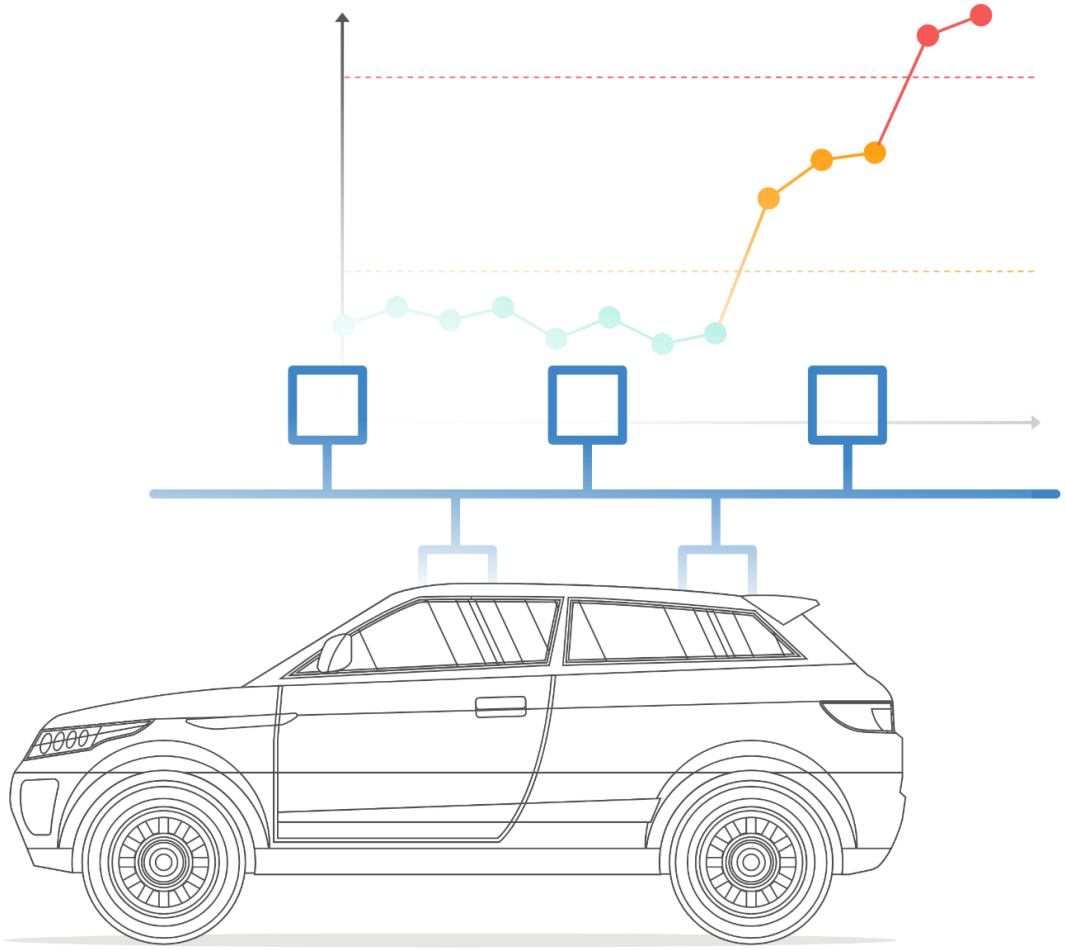

# CAN bus

## the ultimate guide

CAN | J1939 | OBD2 | UDS | CANopen | CAN FD | LIN | DBC | CAN Errors

CSS Electronics | www.csselectronics.com | contact@csselectronics.com
Last modified: May 16, 2022

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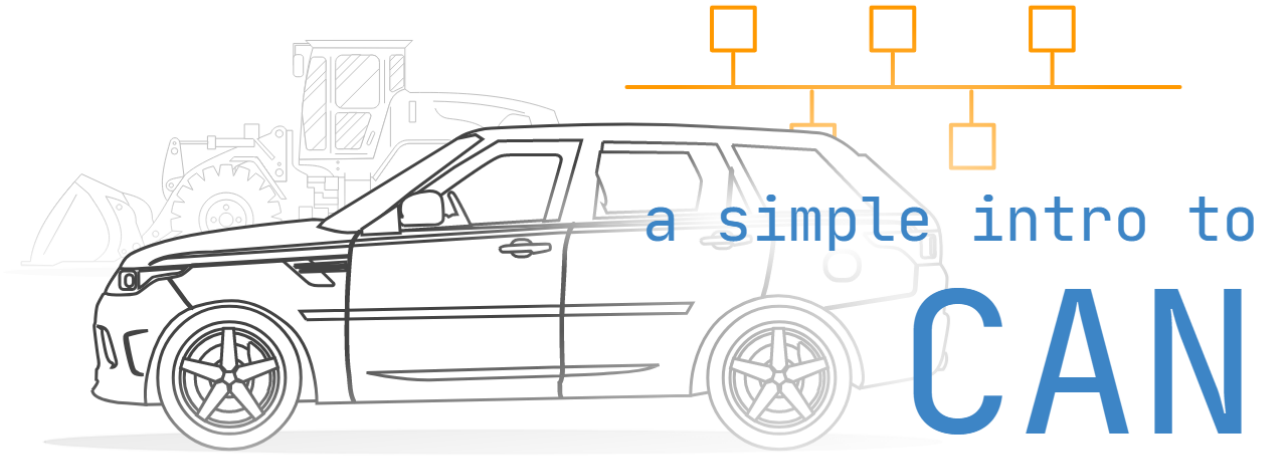



# CAN Bus Explained - A Simple Intro

Need a simple, practical intro to CAN bus? In this tutorial we explain the Controller Area Network (CAN bus) 'for dummies' incl. message interpretation, CAN logging - and the link to OBD2, J1939 and CANopen.

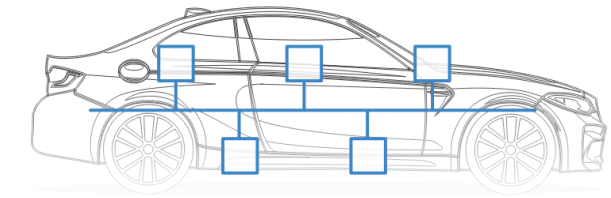
Read on to learn why this has become the #1 guide on CAN bus.

## What is CAN bus?

Your car is like a human body:

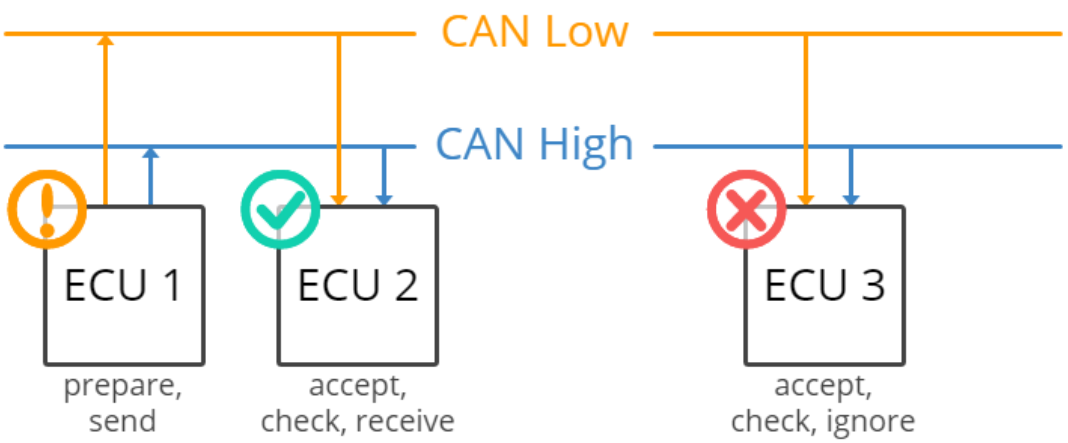
The Controller Area Network (CAN bus) is the nervous system, enabling communication.

In turn, 'nodes' or 'electronic control units' (ECUs) are like parts of the body, interconnected via the CAN bus. Information sensed by one part can be shared with another.




So what is an ECU?

In an automotive CAN bus system, ECUs can e.g. be the engine control unit, airbags, audio system etc. A modern car may have up to 70 ECUs - and each of them may have information that needs to be shared with other parts of the network.




**This is where the CAN standard comes in handy:**

The CAN bus system enables each ECU to communicate with all other ECUs - without complex dedicated wiring.

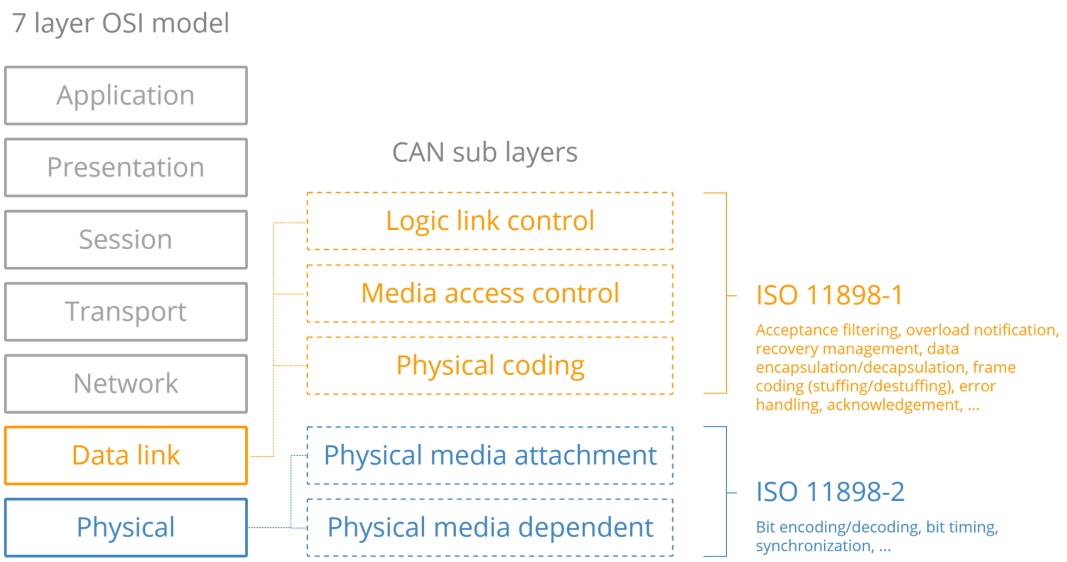
Specifically, an ECU can prepare and broadcast information (e.g. sensor data) via the CAN bus (consisting of two wires, CAN low and CAN high). The broadcasted data is accepted by all other ECUs on the CAN network - and each ECU can then check the data and decide whether to receive or ignore it.

