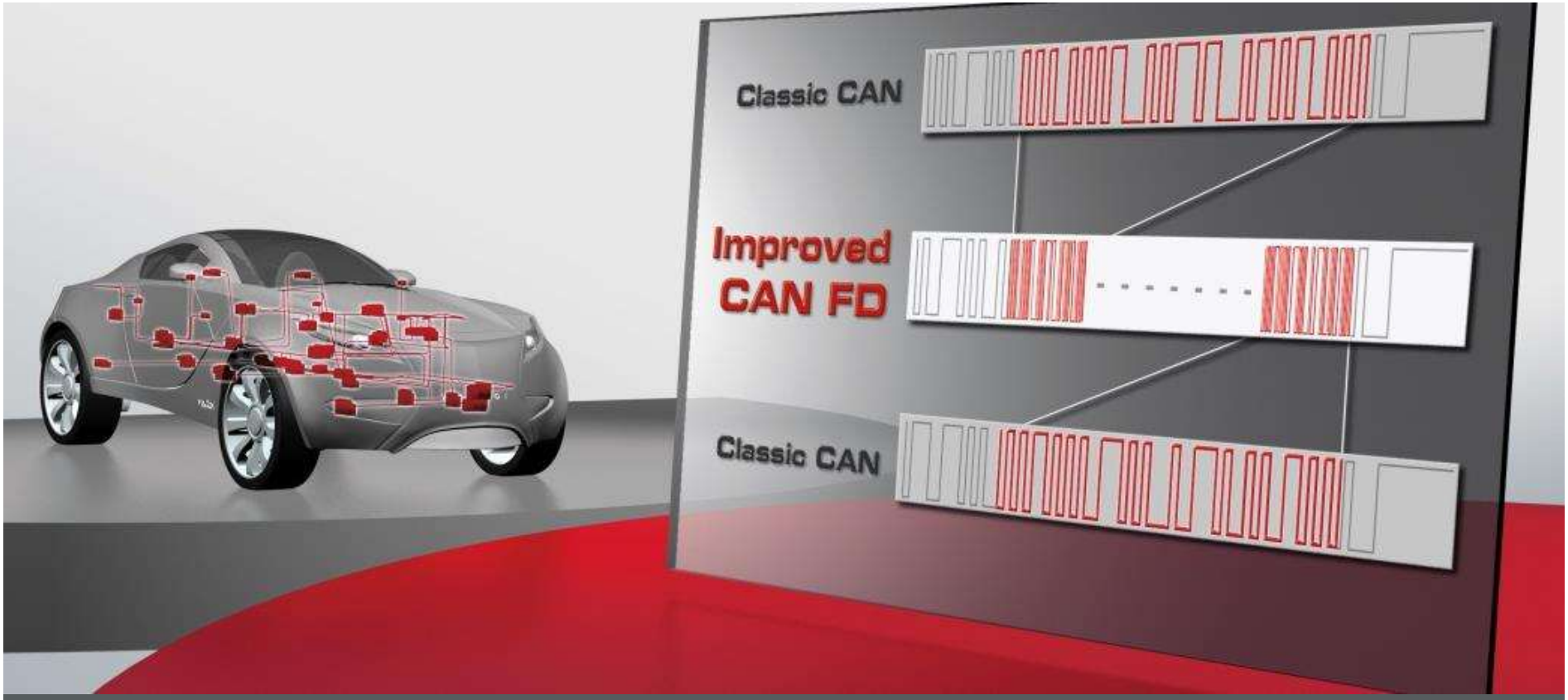
VECTOR



CAN FD

An Introduction

V1.02 | 2018-10-11

Agenda

- **Why CAN FD?**
- What is CAN FD?
- CAN FD Use Cases
- Automotive Application Domains
- CAN FD Frame
- CAN FD Controller
- CAN FD Performance
- CAN FD Devices
- CAN FD Standardization
- Summary
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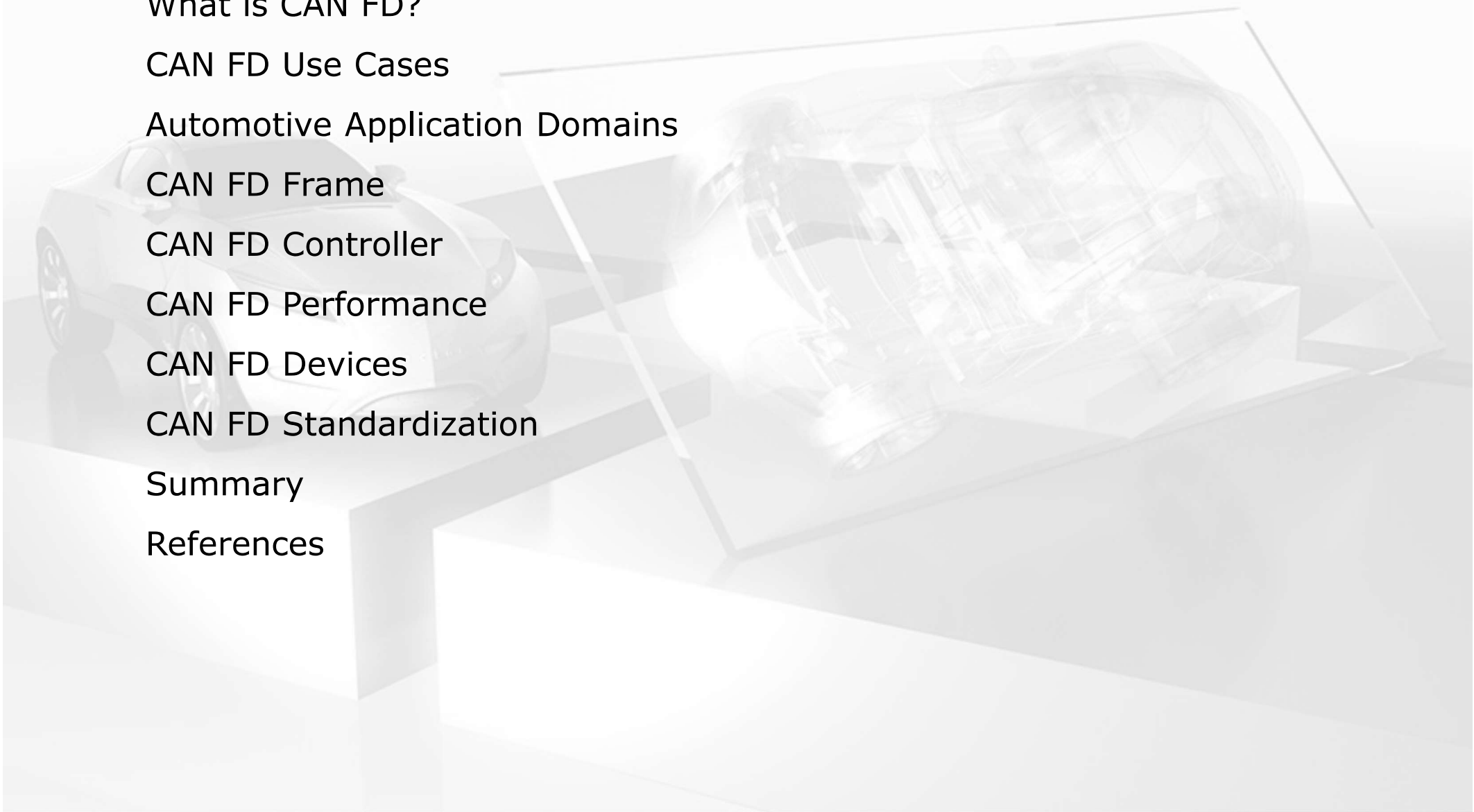
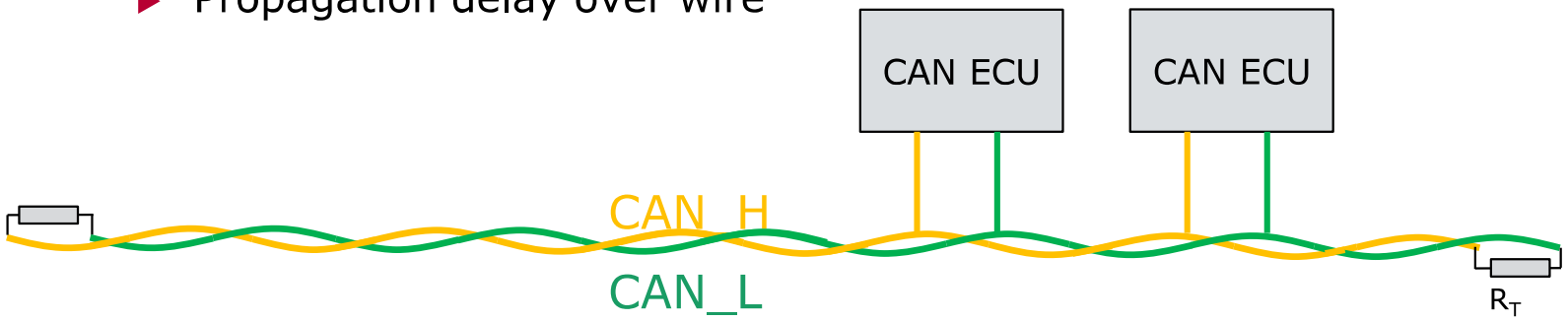


Many CAN buses have reached 50 % … 95 % network load level

1. **Network speed limited to 1 Mbit/s** (typical ≤ 500 kbit/s)
   - Limited by physical characteristics of in-vehicle wiring due to the In-Frame response mechanism:
     - ACK generation delay in CAN controller
       - Propagation delay through the transceiver
       - Propagation delay over wire



2. **CAN messages contain ≥ 50 % overhead**
   - Other protocols have less overhead
     - Ethernet UDP – ~1500 bytes/datagram, 64 bytes overhead (IPv4)
     - FlexRay – 254 bytes/frame, 8 bytes of overhead

