ID and fixed bit rate
    - Standard CAN-FD – 11 bit ID and flexible bit rate
    - Extended CAN-FD – 29 bit ID and flexible bit rate

- Error frames – identical to CAN error frames

- Remote frames – only possible with standard CAN format

CAN-FD performance

- Frame overhead decreases with the increase in data field size
- Busload can be also reduced by using CAN-FD

Frame Type	No. Data-Bytes	Arb. Bit-Rate	Opt. Bit-Rate	Avg. Bit-Rate	Frame Duration
CAN	8	1 Mbit/s	-		111 us
CAN FD	8	1 Mbit/s	4 Mbit/s	2.3 Mbit/s	50.75 us
CAN FD	8	1 Mbit/s	8 Mbit/s	2.9 Mbit/s	39.875 us
CAN FD	64	1 Mbit/s	4 Mbit/s	3.5 Mbit/s	163.75 us
CAN FD	64	1 Mbit/s	8 Mbit/s	5.9 Mbit/s	96.375 us

Tariq Javaid, New Network Technologies & Challenges for the Future-FlexRay, CAN FD, IP