### CAN bus physical & data link layer (OSI)

In more technical terms, the controller area network is described by a data link layer and physical layer. In the case of high speed CAN, ISO 11898-1 describes the data link layer, while ISO 11898-2 describes the physical layer. The role of CAN is often presented in the 7 layer OSI model as per the illustration.

The CAN bus physical layer defines things like cable types, electrical signal levels, node requirements, cable impedance etc. For example, ISO 11898-2 dictates a number of things, including below:

- Baud rate: CAN nodes must be connected via a two wire bus with baud rates up to 1 Mbit/s (Classical CAN) or 5 Mbit/s (CAN FD)
- Cable length: Maximal CAN cable lengths should be between 500 meters (125 kbit/s) and 40 meters (1 Mbit/s)
- Termination: The CAN bus must be properly terminated using a 120 Ohms CAN bus termination resistor at each end of the bus



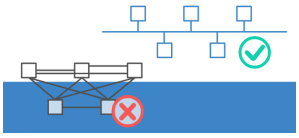

## High speed CAN, low speed CAN, LIN bus, ...

In the context of automotive vehicle networks, you'll often encounter a number of different types of network types. Below we provide a very brief outline:

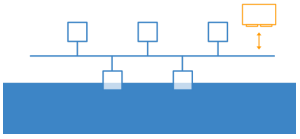
- **High speed CAN bus:** The focus of this article is on high speed CAN bus (ISO 11898). It is by far the most popular CAN standard for the physical layer, supporting bit rates from 40 kbit/s to 1 Mbit/s (Classical CAN). It provides simple cabling and is used in practically all automotive applications today. It also serves as the basis for several higher layer protocols such as OBD2, J1939, NMEA 2000, CANopen etc. The second generation of CAN is referred to as CAN FD (CAN with Flexible Data-rate)
- **Low speed CAN bus:** This standard enables bit rates from 40 kbit/s to 125 kbit/s and allows the CAN bus commmunication to continue even if there is a fault on one of the two wires - hence it is also referred to as 'fault tolerant CAN'. In this system, each CAN node has it's own CAN termination
- **LIN bus:** LIN bus is a lower cost supplement to CAN bus networks, with less harness and cheaper nodes. LIN bus clusters typically consist of a LIN master acting as gateway and up to 16 slave nodes. Typical use cases include e.g. non-critical vehicle functions like aircondition, door functionality etc. - for details see our LIN bus intro or LIN bus data logger article
- **Automotive ethernet:** This is increasingly being rolled out in the automotive sector to support the high bandwidth requirements of ADAS (Advanced Driver Assistance Systems), infotainment systems, cameras etc. Automotive ethernet offers much higher data transfer rates vs. CAN bus, but lacks some of the safety/performance features of Classical CAN and CAN FD. Most likely, the coming years will see both automotive ethernet, CAN FD and CAN XL being used in new automotive and industrial development

# Top 4 benefits of CAN bus

The CAN bus standard is used in practically all vehicles and many machines due to below key benefits:

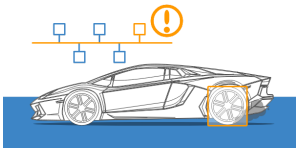


**Simple & low cost**
ECUs communicate via a single CAN system instead of via direct complex analogue signal lines - reducing errors, weight, wiring and costs



**Fully centralized**
The CAN bus provides 'one point-of-entry' to communicate with all network ECUs - enabling central diagnostics, data logging and configuration

**Extremely robust**
The system is robust towards electric disturbances and electromagnetic interference - ideal for safety critical applications (e.g. vehicles)

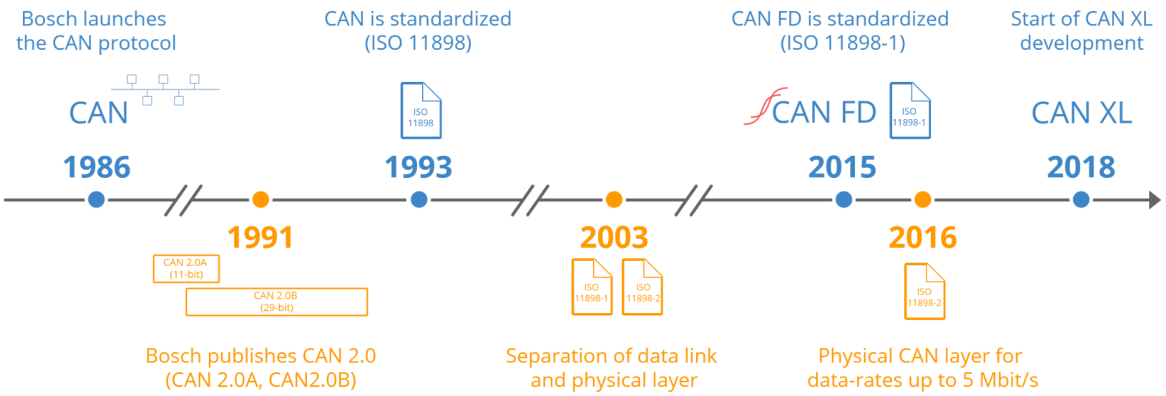


**Efficient**
CAN frames are prioritized by ID so that top priority data gets immediate bus access, without causing interruption of other frames

# The CAN bus history in short

- Pre CAN: Car ECUs relied on complex point-to-point wiring
- 1986: Bosch developed the CAN protocol as a solution
- 1991: Bosch published CAN 2.0 (CAN 2.0A: 11 bit, 2.0B: 29 bit)
- 1993: CAN is adopted as international standard (ISO 11898)
- 2003: ISO 11898 becomes a standard series
- 2012: Bosch released the CAN FD 1.0 (flexible data rate)
- 2015: The CAN FD protocol is standardized (ISO 11898-1)
- 2016: The physical CAN layer for data-rates up to 5 Mbit/s standardized in ISO 11898-2

Today, CAN is standard in automotives (cars, trucks, buses, tractors, ...), ships, planes, EV batteries, machinery and more.



# The future of CAN bus

Looking ahead, the CAN bus protocol will stay relevant - though it will be impacted by major trends:

- A need for increasingly advanced vehicle functionality
- The rise of cloud computing
- Growth in Internet of Things (IoT) and connected vehicles
- The impact of autonomous vehicles

In particular, the rise in connected vehicles (V2X) and cloud will lead to a rapid growth in vehicle telematics and IoT CAN loggers. In turn, bringing the CAN bus network 'online' also exposes vehicles to security risks - and may require a shift to new CAN protocols like CAN FD.

### The rise of CAN FD

As vehicle functionality expands, so does the load on the CANbus. To support this, CAN FD (Flexible Data Rate) has been designed as the 'next generation' CAN bus. Specifically, CAN FD offers three benefits (vs Classical CAN):

- It enables data rates up to 8 Mbit/s (vs 1 Mbit/s)
- It allows data payloads of up to 64 bytes (vs 8 bytes)
- It enables improved security via authentication

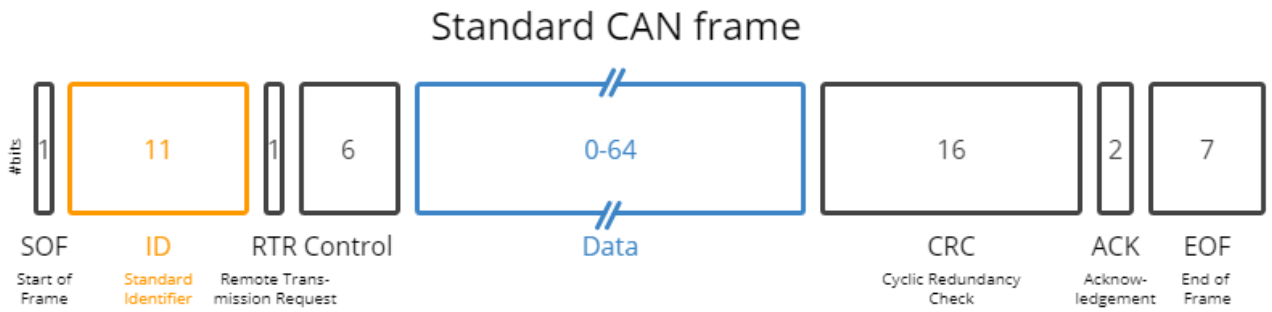
In short, CAN FD boosts speed and efficiency - and it is therefore being rolled out in newer vehicles. This will also drive an increasing need for IoT CAN FD data loggers.

***"The first cars using CAN FD will appear in 2019/2020 and CAN FD will replace step-by-step Classical CAN"***
- CAN in Automation (CiA), "CAN 2020: The Future of CAN Technology"

# What is a CAN frame?

Communication over the CAN bus is done via CAN frames.

Below is a standard CAN frame with 11 bits identifier (CAN 2.0A), which is the type used in most cars. The extended 29-bit identifier frame (CAN 2.0B) is identical except the longer ID. It is e.g. used in the J1939 protocol for heavy-duty vehicles. Note that the CAN ID and Data are highlighted - these are important when recording CAN bus data, as we'll see below.