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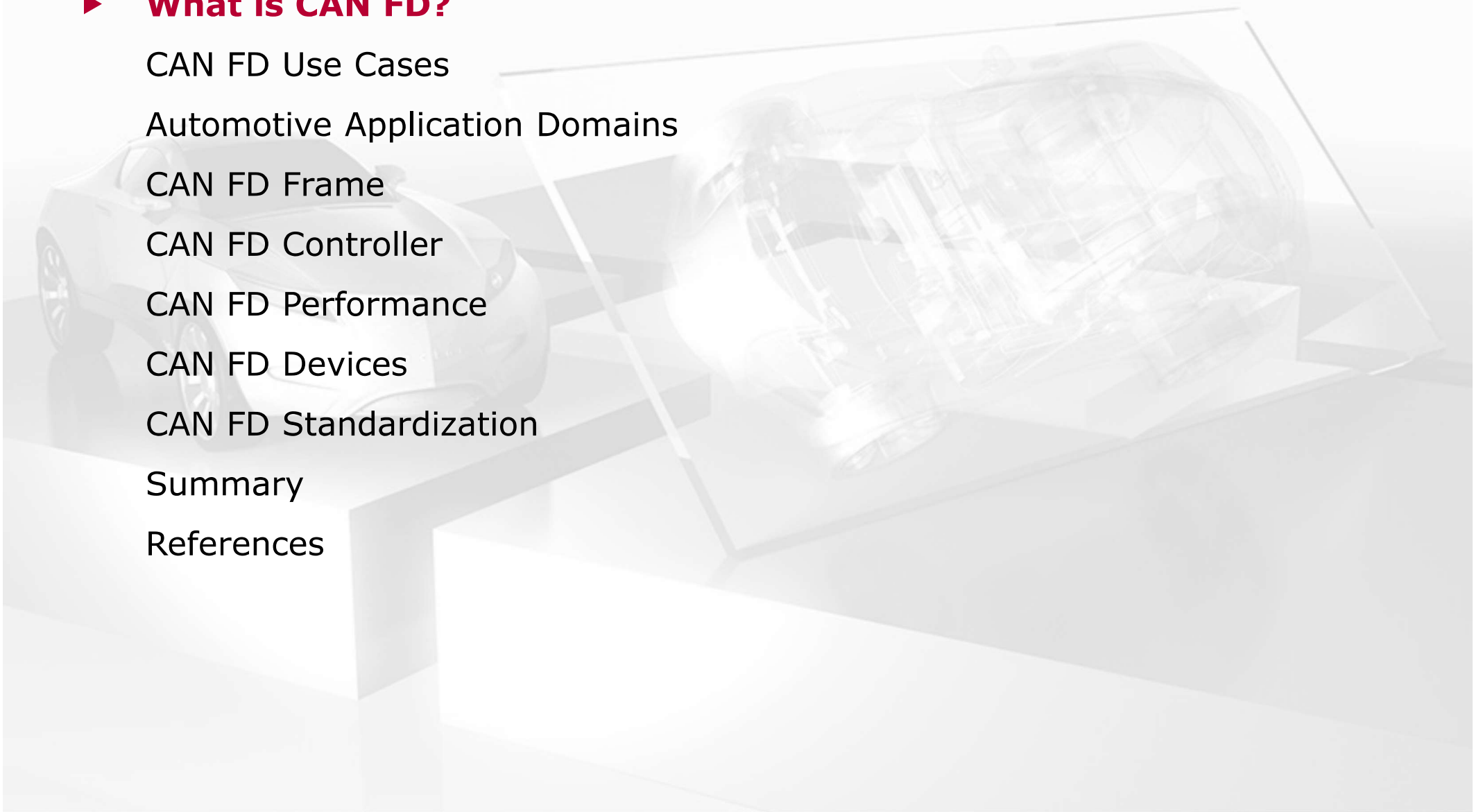

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- CAN FD is an improved CAN protocol (based on CAN 2.0)

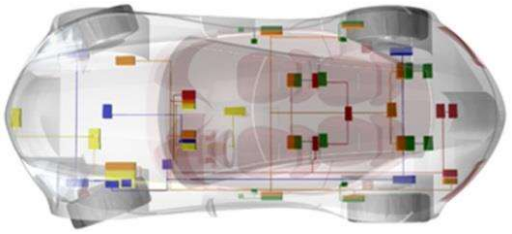
- Two features added:
  - Changes limited to CAN controller hardware

  1. **Support dual bit rates within a message**
     - Arbitration Phase: same bit rate as standard CAN
     - Data Phase: bit rates up to 5 Mbit/s depending on the application
     - ➔ small software change needed (due to change of timing)

  2. **Support larger payload (data length)**
     - Up to 64 bytes/message
     - ➔ larger software change needed

- System cost similar to standard CAN
  - Controller, crystal, transceiver, node interconnection cost
  - Existing CAN transceivers usable up to 2-5 Mbit/s depending on the application
  - Well known technology: Event triggered system

- Smooth migration at reasonable cost possible
  - Classic CAN and CAN FD ECUs can be mixed under certain conditions



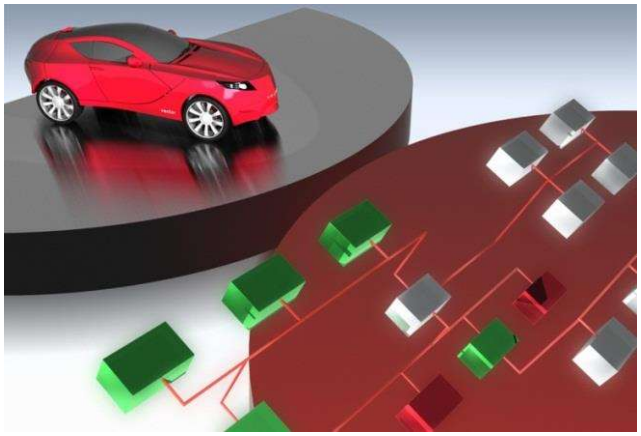
Combining CAN and CAN FD

Scenario 1

- Some nodes are not CAN FD capable:
  - Communicate only with classic CAN messages or switch off the not-capable nodes (e.g. during flashing)
    - Partial network transceiver
    - Sophisticated filter transceivers (e.g. NXP Shield Transceiver)

Scenario 2

- All nodes are CAN FD capable:
  - Classic and FD messages can be mixed



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Combining CAN and CAN FD

	Receive	
Transmit	Classical	FD
Classical	✓	✓
FD	✗	✓

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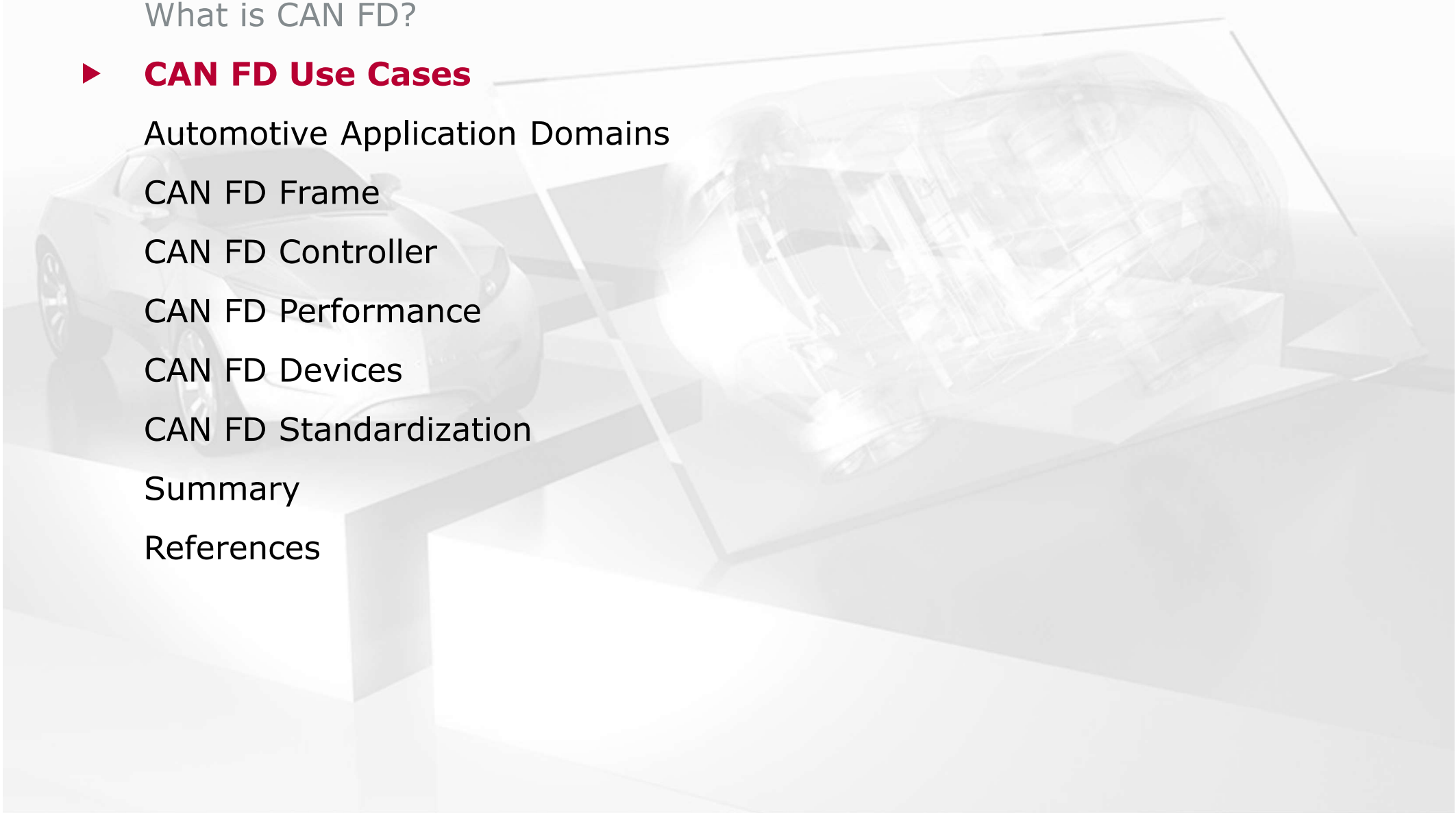