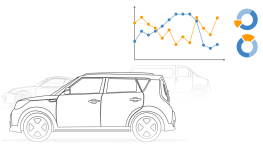

### The 8 CAN bus protocol message fields

- **SOF**: The Start of Frame is a 'dominant 0' to tell the other nodes that a CAN node intends to talk
- **ID**: The ID is the frame identifier - lower values have higher priority

- **RTR**: The Remote Transmission Request indicates whether a node sends data or requests dedicated data from another node
- **Control**: The Control contains the Identifier Extension Bit (IDE) which is a 'dominant 0' for 11-bit. It also contains the 4 bit Data Length Code (DLC) that specifies the length of the data bytes to be transmitted (0 to 8 bytes)
- **Data**: The Data contains the data bytes aka payload, which includes CAN signals that can be extracted and decoded for information
- **CRC**: The Cyclic Redundancy Check is used to ensure data integrity
- **ACK**: The ACK slot indicates if the node has acknowledged and received the data correctly
- **EOF**: The EOF marks the end of the CAN frame

# Logging CAN data - example use cases

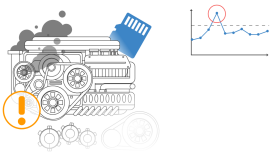
There are several common use cases for recording CAN bus data frames:



**Logging/streaming data from cars**
OBD2 data from cars can e.g. be used to reduce fuel costs, improve driving, test prototype parts and insurance
learn more

**Heavy duty fleet telematics**
J1939 data from trucks, buses, tractors etc. can be used in fleet management to reduce costs or improve safety
learn more

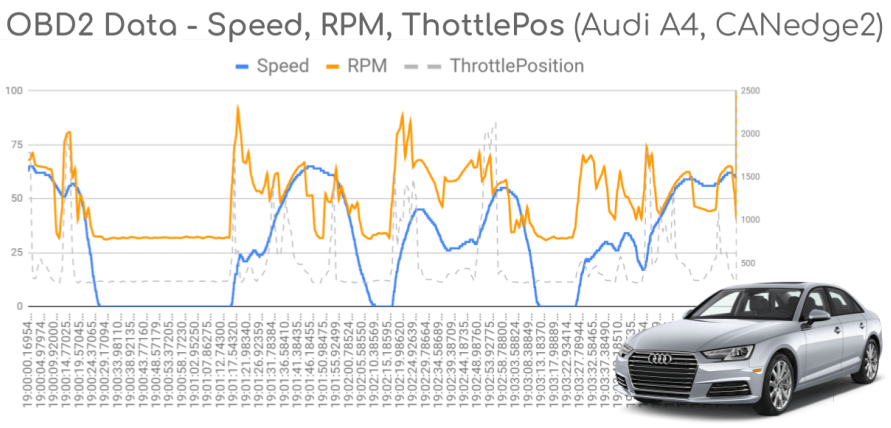
**Predictive maintenance**
Vehicles and machinery can be monitored via IoT CAN loggers in the cloud to predict and avoid breakdowns
learn more



**Vehicle/machine blackbox**
A CAN logger can serve as a 'blackbox' for vehicles or equipment, providing data for e.g. disputes or diagnostics
learn more

# How to log CAN bus data

As mentioned, two CAN fields are important for CAN logging: The CAN ID and the Data. To record CAN data you need a CAN logger. This lets you log timestamped CAN data to an SD card. In some cases, you need a CAN interface to stream data to a PC - e.g. for car hacking.



### Connecting to the CAN bus

This first step is to connect your CAN logger to your CAN bus. Typically this involves using an adapter cable:

- **Cars**: In most cars, you simply use an OBD2 adapter to connect. In most cars, this will let you log raw CAN data, as well as perform requests to log OBD2 or UDS (Unified Diagnostic Services) data
- **Heavy duty vehicles**: To log J1939 data from trucks, excavators, tractors etc you can typically connect to the J1939 CAN bus via a standard J1939 connector cable (deutsch 9-pin)
- **Maritime**: Most ships/boats use the NMEA 2000 protocol and enable connection via an M12 adapter to log marine data
- **CANopen**: For CANopen logging, you can often directly use the CiA 303-1 DB9 connector (i.e. the default connector for our CAN loggers), optionally with a CAN bus extension cable
- **Contactless**: If no connector is available, a typical solution is to use a contactless CAN reader - e.g. the CANCrocodile. This lets you log data directly from the raw CAN twisted wiring harness, without direct connection to the CAN bus (often useful for warranty purposes)
- **Other**: In practice, countless other connectors are used and often you'll need to create a custom CAN bus adapter - here a generic open-wire adapter is useful

When you've identified the right connector and verified the pin-out, you can connect your CAN logger to start recording data. For the CANedge/CLX000, the CAN baud rate is auto-detected and the device will start logging raw CAN data immediately.

### Example: Raw CAN sample data (J1939)

You can optionally download raw OBD2 and J1939 samples from the CANedge2 in our intro docs. You can e.g. load this data in the free CAN bus decoder software tools. Data from the CANedge is recorded in the popular binary format, MF4, but can be converted to any file format via our simple MF4 converters (e.g. to CSV, ASC, TRC, ...).

Below is a CSV example of raw CAN frames logged from a heavy-duty truck using the J1939 protocol. Notice that the CAN IDs and data bytes are in hexadecimal format:

```
TimestampEpoch;BusChannel;ID;IDE;DLC;DataLength;Dir;EDL;BRS;DataBytes
1578922367.777150;1;14FEF131;1;8;8;0;0;0;CFFFFFF300FFFF30
1578922367.777750;1;10F01A01;1;8;8;0;0;0;2448FFFFFFFFFFF
1578922367.778300;1;CF00400;1;8;8;0;0;0;107D82BD1200F482
1578922367.778900;1;14FF0121;1;8;8;0;0;0;FFFFFFFFFFFFFCFF
...
```

### Example: CANedge CAN logger

The CANedge1 lets you easily record data from any CAN bus to an 8-32 GB SD card. Simply connect it to e.g. a car or truck to start logging - and decode the data via free software/APIs. Further, the CANedge2 adds WiFi, letting you auto-transfer data to your own server - and update devices over-the-air.


# How to decode raw CAN data to 'physical values'

If you review the raw CAN bus data sample above, you will probably notice something: Raw CAN bus data is not human-readable.

To interpret it, you need to decode the CAN frames into scaled engineering values aka physical values (km/h, degC, ...).

Below we show step-by-step how this works.

## Extracting CAN signals from raw CAN frames

Each CAN frame on the bus contains a number of CAN signals (parameters) within the CAN databytes. For example, a CAN frame with a specific CAN ID may carry data for e.g. 2 CAN signals.


To extract the physical value of a CAN signal, the following information is required:

- Bit start: Which bit the signal starts at
- Bit length: The length of the signal in bits
- Offset: Value to offset the signal value by
- Scale: Value to multiply the signal value by

To extract a CAN signal, you 'carve out' the relevant bits, take the decimal value and perform a linear scaling: physical_value = offset + scale * raw_value_decimal

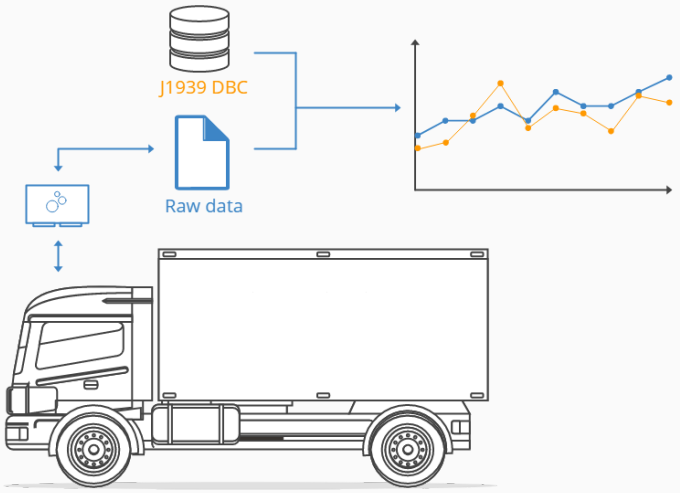
## The challenge of proprietary CAN data

Most often, the CAN bus "decoding rules" are proprietary and not easily available (except to the OEM, i.e. Original Equipment Manufacturer). There are a number of solutions to this when you're not the OEM:

- **Record J1939 data**: If you're logging raw data from heavy duty vehicles (trucks, tractors, ...), you're typically recording J1939 data. This is standardized across brands - and you can use our J1939 DBC file to decode data. See also our J1939 data logger intro
- **Record OBD2/UDS data**: If you need to log data from cars, you can typically request OBD2/UDS data, which is a standardized protocol across cars. For details see our OBD2 data logger intro and our free OBD2 DBC file
- **Use public DBC files**: For cars, online databases exist where others have reverse engineered proprietary some of the CAN data. We keep a list of such databases in our DBC file intro
- **Reverse engineer data**: You can also attempt to reverse engineer data yourself by using a CAN bus sniffer, though it can be time consuming and difficult
- **Use sensor modules**: In some cases you may need sensor data that is not available on the CAN bus (or which is difficult to reverse engineer). Here, sensor-to-CAN modules like the CANmod series can be used. You can integrate such modules with your CAN bus, or use them as add-ons for your CAN logger to add data such as GNSS/IMU or temperature data
- **Partner with the OEM**: In some cases the OEM will provide decoding rules as part of the CAN bus system technical specs. In other cases you may be able to get the information through e.g. a partnership

### CAN database files (DBC) - J1939 example

In some cases, conversion rules are standard across manufacturers - e.g. in the J1939 protocol for heavy-duty.
This means that you can use the J1939 parameter conversion rules on practically any heavy-duty vehicle to convert a large share of your data. To make this practical, you need a format for storing the conversion rules. Here, the CAN database (DBC) format is the industry standard - and is supported by most CAN bus decoder software incl. the supporting tools for our CAN loggers, asammdf and CANvas. We also offer a low cost J1939 DBC file, which you can purchase as a digital download. With this, you can get quickly from raw J1939 data to human-readable form. Learn more!




### Example: Decoded CAN sample data (physical values)

To illustrate how you can extract CAN signals from raw CAN data frames, we include below the previous J1939 sample data - but now decoded via a J1939 DBC file using the asammdf GUI tool.
As evident, the result is timeseries data with parameters like oil temperature, engine speed, GPS, fuel rate and speed:

```
timestamps,ActualEnginePercentTorque,EngineSpeed,EngineCoolantTemperature,EngineOilTemperature1,EngineFu
elRate,EngineTotalIdleHours,FuelLevel1,Latitude,Longitude,WheelBasedVehicleSpeed
2020-01-13 16:00:13.259449959+01:00,0,1520.13,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.268850088+01:00,0,1522.88,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.270649910+01:00,0,1523.34,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.271549940+01:00,0,1523.58,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.278949976+01:00,0,1525.5,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
…
```

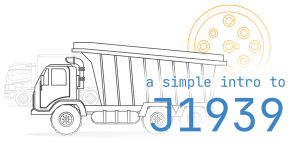
For more on logging J1939 data, see our J1939 data logger and mining telematics articles. You can also learn how to analyze/visualize your CAN data via the free asammdf GUI tool or telematics dashboards.

# What is the link between CAN, J1939, OBD2, CANopen …?

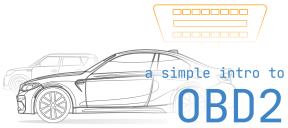
**The Controller Area Network provides the basis for communication - but not a lot more.**

For example, the CAN standard does not specify how to handle messages larger than 8 bytes - or how to decode the raw data. Therefore a set of **standardized protocols** exist to further specify how data is communicated between CAN nodes of a given network.