- Faster software download
- Avoid split of data into several frames
- Decrease bus load of an existing bus
- Increase no. of ECUs on the bus
- Avoid split of networks
- Accelerate communication on long bus lines (truck/bus)

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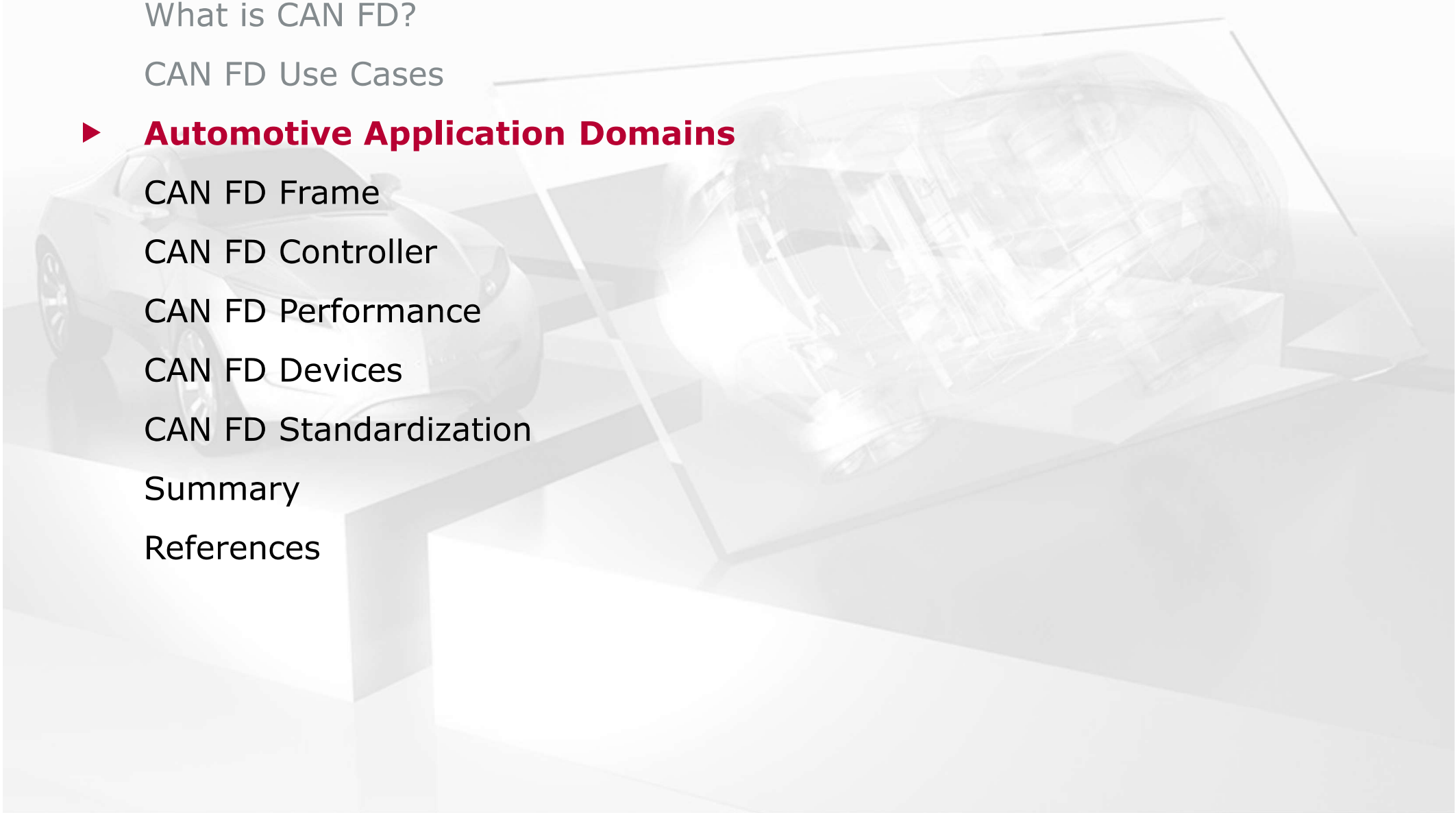

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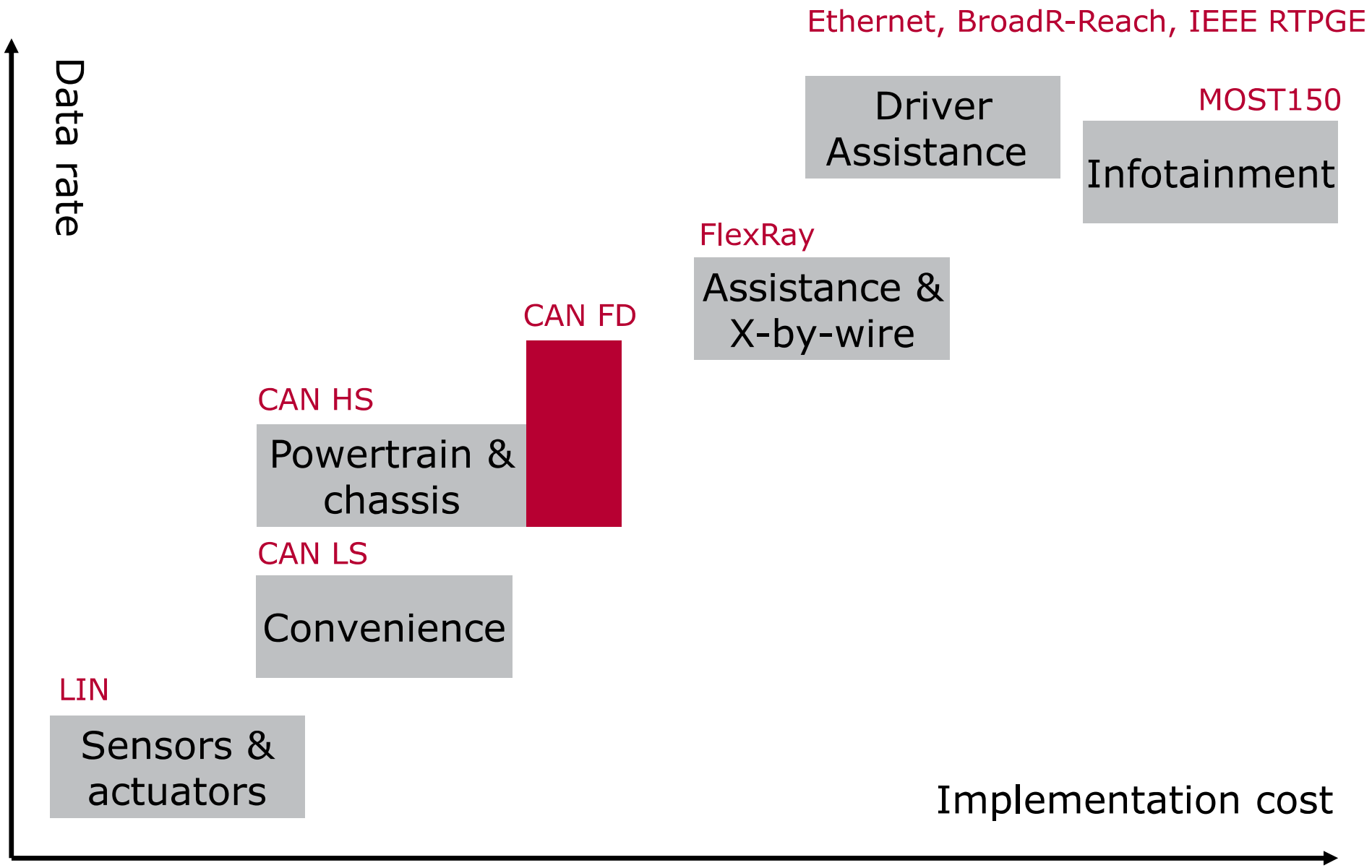
Bandwidth and Cost



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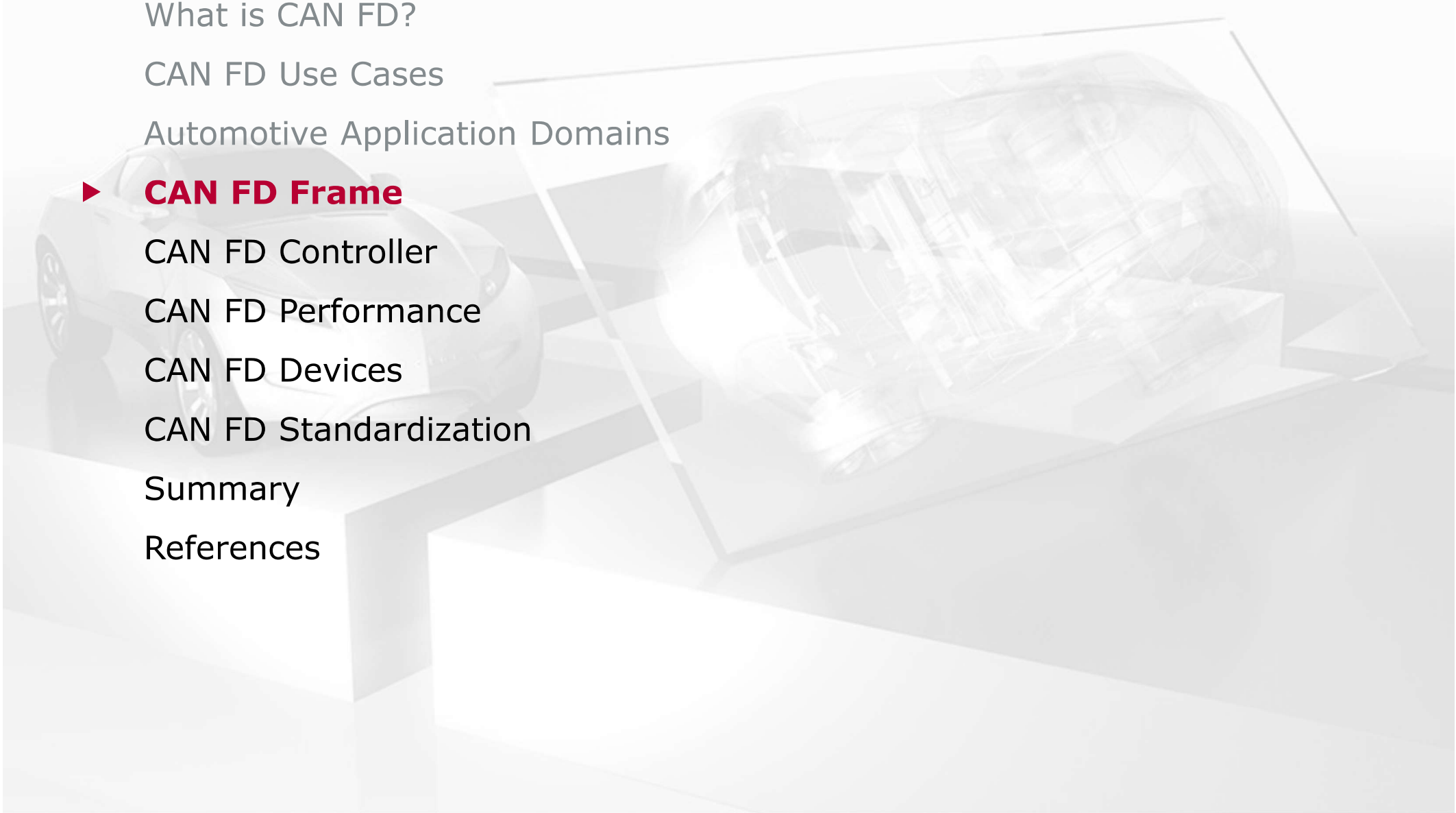
CAN FD vs. FlexRay

- CAN FD closes the gap between classic CAN (1 MBit/s) and FlexRay (10 MBit/s) but
  - Higher effort for FlexRay migration
  - FlexRay is less flexible but offers high predictability (bus load, …)
  - FlexRay is not efficient for ECU flashing

CAN FD vs. Ethernet

- Ethernet provides the necessary bandwidth e.g. for Car2x, and camera applications
  - Higher effort for Ethernet migration
  - Ethernet (UDP) more efficient for streaming applications
  - Event triggered system vs. switched network

Agenda



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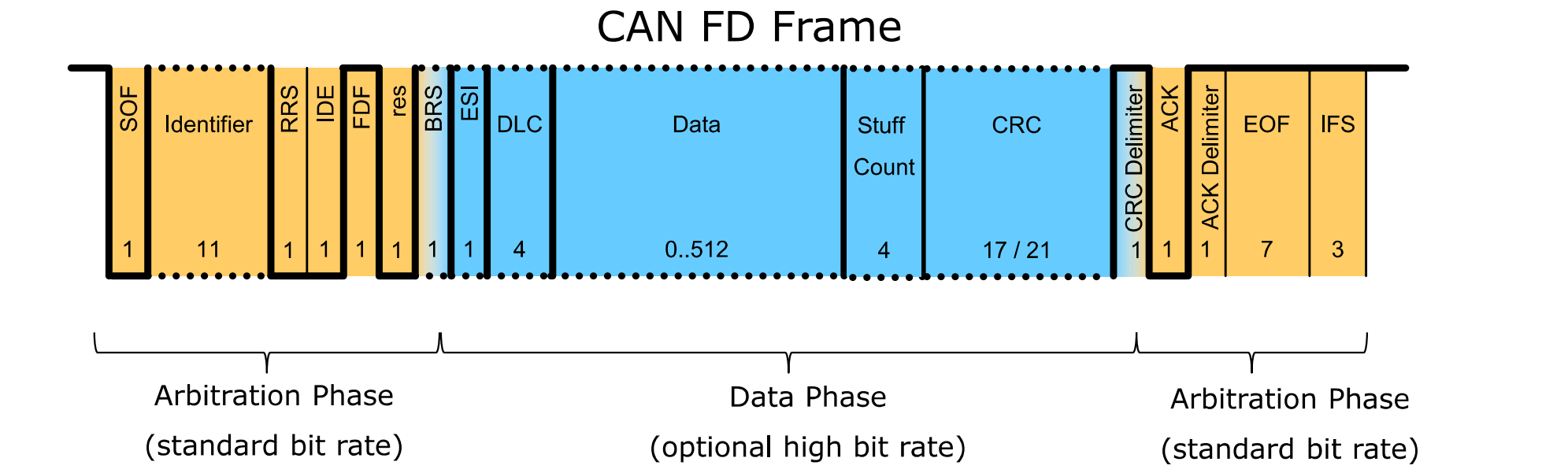
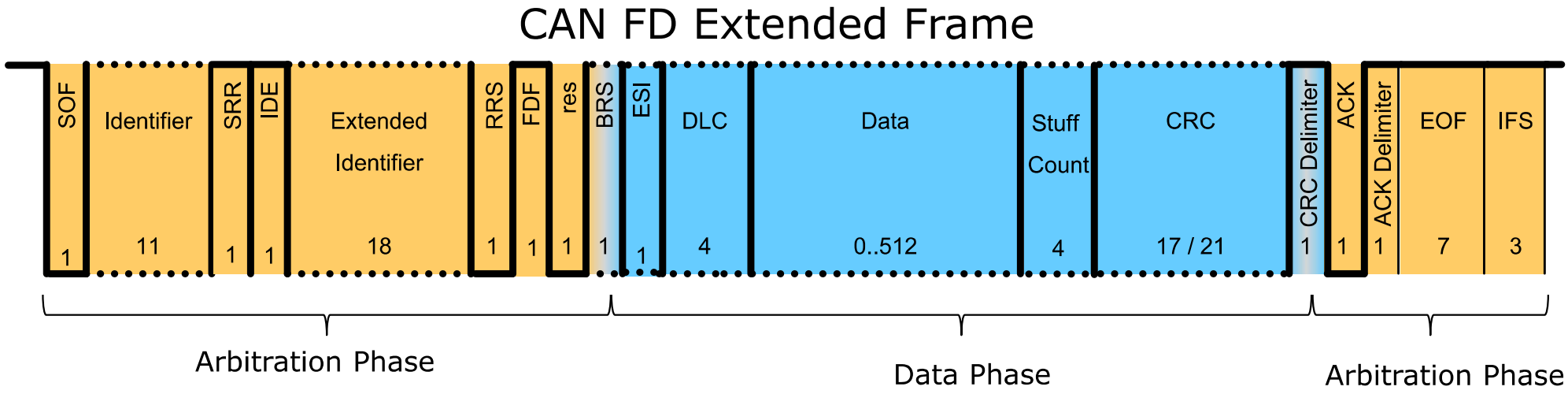
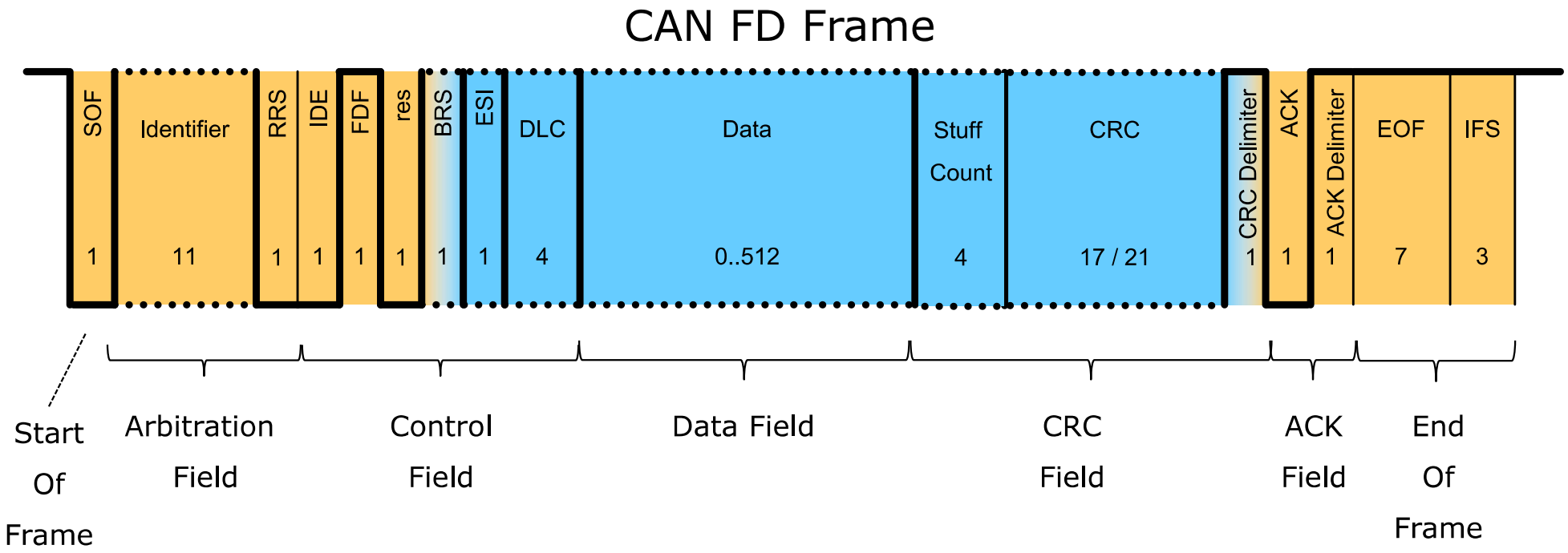
Arbitration Phase and Data Phase