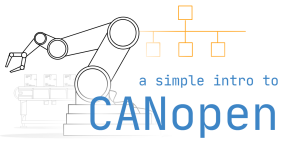
Some of the most common standards include SAE J1939, OBD2 and CANopen. Further, these higher-layer protocols will increasingly be based on the 'next generation' of CAN, CAN FD (e.g. CANopen FD and J1939-17/22).




**SAE J1939**
J1939 is the standard in-vehicle network for heavy-duty vehicles (e.g. trucks & buses). J1939 parameters (e.g. RPM, speed, ...) are identified by a suspect parameter number (SPN), which are grouped in parameter groups identified by a PG number (PGN).
j1939 intro
j1939 telematics

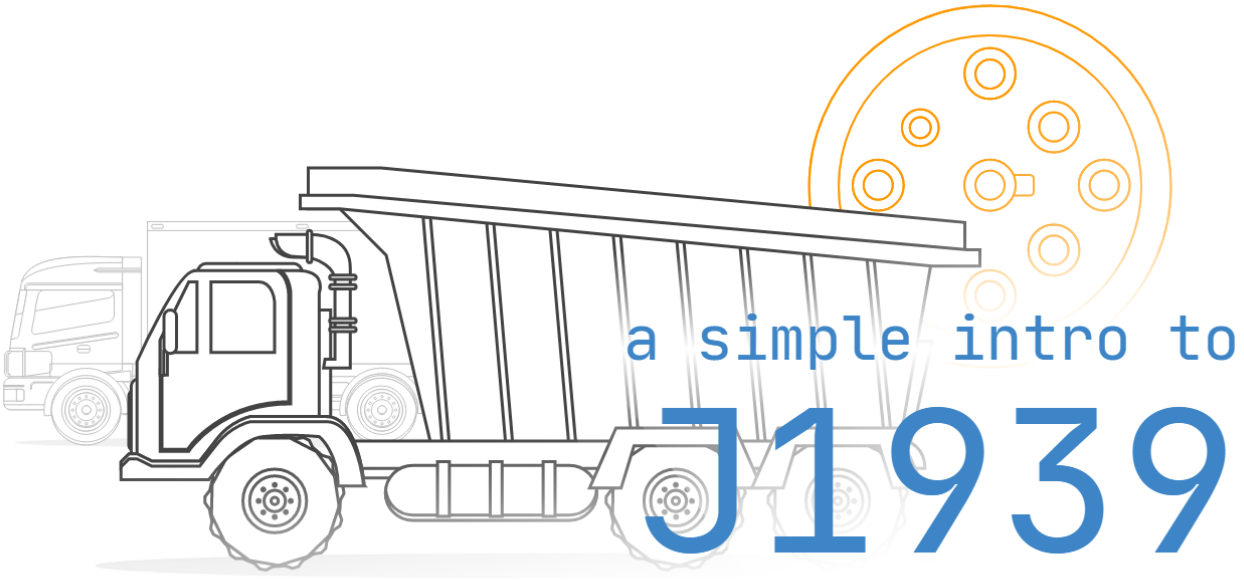



**OBD2**
On-board diagnostics (OBD, ISO 15765) is a self-diagnostic and reporting capability that e.g. mechanics use to identify car issues. OBD2 specifies diagnostic trouble codes (DTCs) and real-time data (e.g. speed, RPM), which can be recorded via OBD2 loggers.
obd2 intro
obd2 logging




**CANopen**
CANopen is used widely in embedded control applications, incl. e.g. industrial automation. It is based on CAN, meaning that a CAN bus data logger is also able to log CANopen data. This is key in e.g. machine diagnostics or optimizing production.
canopen intro
canopen logger


**CAN FD**
CAN bus with flexible data-rate (CAN FD) is an extension of the Classical CAN data link layer. It increases the payload from 8 to 64 bytes and allows for a higher data bit rate, dependent on the CAN transceiver. This enables increasingly data-intensive use cases like EVs.
can fd intro
can fd logger




# J1939 Explained - A Simple Intro

In this guide we introduce the J1939 protocol basics incl. PGNs and SPNs. This is a practical intro so you will also learn how to decode J1939 data via DBC files, how J1939 logging works, key use cases and practical tips.

## What is J1939?

In short, SAE J1939 is a set of standards that define how ECUs communicate via the CAN bus in heavy-duty vehicles.
As explained in our CAN bus intro, most vehicles today use the Controller Area Network (CAN) for ECU communication.
However, CAN bus only provides a "basis" for communication (like a telephone) - not a "language" for conversation.

In most heavy-duty vehicles, this language is the SAE J1939 standard defined by the Society of Automotive Engineers (SAE). In more technical terms, J1939 provides a higher layer protocol (HLP) based on CAN as the "physical layer".
What does that mean, though?

### One standard across heavy-duty vehicles

In simple terms, J1939 offers a standardized method for communication across ECUs, or in other words:
J1939 provides a common language across manufacturers.
In contrast, e.g. cars use proprietary OEM specific protocols.

#### J1939 application examples

Heavy-duty vehicles (e.g. trucks and buses) is one of the most well-known applications. However, several other key industries leverage SAE J1939 today either directly or via derived standards (e.g. ISO 11783, MilCAN, NMEA 2000, FMS):

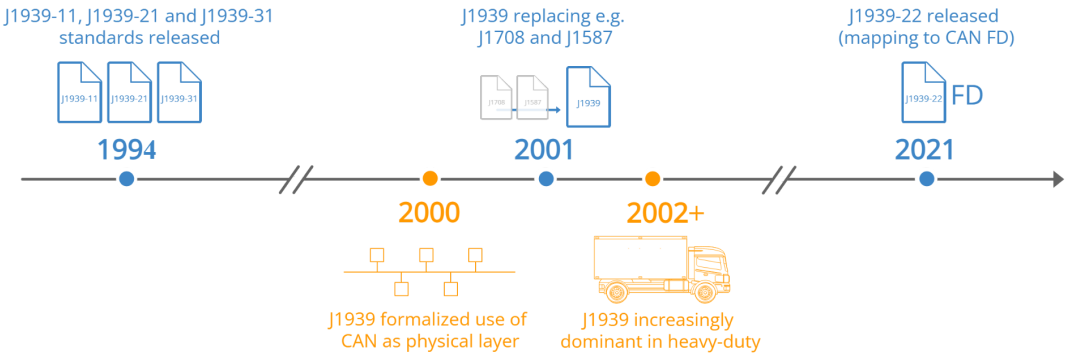
- Foresting machines (e.g. delimbers, forwarders, skidders)
- Mining vehicles (e.g. bulldozers, draglines, excavators, ...)
- Military vehicles (e.g. tanks, transport vehicles, ...)
- Agriculture (e.g. tractors, harvesters, ...)

- Construction (e.g. mobile hydraulics, cranes, ...)
- Fire & Rescue (e.g. ambulances, fire trucks, ...)
- Other (e.g. ships, pumping, e-buses, power generation, ...)

# J1939 history & future

## History

- 1994: First docs were released (J1939-11, J1939-21, J1939-31)
- 2000: The initial top level document was published
- 2000: CAN formally included as part of J1939 standard
- 2001: J1939 starts replacing former standards SAE J1708/J1587



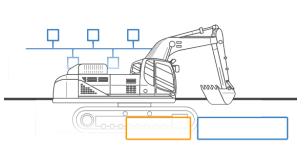

## Future

With the rise of heavy-duty telematics, J1939 will increasingly play a role in the market for connected vehicles. In turn, this will increase the need for secure J1939 IoT loggers. In parallel, OEMs will increasingly shift from Classical CAN to CAN FD as part of the transition to J1939 with flexible data-rate. In turn, this will increase the need for J1939 FD data loggers.

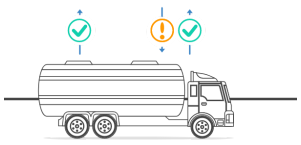
***"The market for in-vehicle connectivity - the hardware and services bringing all kinds of new functionality to drivers and fleet owners - is expected to reach EUR 120 billion by 2020."***
- Boston Consulting Group, Connected Vehicles and the Road to Revenue

# 4 key characteristics of J1939

The J1939 protocol has a set of defining characteristics outlined below:

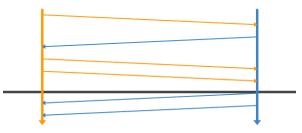


**250K baud rate & 29-bit extended ID**
The J1939 baud rate is typically 250K (though recently with support for 500K) - and the identifier is extended 29-bit (CAN 2.0B)



**Broadcast + on-request data**
Most J1939 messages are broadcast on the CAN-bus, though some data is only available by requesting the data via the CAN bus

**PGN identifiers & SPN parameters**
J1939 messages are identified by 18-bit Parameter Group Numbers (PGN), while J1939 signals are called Suspect Parameter Numbers (SPN)



**Multibyte variables & Multi-packets**
Multibyte variables are sent least significant byte first (Intel byte order). PGNs with up to 1785 bytes are supported via J1939 transport protocol

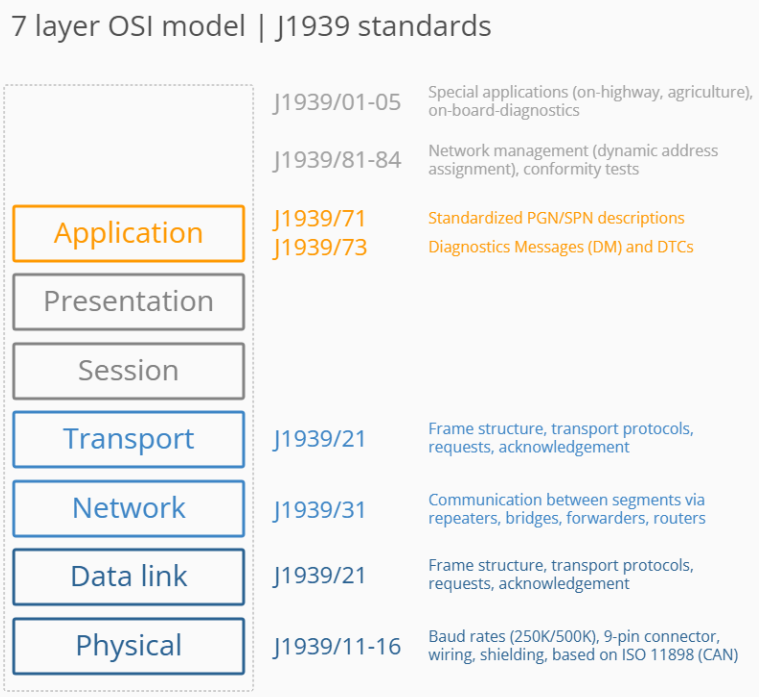
## Additional J1939 characteristics

Below are a set of additional characteristics of the J1939 protocol:

- Reserved: J1939 includes a large range of standard PGNs, though PGNs 00FF00 through 00FFFF are reserved for proprietary use
- Special Values: A data byte of 0xFF (255) reflects N/A data, while 0xFE (254) reflects an error
- J1939 address claim: The SAE J1939 standard defines a procedure for assigning source addresses to J1939 ECUs after network initialization via an 8-bit address in a dynamic way

## Technical: J1939 'higher layer protocol' explained

J1939 is based on CAN, which provides the basic "physical layer" and "data link layer", the lowest layers in the OSI model. Basically, CAN allows the communication of small packets on the CAN bus, but not a lot more than that. Here, J1939 serves as a higher layer protocol on top, enabling more complex communication.



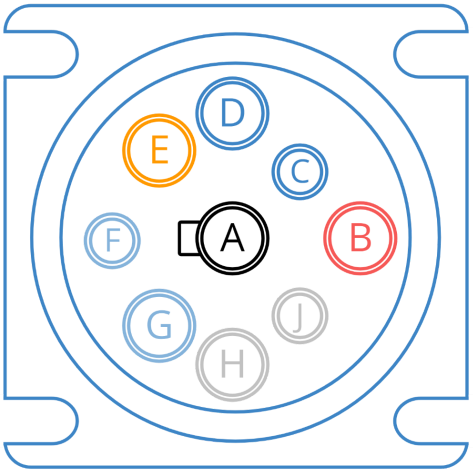

A higher layer protocol enables communication across the large complex networks of e.g. vehicle manufacturers.

For example, the SAE J1939 protocol specifies how to handle "multi-packet messages", i.e. when data larger than 8 bytes needs to be transferred. Similarly, it specifies how data is to be converted into human-readable data.
It does so by providing a family of standards. For example, J1939-71 is a document detailing the information required to convert a large set of cross-manufacturer standardized J1939 messages into human-readable data (more on this below). Many other CAN based higher layer protocols exist, e.g. CANopen, DeviceNet, Unified Diagnostic Services. These typically offer some level of standardization within their respective industries - though all of them can be extended by manufacturers.

In comparison, the aforementioned passenger cars have unique standards per manufacturer. In other words, you can use the same J1939 database file to convert e.g. engine speed across two trucks from different manufacturers - but you cannot e.g. read the data from an Audi A4 using the same IDs & scaling parameters as for a Peugeot 207.

# The J1939 connector (9-pin)

The J1939-13 standard specifies the 'off-board diagnostic connector' - also known as the J1939 connector or 9-pin deutsch connector. This is a standardized method for interfacing with the J1939 network of most heavy duty vehicles - see the illustration for the J1939 connector pinout.




| | |
|---|---|
| A | Ground |
| B | Battery power |
| C | CAN 1 H |
| D | CAN 1 L |
| E | CAN shield |
| F | J1708 (+) / CAN 2 H |
| G | J1708 (-) / CAN 2 L |
| H | OEM specific |
| J | OEM specific |

Type 1 (black): CAN 1 = 250K
Type 2 (green): CAN 1 = 500K

## Black type 1 vs green type 2

Note that the J1939 deutsch connector comes in two variants: The original black connector (type 1) and the newer green connector (type 2), which started getting rolled out around 2013-14.


J1939 type 2 female connectors are physically backwards compatible, while type 1 female connectors only fit type 1 male sockets. The type 2 connector was designed for the SAE J1939-14 standard, which adds support for 500K bit rates. The purpose of "blocking" type 1 connectors is to ensure that older hardware (presumably using 250K bit rates) is not connected to type 2 500K bit rate J1939 networks. Specifically, the physical block is through a smaller hole for pin F in the type 2 male connectors. See also the example of a DB9-J1939 adapter cable (type 2).

### Multiple J1939 networks

As evident, the J1939 deutsch connector provides access to the J1939 network through pins C (CAN high) and D (CAN low). This makes it easy to interface with the J1939 network across most heavy duty vehicles.

In some cases, however, you may also be able to access a secondary J1939 network through pins F and G or pins H and J (with H being CAN H and J being CAN L).

Many of today's heavy duty vehicles have 2 or more parallel CAN bus networks and in some cases at least two of these will be available through the same J1939 connector. This also means that you will not necessarily have gained access to all the available J1939 data if you've only attempted to interface through the 'standard' pins C and D.

### Other heavy duty connectors

While the J1939 deutsch connector is the most common way to interface with the J1939 network of heavy duty vehicles, other connectors of course exist. Below are some examples:

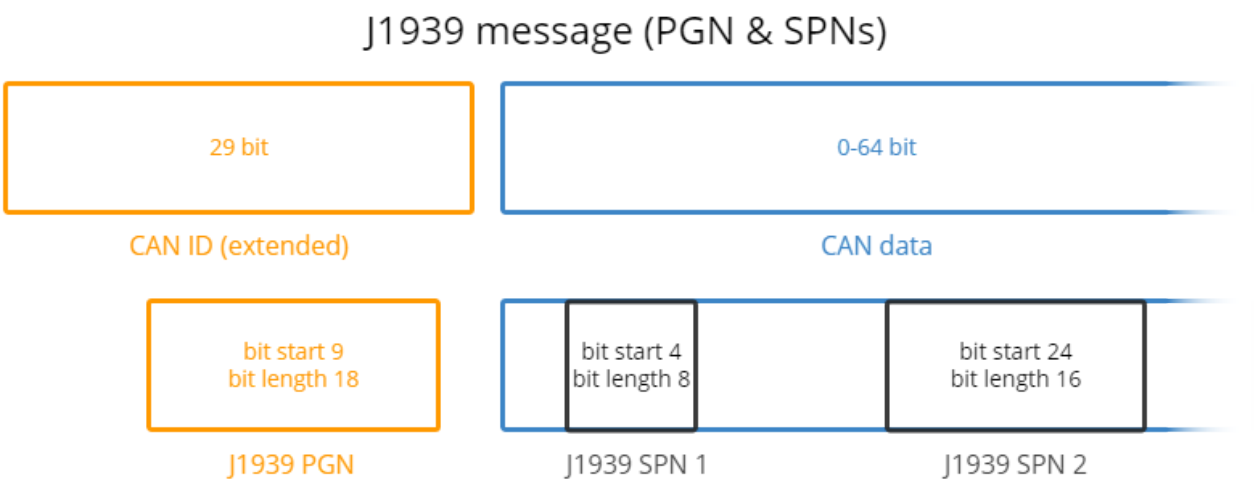
- J1939 Backbone Connector: This 3-pin deutsch connector provides pins for CAN H/L a CAN shield (no power/ground)
- CAT connector: The Caterpillar industrial connector is a grey 9-pin deutsch connector. However, the pin-out differs from the J1939 connector (A: Power, B: Ground, F: CAN L, G: CAN H) and the connector physically blocks access from standard type 1 and 2 J1939 connectors
- OBD2 type B connector: The type B OBD2 connector (SAE J1962) in heavy duty vehicles sometimes provide direct access to the J1939 network through pins 6 and 14
- Volvo 2013 OBD2 connector: This variant matches the type B OBD2 connector, but also adds access to the J1939 high via pin 3 and J1939 low via pin 11

# The J1939 PGN and SPN

In the following section we explain the J1939 PGNs and SPNs.

### Parameter Group Number (PGN)

The J1939 PGN comprises an 18-bit subset of the 29-bit extended CAN ID. In simple terms, the PGN serves as a unique frame identifier within the J1939 standard. For example, you can look this up in the J1939-71 standard documentation, which lists PGNs/SPNs.




## Example: J1939 PGN 61444 (EEC1)

Assume you recorded a J1939 message with HEX ID 0CF00401. Here, the PGN starts at bit 9, with length 18 (indexed from 1). The resulting PGN is 0F004 or in decimal 61444. Looking this up in the SAE J1939-71 documentation, you will find that it is the "Electronic Engine Controller 1 - EEC1". Further, the document will have details on the PGN including priority, transmission rate and a list of the associated SPNs - cf. the illustration. For this PGN, there are seven SPNs (e.g. Engine Speed, RPM), each of which can be looked up in the J1939-71 documentation for further details.

### PGN61444 - Electronic Engine Controller 1 - EEC1

Transmission Repetition Rate: Engine speed dependent
Data Length: 8 bytes
Data Page: 0
PDU Format: 240
PDU Specific: 4
Default Priority: 3
Parameter Group Number: 61444 (0x00F004)

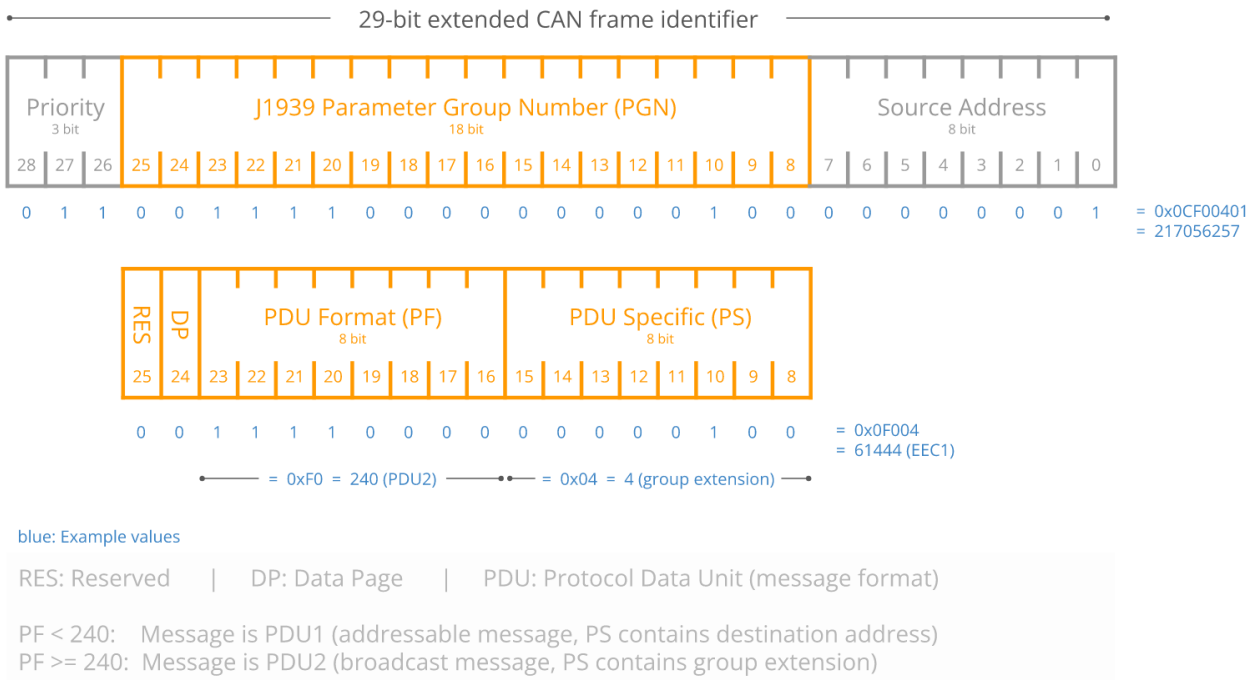
| Bit Start/Byte | Length | SPN ID | SPN Description |
|---|---|---|---|
| 1.1 | 4 bits | 899 | Engine Torque Mode |
| 2 | 1 byte | 512 | Driver's Demand Engine - % Torque |
| 3 | 1 byte | 513 | Actual Engine - Percent Torque |
| 4-5 | 2 bytes | 190 | Engine Speed |
| 6 | 1 byte | 1483 | SA of Controlling Device for Engine Control |
| 7.1 | 4 bits | 1675 | Engine Starter Mode |
| 8 | 1 byte | 2432 | Engine Demand - Percent Torque |