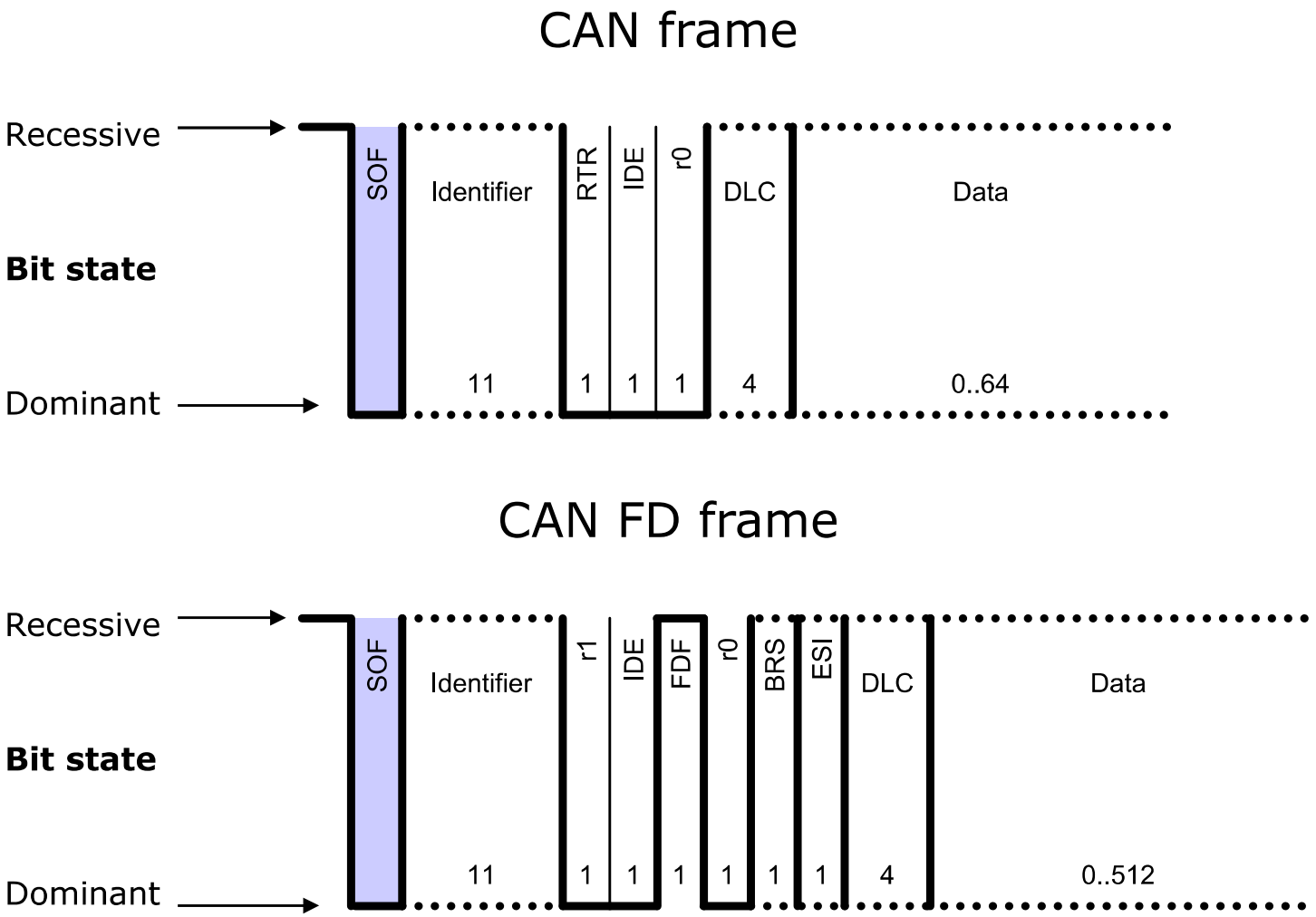
CAN FD Frame Fields

- … and seven different bit fields – *SOF, Arbitration, Control, Data, CRC (Stuff Count + CRC Sequence), ACK, EOF*



Start of Frame

- CAN and CAN FD use the same SOF – a single “dominant” bit



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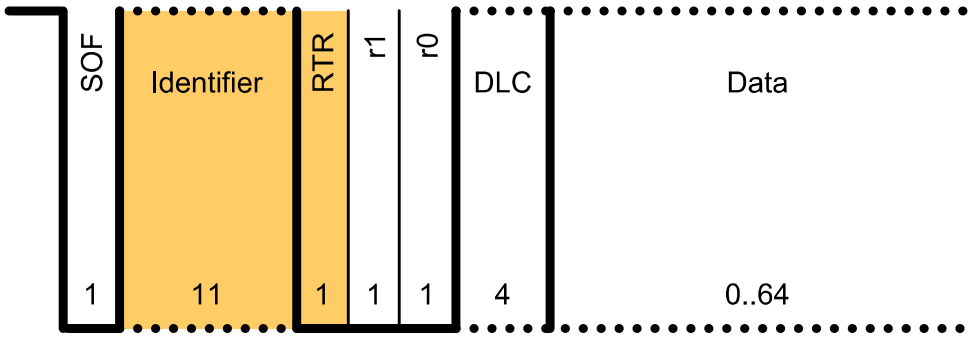
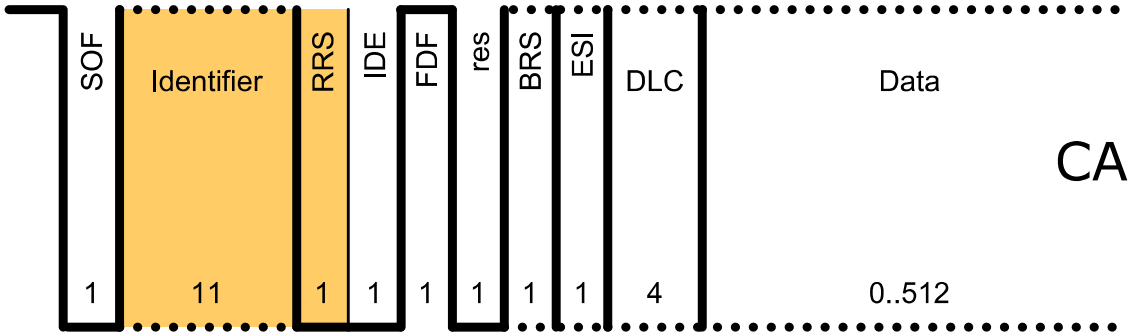
Arbitration Field

- Little difference between CAN and CAN FD arbitration fields
  - Both share the same addressing for Standard and Extended formats
  - CAN FD removes the RTR bit and maintains an always dominant RRS bit



CAN frame

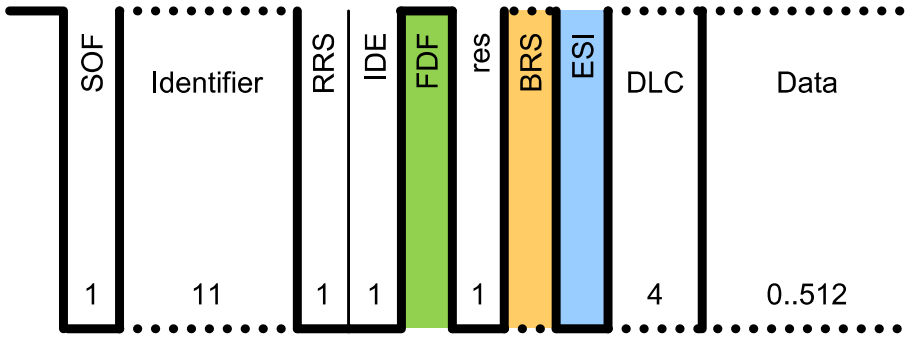


CAN FD frame

VECTOR

Control Field

- CAN and CAN FD share the following bits:
  - IDE, res and the DLC bits



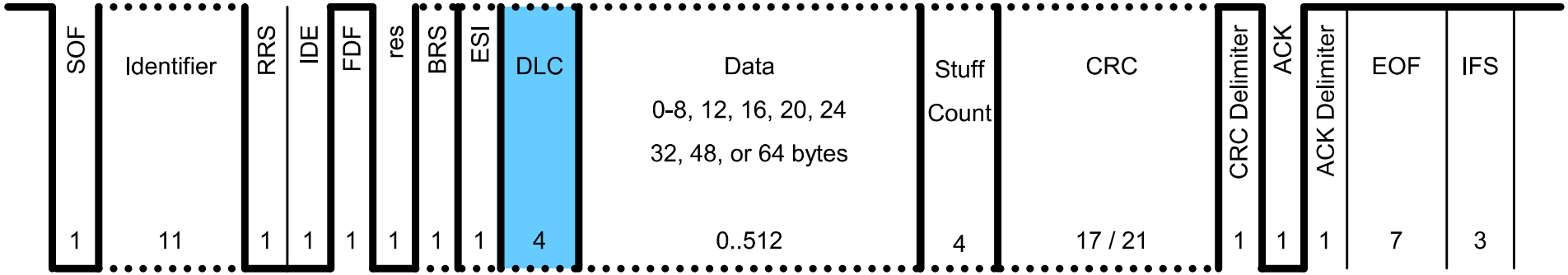
- CAN FD adds the following bits to the control field:
  - FDF – FD Format
    - Determines if CAN (dominant) or CAN FD (recessive)
  - BRS – Bit Rate Switch
    - Separates Arbitration Phase from Data Phase in CAN FD
    - Clock rate switches when BRS is recessive
  - ESI – Error State Indicator (error active/passive)

VECTOR

Control Field: DLC

- Data Length Code (DLC)
  - 4 bits used for both formats
  - CAN FD compatible with CAN at data lengths ≤ 7
    - CAN ignores 3 lsb if DLC = 8, CAN FD does not
    - For lengths ≥ 8, CAN FD uses the following DLCs:

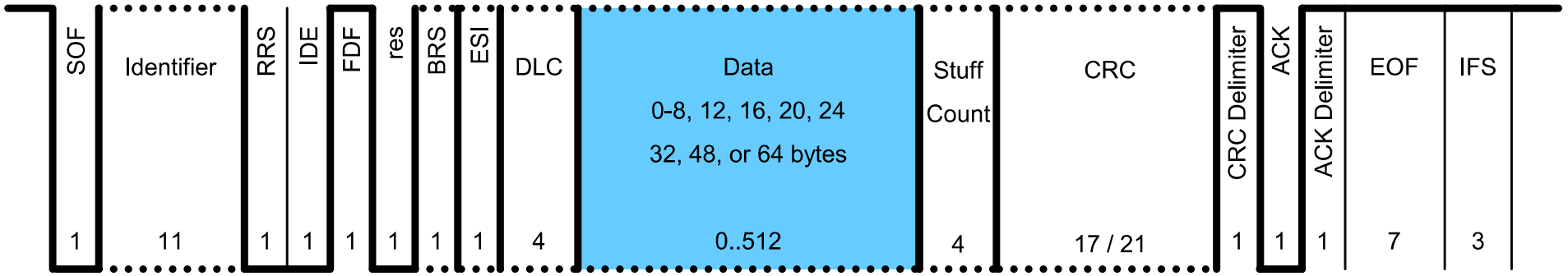
1000 = 8	1100 = 24
1001 = 12	1101 = 32
1010 = 16	1110 = 48
1011 = 20	1111 = 64



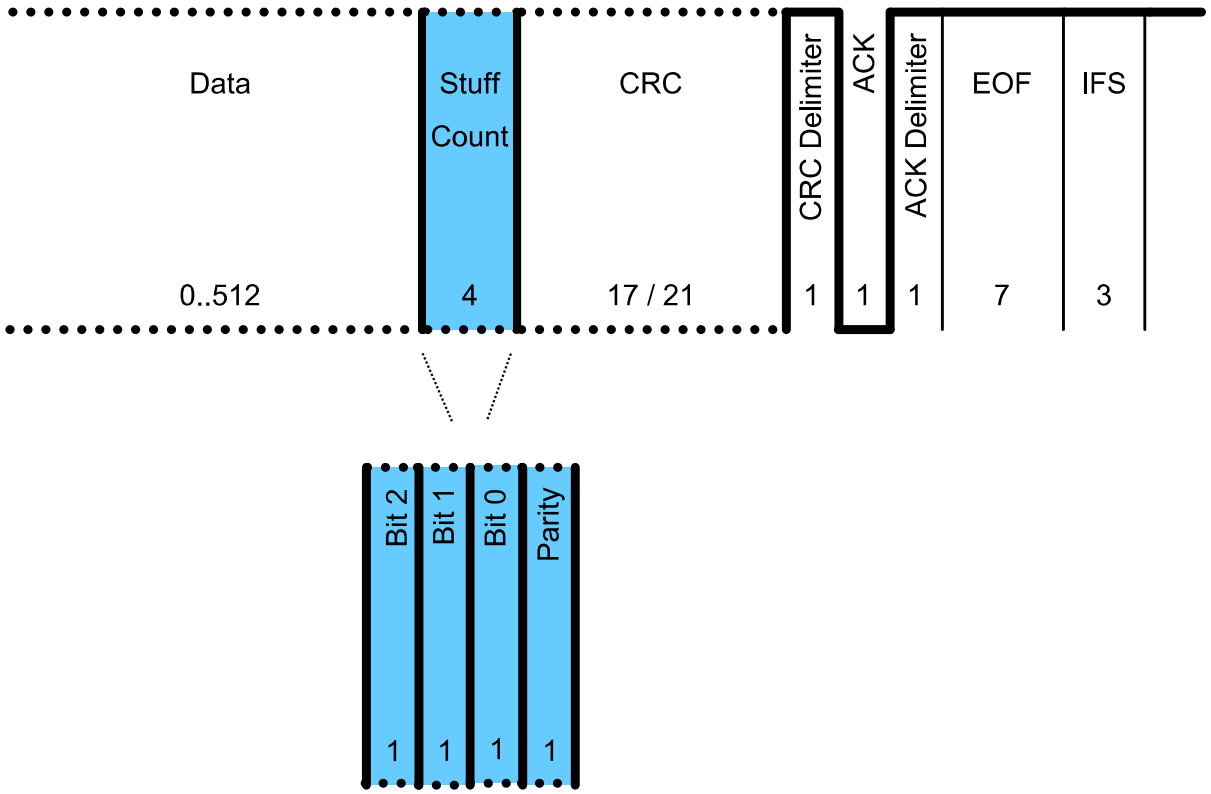
VECTOR

Data Field

- 0-8 bytes in CAN
- 0-8, 12, 16, 20, 24, 32, 48, or 64 bytes in CAN FD
  - Bytes are transferred msb first
- No data field if DLC = 0

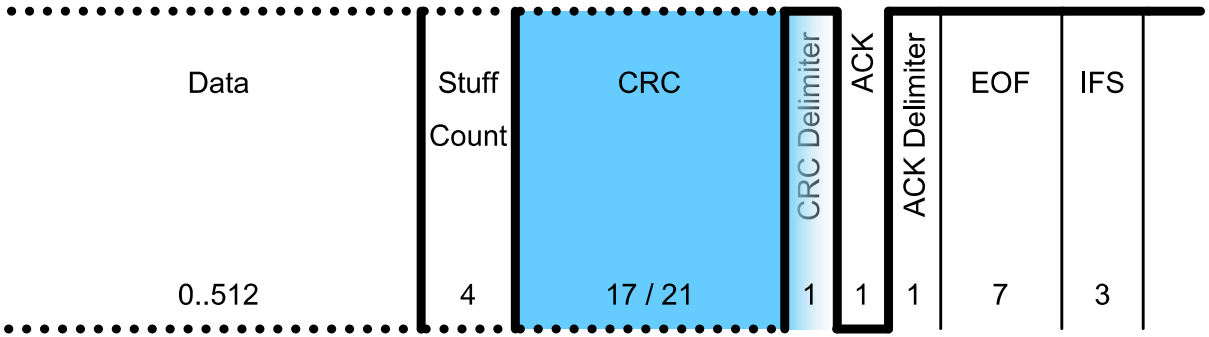


CRC Field: Stuff Count



- Preceding stuff bits are included in the CAN FD CRC calculation
  - CAN does not use stuff bits in the CRC calculation
- This makes it necessary to transmit the total number of bits.
  - Therefore the number of dynamic stuff bits is included into the frame format (stuff bit count modulo 8).
- Two safeguards for the Stuff Count are implemented:
  - 1. Adding a parity-bit (even parity)
  - 2. Gray-coding the stuff bit count (Bit0-2)

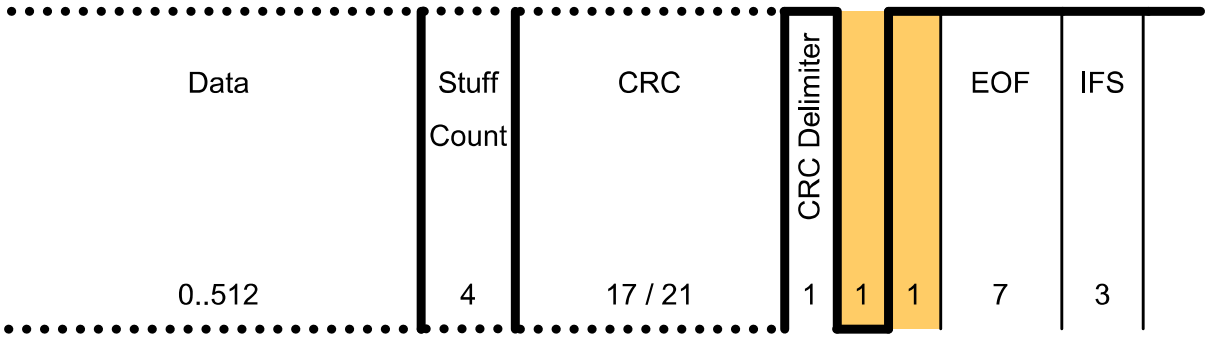
CRC Field: CRC Sequence



- Size of CRC differs based on CAN/CAN FD and length of DLC
  - 15 bits for CAN
  - 17 bits for CAN FD where data field ≤ 16 bytes
  - 21 bits for CAN FD where data field > 16 bytes

- CAN FD CRC delimiter is always transmitted as 1 bit, but due to phase shift between nodes a transmitter accepts up to 2 bit times
  - Data Phase of CAN FD frame ends with the sample point of the first bit of the CRC delimiter

ACK Field

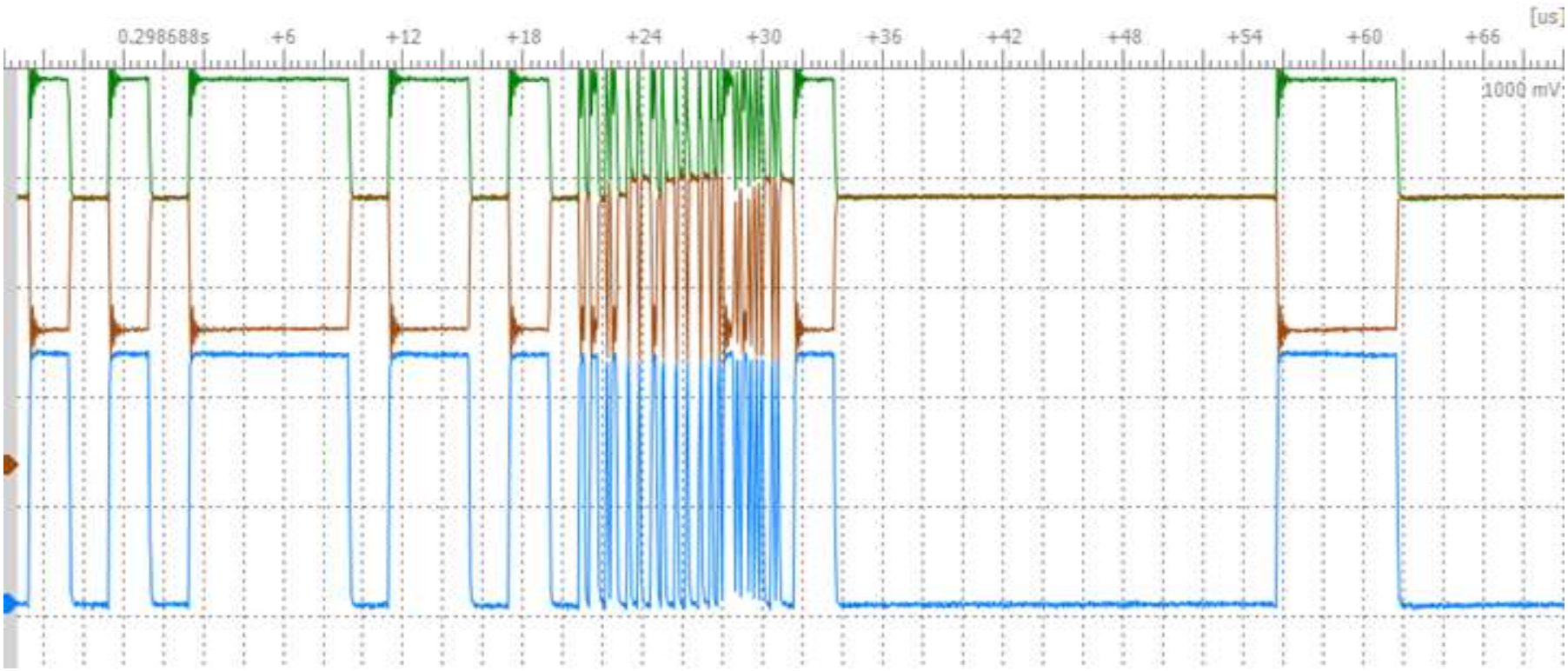


- ACK sent at the end of the CRC delimiter bit
- Slight difference in the format between CAN and CAN FD
  - CAN FD nodes recognize up to two bit times as a valid ACK
    - 1 extra bit time allowed to compensate for transceiver phase shift and bus propagation delay due to the switch from a high Data Phase clock to a low Arbitration Phase clock

End of Frame

- Frames are delimited by a group of 7 recessive bits

CAN FD Oscilloscope Trace



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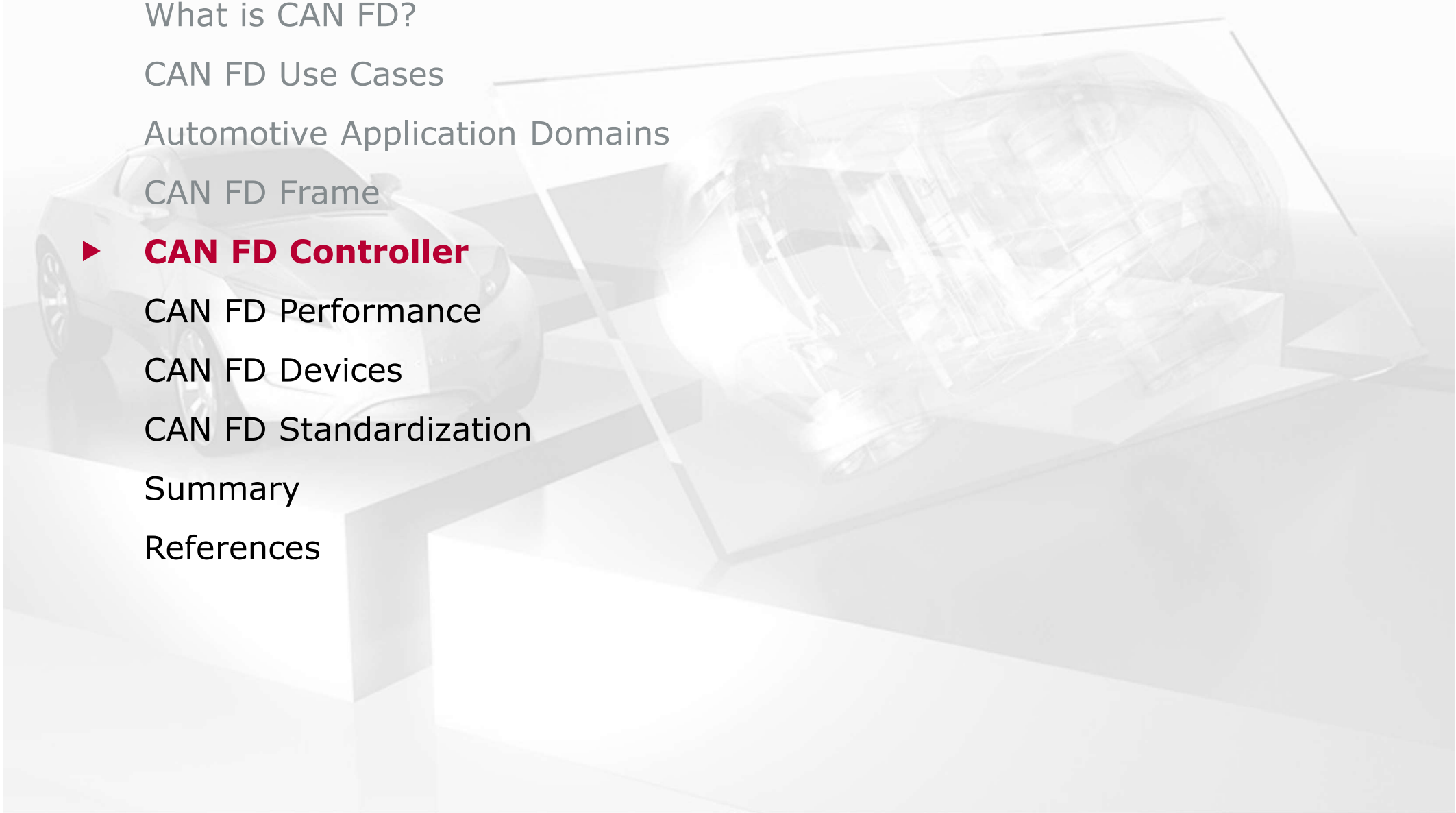

- Controller allows for dynamic switching between CAN – CAN FD
- Four Frame Formats:
  - CAN base format – 11 bit identifier and fixed bit rate
  - CAN extended format – 29 bit identifier and fixed bit rate
  - CAN FD base format – 11 bit identifier and dual bit rate
  - CAN FD extended format – 29 bit identifier and dual bit rate

- Error Frame:
  - Identical to CAN error frame
  - Error frame is always sent with arbitration bit rate
  - Controller switches automatically to arbitration bit rate

- Remote Frame:
  - Remote frame in CAN base format
  - Remote frame in CAN extended format
  - Remote frames are **undefined** in CAN FD format
    - RTR bit removed from CAN FD bit-stream

- Overload Frame:
  - Identical to CAN overload frame
  - Overload frame is always send with arbitration bit rate

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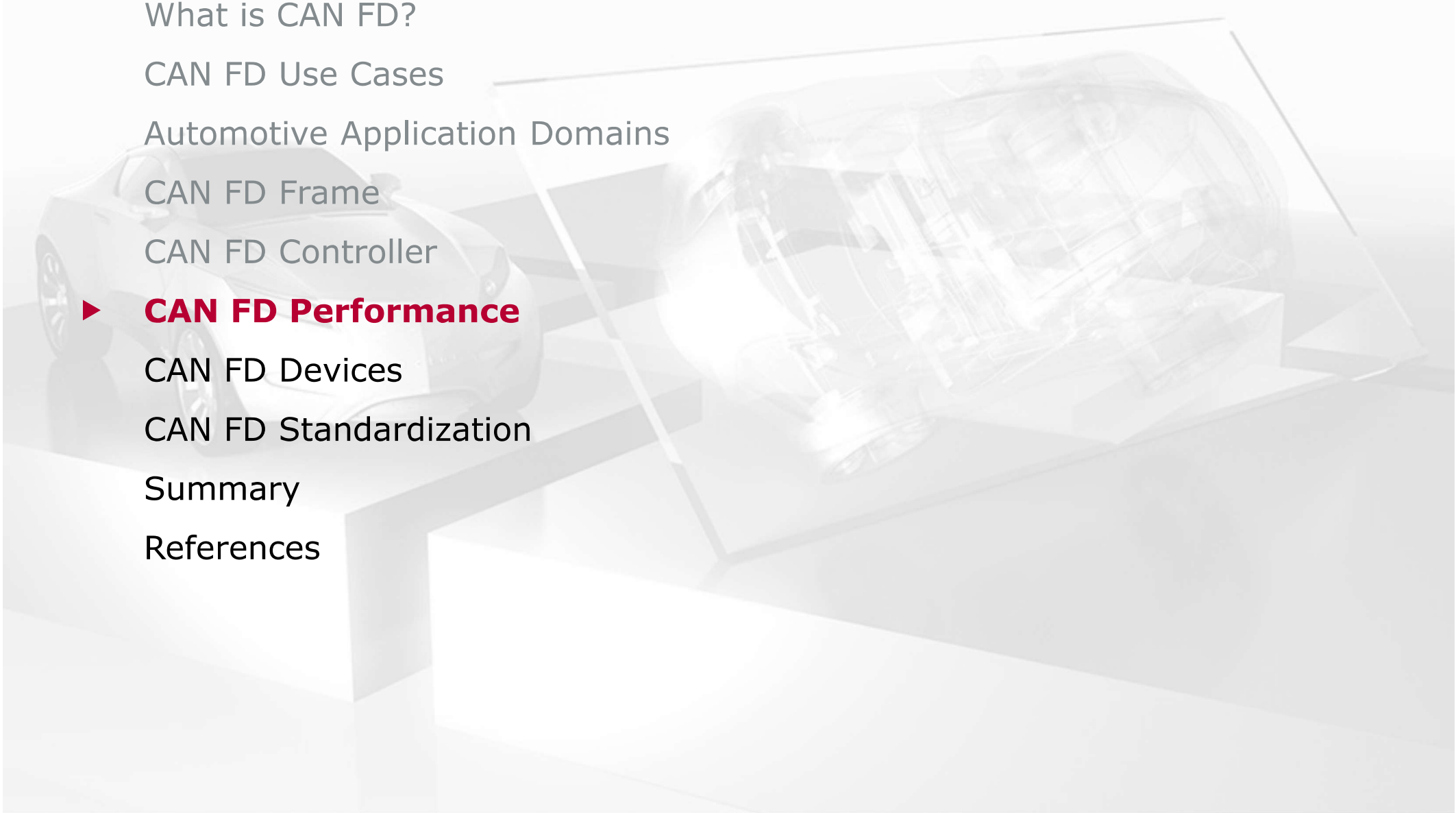
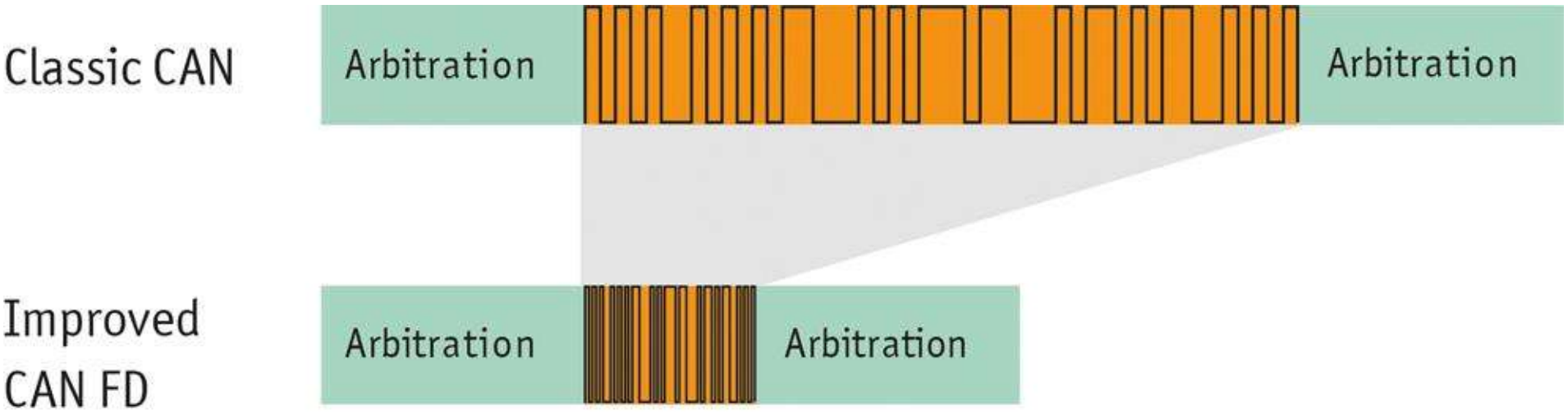