## Detailed breakdown of the J1939 PGN

Let's look at the CAN ID to PGN transition in detail. Specifically, the 29 bit CAN ID comprises the Priority (3 bits), the J1939 PGN (18 bits) and the Source Address (8 bits). In turn, the PGN can be split into the Reserved Bit (1 bit), Data Page (1 bit), PDU format (8 bit) and PDU Specific (8 bit).

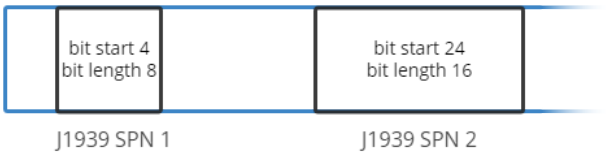
The detailed PGN illustration also includes example values for each field in binary, decimal and hexadecimal form.

To learn more about the transition from 29 bit CAN ID to 18 bit J1939 PGN, see also our online CAN ID to J1939 PGN converter. The converter also includes a full J1939 PGN list for PGNs included in our J1939 DBC file.




## Suspect Parameter Number (SPN)

The J1939 SPN serves as the identifier for the CAN signals (parameters) contained in the databytes. SPNs are grouped by PGNs and can be described in terms of their bit start position, bit length, scale, offset and unit - information required to extract and scale the SPN data to physical values.




### Example: Extracting J1939 SPN 190 (Engine Speed)

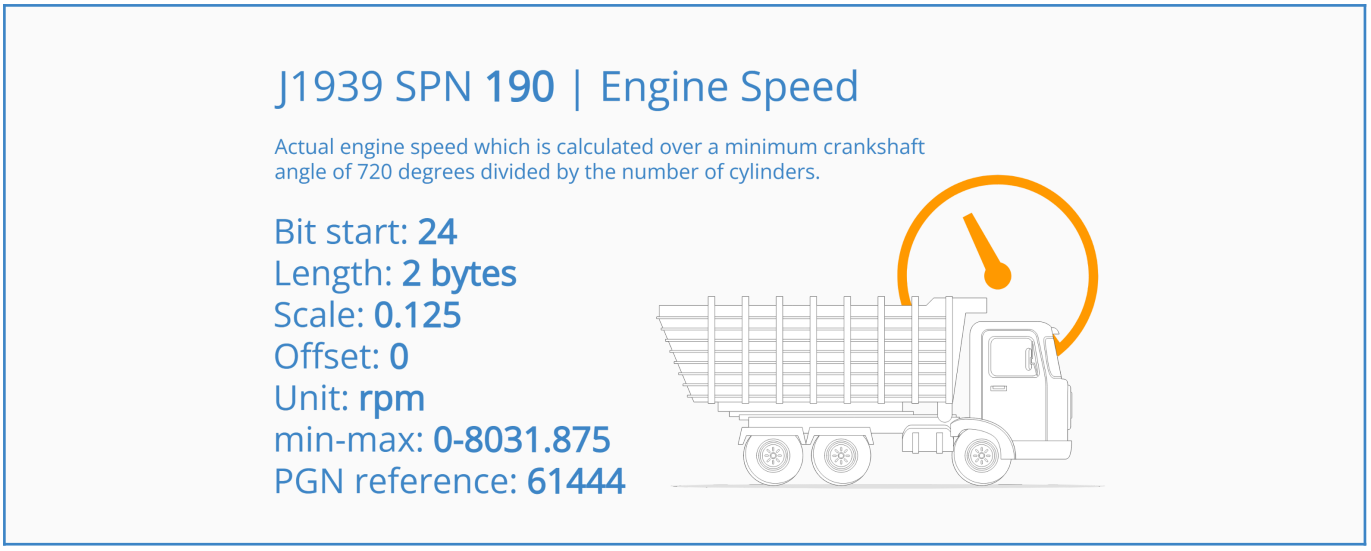
Assume you have recorded a raw J1939 frame as below:

| CAN ID | Data bytes |
|---|---|
| 0CF00401 | FF FF FF 68 13 FF FF FF |

By converting the CAN ID to the J1939 PGN you identify that this is the PGN 61444 from before. From the J1939-71 document, you observe that one of the SPNs within this PGN is Engine Speed (SPN 190) with details as in the illustration below.

Using these details, it is possible to extract the Engine Speed physical value data e.g. for plot purposes. To do so, note from the SPN info that the relevant data is in bytes 4 and 5, i.e. the HEX data bytes 68 and 13. Taking the decimal form of the HEX value 1368 (Intel byte order), we get 4968 in decimal. To arrive at the RPM, we conduct a scaling of this value using the offset 0 and the scale 0.125 RPM/bit. The physical value (aka scaled engineering value) is 621 RPM.

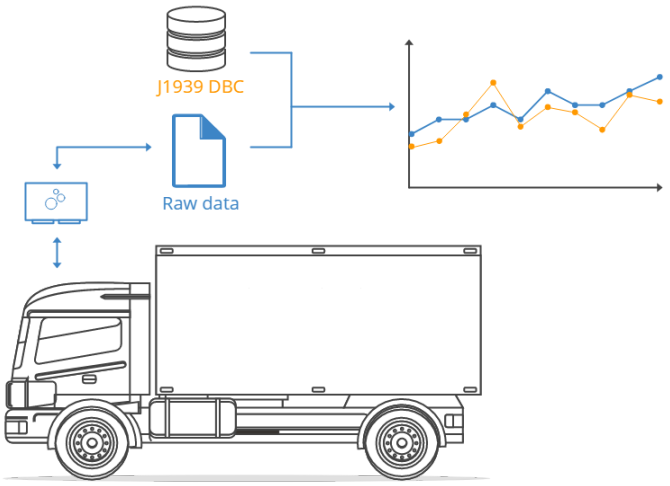
Note how some data bytes in the above are FF or 255 decimal, i.e. not available. While the PGN may theoretically support SPNs in this range, the FF padding means that this particular application does not support these parameters.




In practice, you will not 'PDF-lookup' rules for J1939 data - instead, this info is stored in a CAN database file (DBC).

### Example: J1939 DBC file

A J1939 DBC file can be used to decode data across most heavy-duty vehicles. For example, raw J1939 data can be recorded with a CAN bus data logger and analyzed in a CAN software tool that supports DBC conversion (e.g. asammdf). This will typically result in a conversion of 40-60% of the vehicle data - with the rest being OEM specific proprietary data that requires reverse engineering.




# J1939 truck sample data: Raw & physical values

Below we illustrate what real J1939 data looks like. The 'raw' J1939 data was recorded from a heavy duty truck using a CANedge2, while the 'physical values' reflect the output after decoding the raw data via the free asammdf software and the J1939 DBC.

### Sample: Raw J1939 truck data (CSV)

Data from the CANedge is recorded in a standardized binary format, MDF4, which can be converted to any file format via our MDF4 converters (e.g. to CSV, ASC, TRC, ...). Below is a CSV version of the raw J1939 frames. Notice that the CAN IDs and data bytes are in hexadecimal format:

```
TimestampEpoch;BusChannel;ID;IDE;DLC;DataLength;Dir;EDL;BRS;DataBytes
1578922367.777150;1;14FEF131;1;8;8;0;0;0;CFFFFFF300FFFF30
1578922367.777750;1;10F01A01;1;8;8;0;0;0;2448FFFFFFFFFFF
1578922367.778300;1;CF00400;1;8;8;0;0;0;107D82BD1200F482
1578922367.778900;1;14FF0121;1;8;8;0;0;0;FFFFFFFFFFFFFCFF
1578922367.779500;1;18F0000F;1;8;8;0;0;0;007DFFFF0F7DFFFF
1578922367.780050;1;18FFA03D;1;8;8;0;0;0;2228240019001AFF
1578922367.780600;1;10FCFD01;1;8;8;0;0;0;FFFFFFFF1623FFFF
1578922367.781200;1;18FD9401;1;8;8;0;0;0;A835FFFFA9168F03
1578922367.781750;1;18FDA101;1;8;8;0;0;0;1224FFFFFFFF00FF
1578922367.782350;1;18F00E3D;1;8;8;0;0;0;741DFFFFFFFFFFF
1578922367.782950;1;18F00F3D;1;8;8;0;0;0;B40FFFFFFFFFFFF
1578922367.783500;1;10FDA301;1;8;8;0;0;0;FFFFFFFFFFFFFFFF
...
```

You can optionally download full raw J1939 MDF4 samples from the CANedge2 in our intro docs. The sample data also includes a demo J1939 DBC so that you can replicate the conversion steps via asammdf.