- Basic calculation principles:
  - Stuff bits excluded
  - Max CAN frame with 111 bits
  - Max CAN FD frames with 120/572 bits

Frame Type	No. Data Bytes	Arb. Bit-Rate	Opt. Bit-Rate	Avg. Bit-Rate	Frame Duration
CAN	8	500 Kbit/s	-		222 us
CAN FD	8	500 Kbit/s	2 Mbit/s	1.16 Mbit/s	103.5 us
CAN FD	8	500 Kbit/s	5 Mbit/s	1.57 Mbit/s	76.2 us
CAN FD	64	500 Kbit/s	2 Mbit/s	1.74 Mbit/s	329.5 us
CAN FD	64	500 Kbit/s	5 Mbit/s	3.43 Mbit/s	166.6 us

- CAN FD average bit rate converges due to Arbitration Phase
- Arbitration phase becomes dominant at a certain baud rate for the Data Phase.
- This means that the overall frame length becomes not much smaller through a further increase of the Data Phase bit rate.



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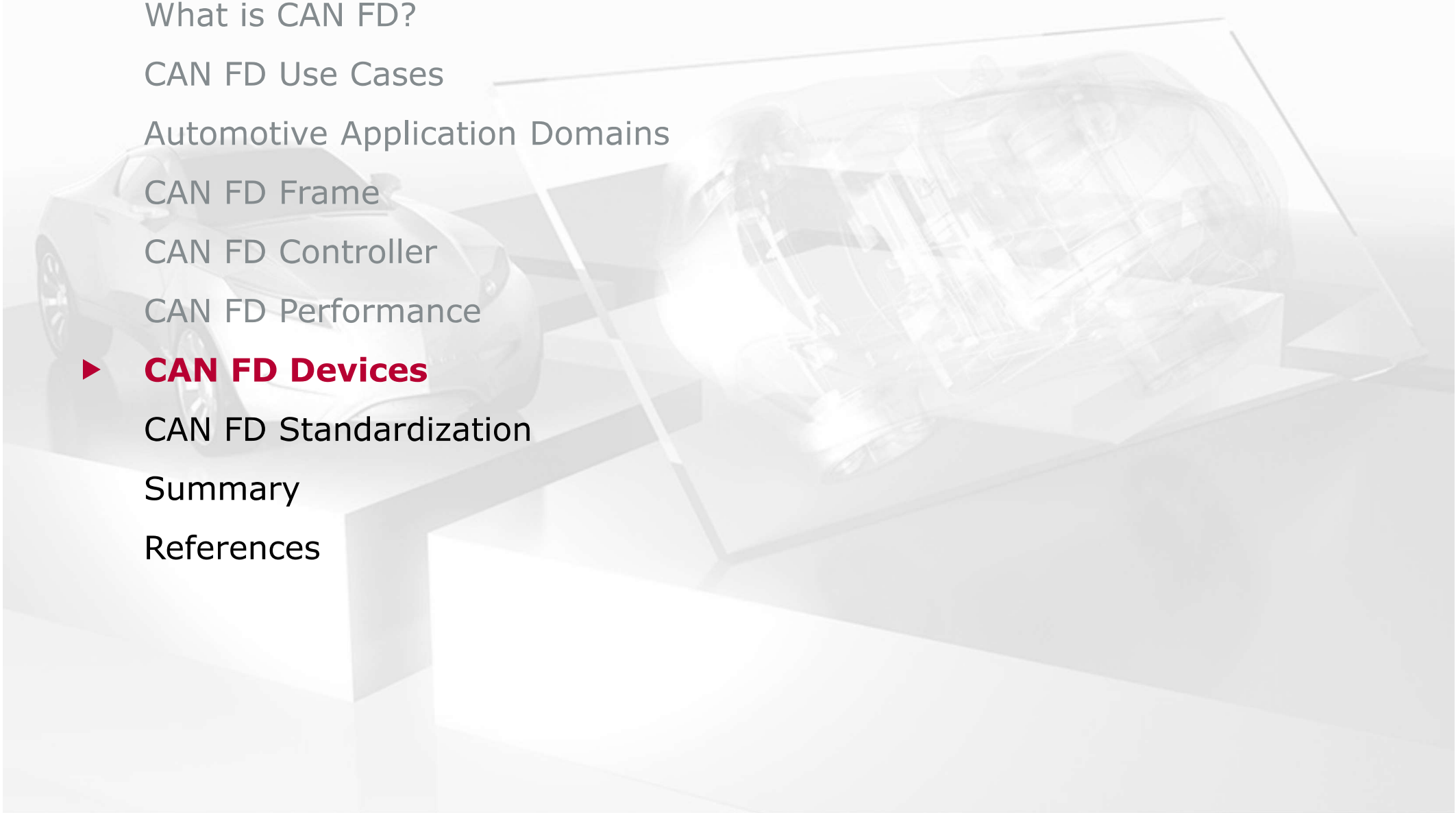

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CAN Controller

- MCUs with full CAN FD support available (ISO)
  - Freescale, ST, Renesas, Spansion, Infineon …

CAN Transceiver

- Typical bit rates of automotive transceivers for CAN FD
  - Functional messages: 2 Mbit/s
  - Reprogramming: 5 Mbit/s
- Transceivers for CAN FD operation available from different manufacturers
  - Support of 2 Mbit/s within current emission limits

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CAN ISO 11898

- CAN FD as part of ISO 11898-1 (CAN Controller)
  - International Standard (IS 2015)
- ISO 11898-2 (CAN Transceiver)
  - International Standard (IS 2016)
  - Substitutes the previous versions of part 2, part 5, and part 6.
  - Specifies the transceiver characteristics for bit-rates up to 5 Mbit/s.

CAN ISO 16845

- Upgrade of CAN controller conformance test ISO 16845-1
  - International Standard (IS 2016)
- Upgrade of CAN transceiver conformance test ISO 16845-2
  - International Standard (IS 2018)

AUTOSAR

- CAN FD (8 byte) in Autosar 4.1.1
- CAN FD (64 byte) in Autosar 4.2.1

J1939

- CAN FD upgrade ➔ ongoing

ISO 15765-2: ISO TP

- ISO transport protocol supports the CAN FD data link layer with data fields up to 64 byte
  - International Standard (IS 2016)

CANopen

- CiA SIG CANopen is updating the CiA 301 application layer to support the CAN FD data link layer

Changes in ISO 15765-2

- New Single Frame for payloads > 8 bytes

Type	Byte 1 Bits 7-4	Byte 1 Bits 0-3	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6
Single Frame	0000_2	0000_2	Length SF				

Escape Sequence

- New First Frame for Message Length > 4095 byte

Type	Byte 1 Bits 7-4	Byte 1 Bits 0-3	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6
First Frame	0001_2	0000_2	$0000\ 0000_2$	Message Length			

Escape Sequence

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Serial communication networks require increased bandwidth

- Due to high bus load levels
- For flashing applications

CAN FD can provide significantly increased bandwidth

- Due to increased data clock rates
- Due to larger data payloads

CAN FD is an improvement of well known CAN technology

- Event triggered system
- Unchanged arbitration and acknowledge mechanism

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- Presentation “CAN FD CAN with Flexible Data Rate” – Florian Hartwich, Robert Bosch, GmbH; Feb. 15, 2012
- http://www.bosch-semiconductors.com/ip-modules/can-ip-modules/m-can
  - M_CAN Controller Area Network User’s Manual
- http://www.bosch-semiconductors.com/ip-modules/can-ip-modules/can-fd
  - Papers about bit timing requirements and robustness of CAN FD networks
- Press Articles from Vector:
  - https://www.vector.com/de/de/know-how/technologien/netzwerke/can/#c42688
  - https://www.vector.com/int/en/know-how/technologies/networks/can/#c9439

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