### Sample: Decoded physical values J1939 truck data (CSV)

Once the raw J1939 data is decoded and exported, the result is timeseries data with parameters like oil temperature, engine speed, GPS, fuel rate and speed:

```
timestamps,ActualEnginePercentTorque,EngineSpeed,EngineCoolantTemperature,EngineOilTemperature1,EngineFu
elRate,EngineTotalIdleHours,FuelLevel1,Latitude,Longitude,WheelBasedVehicleSpeed
2020-01-13 16:00:13.259449959+01:00,0,1520.13,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.268850088+01:00,0,1522.88,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.270649910+01:00,0,1523.34,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.271549940+01:00,0,1523.58,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.278949976+01:00,0,1525.5,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.289050102+01:00,0,1527.88,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.299000025+01:00,0,1528.13,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.308300018+01:00,0,1526.86,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.309099913+01:00,0,1526.75,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.317199945+01:00,0,1526.45,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
...
```

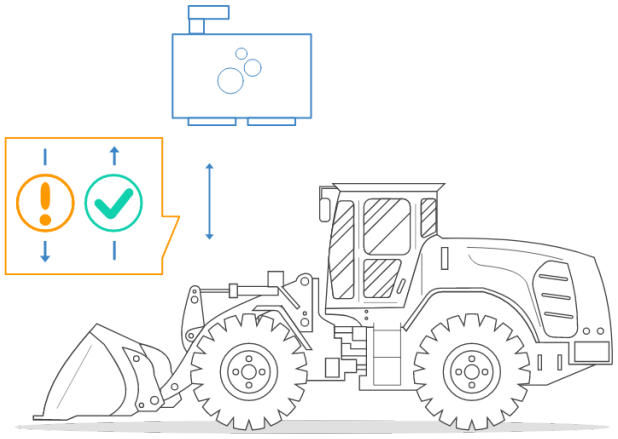
For more on logging J1939 data, see our J1939 data logger and mining telematics articles.

### About the CANedge J1939 logger

The CANedge lets you easily record J1939 data to an 8-32 GB SD card. Simply connect it to e.g. a truck to start logging - and decode the data via free software/APIs and our J1939 DBC. Learn more.

# J1939 request messages

Most J1939 messages are broadcast via the CAN bus, but some are only sent "on-request" (e.g. when polled by a J1939 data logger). On-request data often includes J1939 diagnostic trouble codes (DTCs), making it important in vehicle diagnostics. Below we briefly outline how it works:



### Sending J1939 request messages

To send a J1939 request via the CAN bus, a special 'request message' is used (PGN 59904), which is the only J1939 message with only 3 bytes of data. It has priority 6, a variable transmit rate and can either be sent as a global or specific address request. The data bytes 1-3 should contain the requested PGN (Intel byte order). Examples of requested J1939 messages include the diagnostic messages (e.g. J1939 DM2).

A CAN bus data logger like the CANedge can be set up to send J1939 request messages - see e.g. our CANedge Intro for a detailed step-by-step guide.

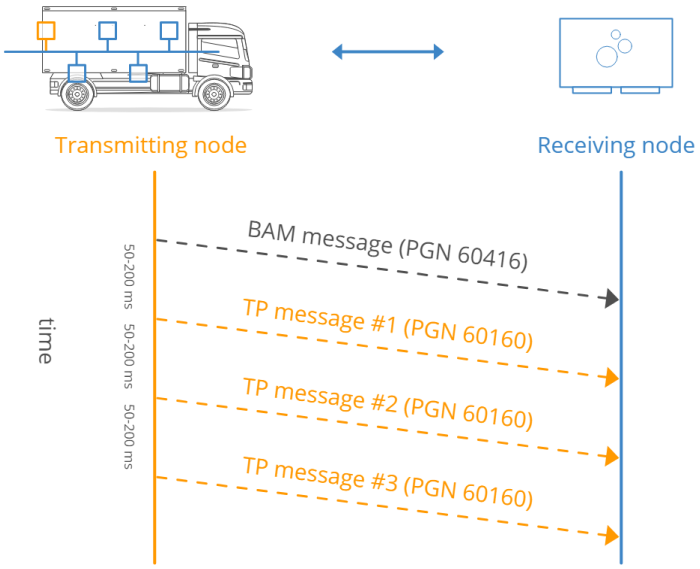
**J1939 code requests vs warranty compliance**
Sending request messages is typically key to requesting J1939 codes and thus J1939 diagnostics. One challenge, however, is that J1939 loggers are often required to have a contactless connection to the J1939 data link, meaning that they're unable to interact with the CAN bus and transmit J1939 request frames. The restriction is often related to warranty compliance as some vehicle manufacturers do not allow direct access by 3rd party devices via the J1939 connector.

In some cases, it is required that the J1939 analyzer is "physically" contactless, e.g. via a CANcrocodile adapter. In other cases, it is sufficient that the J1939 logger operates in "configurable" silent mode. The latter makes it easier to perform ad hoc requests for J1939 fault codes, either via a manual configuration update or via an over-the-air update for the CANedge2.

# J1939 transport protocol (TP)

The previous PGN and SPN examples are based on J1939 messages with 8 data bytes. While these are most common, J1939 multi-frame messages also exist with >8 data bytes - sent via the J1939 transport protocol.

Below we outline how the J1939 transport protocol works, a practical J1939 TP data example and how to decode multi-frame J1939 messages via DBC files:




### How does the J1939 transport protocol work?

The J1939 protocol specifies how to deconstruct, transfer and reassemble packets across multiple frames - a process referred to as the J1939 Transport Protocol (see J1939-21). Two types of the J1939 TP exist:

1. The Connection Mode (intended for a specific device)
2. The BAM (Broadcast Announce Message) which is intended for the entire network

For example, a transmitting ECU may send an initial BAM packet to set up a data transfer. The BAM specifies the PGN identifier for the multi-packet message as well as the number of data bytes and packets to be sent. It is then followed by up to 255 packets/frames of data. Each of the 255 packets use the first data byte to specify the sequence number (1 up to 255), followed by 7 bytes of data. The max number of bytes per multi-packet message is therefore 7 bytes x 255 = 1785 bytes.

The final packet contains at least one byte of data, followed by unused bytes set to FF. In the BAM type scenario, the time between messages is 50-200 ms. In post processing, a conversion software tool can reassemble the multiple entries of 7 data bytes into a single payload and handle it according to the multi-packet PGN and SPN specifications as found in e.g. a J1939 DBC file.

## A practical J1939 transport protocol example

Decoding J1939 multiframe data is more complex than decoding standard J1939 frames. To understand why, consider the below example of a J1939 transport protocol response, recorded with the CANedge2:

```
TimestampEpoch;BusChannel;ID;IDE;DLC;DataLength;Dir;EDL;BRS;DataBytes
1605078459.438750;1;1CECFF00;1;8;8;0;0;0;20270006FFE3FE00
1605078459.498750;1;1CEBFF00;1;8;8;0;0;0;013011B2A041B240
1605078459.559750;1;1CEBFF00;1;8;8;0;0;0;021FB2102CB2603B
1605078459.618750;1;1CEBFF00;1;8;8;0;0;0;03B230430000D309
1605078459.678750;1;1CEBFF00;1;8;8;0;0;0;04C0441E37967DE1
1605078459.738750;1;1CEBFF00;1;8;8;0;0;0;05E02E7B02FFFF80
1605078459.799850;1;1CEBFF00;1;8;8;0;0;0;06E0FFFFFFFFFFFF
```

The above sequence consists of two J1939 message types:

### **PGN 60416** - J1939 Transport Protocol BAM (Connection Management)

Data Length: 8 bytes
Default Priority: 7
Parameter Group Number: 60416 (0xEC00)

| Byte | Description |
|---|---|
| 1 | Fixed at 32 |
| 2-3 | Message size in bytes |
| 4 | Number of packets |
| 5 | Reserved (filled with FF) |
| 6-8 | PGN |

### **PGN 60160** - J1939 Transport Protocol (Data Transfer)

Data Length: 8 bytes
Default Priority: 7
Parameter Group Number: 60160 (0xEB00)

| Byte | Description |
|---|---|
| 1 | Sequence number (1 to 255) |
| 2-8 | Data payload (unused locations in the last frame are set to FF) |

A J1939 BAM message with ID 1CECFF00 (PGN 60416 or EC00), which contains the response data length and J1939 PGN - and a J1939 data transfer messages with ID 1CEBFF00 (PGN 60160 or EB00). These contain the payload across multiple frames.

Below we break down the J1939 transport protocol example with focus on the data byte interpretation:

| Timestamp (Epoch) | CAN ID | PGN (HEX) | PGN (DEC) | DataBytes |
|---|---|---|---|---|
| 1605078459.438750 | 1CECFF00 | EC00 | 60416 | 2027000 6FFE3FE00 |
| 1605078459.498750 | 1CEBFF00 | EB00 | 60160 | 013011B2A041B240 |
| 1605078459.559750 | 1CEBFF00 | EB00 | 60160 | 021FB2102CB2603B |
| 1605078459.618750 | 1CEBFF00 | EB00 | 60160 | 03B230430000D309 |
| 1605078459.678750 | 1CEBFF00 | EB00 | 60160 | 04C0441E37967DE1 |
| 1605078459.738750 | 1CEBFF00 | EB00 | 60160 | 05E02E7B02FFFF80 |
| 1605078459.799850 | 1CEBFF00 | EB00 | 60160 | 06E0FFFFFFFFFFFF |
| 1605078459.438750 | 18FEE3FE | FEE3 | 65251 | 3011B2A041B240 ... E0FFFFFF |

legend
control byte (0x20=BAM)
#data bytes (0x0027=39)
#packets (0x06=6)
reserved
J1939 PGN (0x00FEE3=65251)
sequence numbers
payload data (39 bytes)
unused (3 bytes)

Generally, a J1939 transport protocol response sequence can be processed as follows:

- Identify the BAM frame, indicating a new sequence being initiated (via the PGN 60416)
- Extract the J1939 PGN from bytes 6-8 of the BAM payload to use as the identifier of the new frame
- Construct the new data payload by concatenating bytes 2-8 of the data transfer frames (i.e. excl. the 1st byte)

Above, the last 3 bytes of the BAM equal E3FE00. When reordered, these equal the PGN FEE3 aka Engine Configuration 1 (EC1). Further, the payload is found by combining the the first 39 bytes across the 6 data transfer packets/frames.
Note: The last 3 data payload bytes in this practical example happen to be FF, yet we still include these in the payload as the BAM message specifies the data length to be 39. The final 3 FF bytes in the 6th packet are unused.

## How to decode a J1939 transport protocol message

With the method explained above, we have created a 'constructed' J1939 data frame with a data length exceeding 8 bytes. This frame can be decoded using a J1939 DBC file, just like a regular J1939 data frame. For the PGN EC1, the J1939 DBC specifies a data length of 40 with signals defined for the full payload.

As such, once the J1939 software/API has reconstructed the multiframe response into a single J1939 frame, the DBC decoding can be done as usual. One minor tweak is that most J1939 DBC files expects that the raw log file of J1939 data will contain 29-bit CAN IDs (not 18-bit J1939 PGNs). As such, if the software embeds the reconstructed J1939 TP frame in the original raw data, it may need to convert the extracted J1939 PGN into a 29-bit CAN ID first. You can also see our J1939 google sheet, which breaks down how a J1939 PGN can be converted to a 29-bit CAN ID.

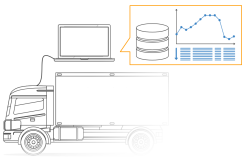
**J1939 TP data & Python API decoding**
The CANedge lets you request and record J1939 transport protocol data. To decode the TP data, you can either convert the raw log files to another format (like Vector ASC), or you can use our Python API. In our api-examples library on github, we provide a basic example of how J1939 transport protocol data can be reconstructed and DBC decoded, incl.

sample data. Since the CANedge Python API enables decoding of J1939 transport protocol data, J1939 signals from multiframe messages can e.g. be visualized in J1939 telematics dashboards.

# Logging J1939 data - example use cases

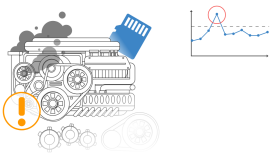
There are several common use cases for recording J1939 data:

**Heavy duty fleet telematics**
J1939 data from trucks, buses, tractors etc. can be used in fleet management to reduce costs or improve safety
learn more



**Live stream diagnostics**
By streaming decoded J1939 data to a PC, technicians can perform real-time J1939 diagnostics on vehicles
learn more

**Predictive maintenance**
Vehicles can be monitored via WiFi CAN loggers in the cloud to predict breakdowns based on the J1939 data
learn more



**Heavy-duty vehicle blackbox**
A CAN logger can serve as a 'blackbox' for heavy-duty vehicles, providing data for e.g. disputes or J1939 diagnostics
learn more

# 6 practical tips for J1939 data logging

Many of our end users work with J1939 logging in the field - and below we share 6 practical logging tips:

### J1939 logger vs J1939 streaming interface

Standalone J1939 data loggers with SD cards are ideal for logging data from e.g. vehicle fleets over weeks or months. A WiFi J1939 logger also enables telematics use cases. In contrast, a J1939 USB-PC interface requires a PC to stream data from the CAN bus in real-time. This is e.g. useful for diagnostic purposes - or analysing physical events. The CLX000 enables both modes of operation, while the CANedge2 is perfect for telematics.

### Direct adapter cable vs contactless reading

To connect your CAN analyzer to a J1939 asset (e.g. a truck) you can typically use the 9-pin J1939 connector. We offer a DB9-J1939 adapter which fits the 9-pin deutsch connector found in many heavy duty vehicles. Alternatively, you may prefer to connect your CAN logger directly to the CAN bus via e.g. a CANCrocodile. This method uses induction to record data silently without cutting any CAN wiring.

### WiFi vs. cellular (3G/4G) data upload

For vehicle fleet management & telematics you will typically upload the data via either WiFi or 3G/4G. The CANedge2 lets you transfer data by connecting to a WiFi access point - which can both be a WLAN router or a 3G/4G hotspot. If you need data from a truck on-the-road, you can install the CANedge2 and use it to power a 3G/4G USB hotspot. The benefit to this is that you'll have continuous access to the device - unless it is out-of-coverage. However, in cases where

data only needs to be periodically uploaded an alternative can be to upload data via WLAN routers when the vehicles visit e.g. specific areas (garages, repair shops etc) - letting you reduce data transfer costs.

### Software selection & J1939 DBC file

When logging or streaming J1939 data, software for post processing is key. In particular, the software should support DBC-based J1939 conversion to allow easy conversion to human-readable data. The free supporting softwares/APIs for our CAN loggers support this. For USB streaming, our free Wireshark plugin enables live DBC conversion. Further, we offer a digital download J1939 DBC file in collaboration with SAE.

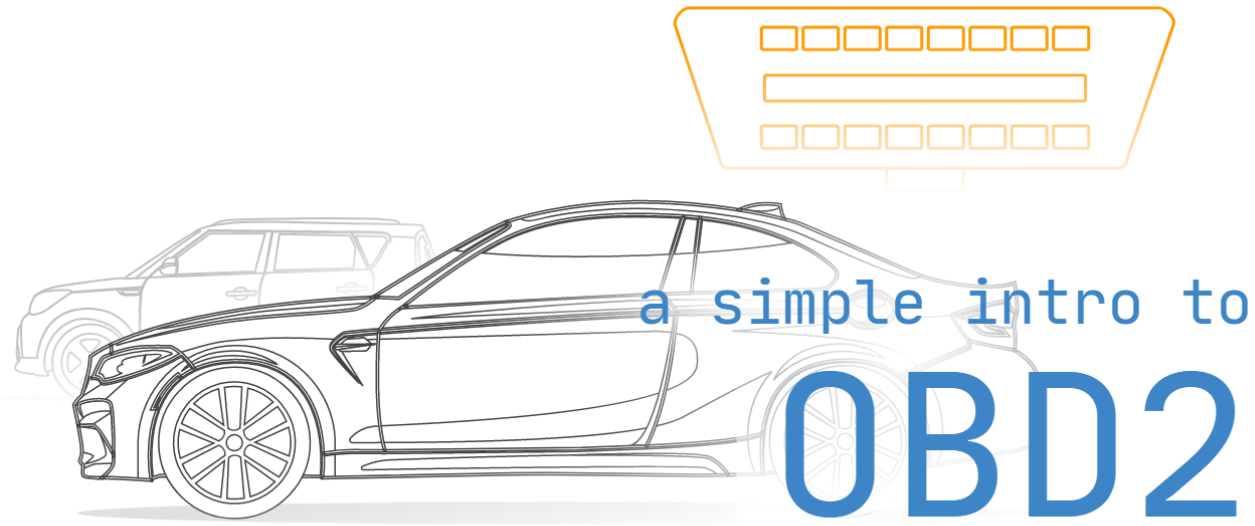
### Consider the need for request PGNs

Some J1939 PGNs are only available on-request, meaning that you need to "poll" the CAN bus to log these. The CANedge and CLX000 are able to transmit custom CAN messages, which can be used to send periodic PGN requests. Note that this is not possible in "silent mode" (i.e. it is not possible if the logger is connected via e.g. a CANCrocodile).

### Filter, compress and encrypt the data

To optimize your J1939 data logging, a number of advanced configurations can be helpful. In particular, the CANedge advanced filters and sampling rate options help optimize the amount of data logged - key for e.g. minimizing cellular bandwidth usage. Other options include silent mode and cyclical logging, with the latter enabling the logger to always prioritize the latest data (useful in e.g. blackbox logging).

Since J1939 is standardized, it is critical to encrypt your data 'at rest' (e.g. on an SD card) and 'in transit' (during upload). Not doing so exposes your data processing to various security risks, incl. GDPR/CCPA fines and loss of confidentiality and data integrity. For details on securing your J1939 data logging, see our intro to secure CAN logging.

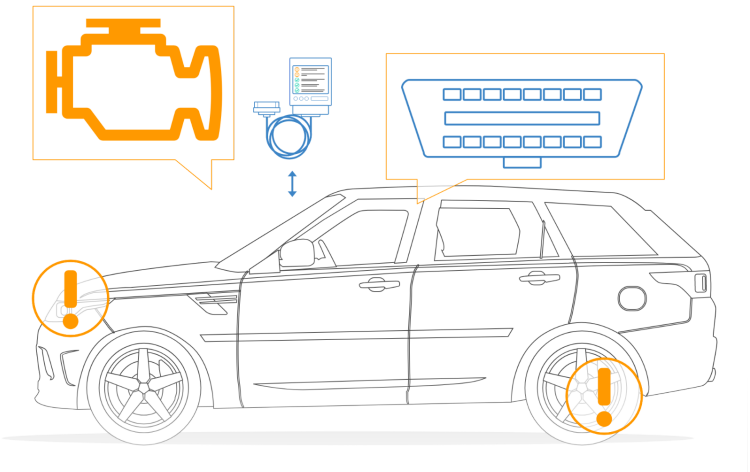



# OBD2 Explained - A Simple Intro

In this guide we introduce the On Board Diagnostic (OBD2) protocol incl. the OBD2 connector, OBD2 parameter IDs (PID) and the link to CAN bus. This is a practical intro so you will also learn how to request and decode OBD2 data, key logging use cases and practical tips.

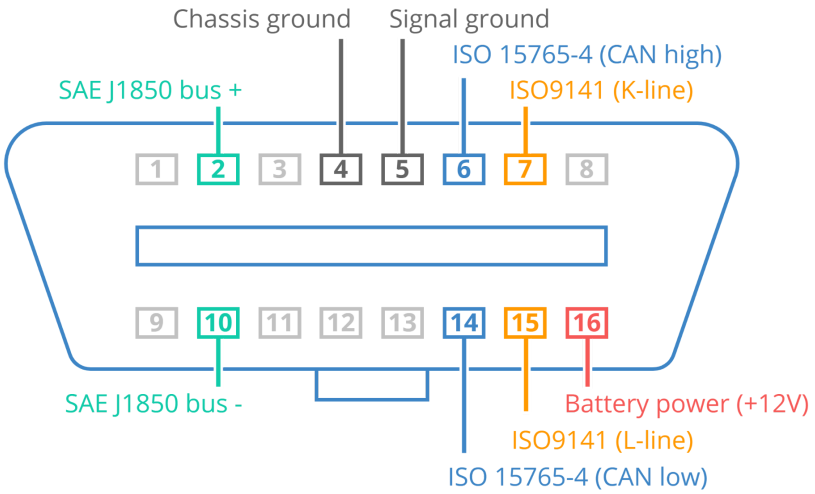
## What is OBD2?

In short, OBD2 is your vehicle's built-in self-diagnostic system. You've probably encountered OBD2 already: Ever noticed the malfunction indicator light on your dashboard? That is your car telling you there is an issue. If you visit a mechanic, he will use an OBD2 scanner to diagnose the issue. To do so, he will connect the OBD2 reader to the OBD2 16 pin connector near the steering wheel. This lets him read OBD2 codes aka Diagnostic Trouble Codes (DTCs) to review and troubleshoot the issue.



# The OBD2 connector

The OBD2 connector lets you access data from your car easily. The standard SAE J1962 specifies two female OBD2 16-pin connector types (A & B). In the illustration is an example of a Type A OBD2 pin connector (also sometimes referred to as the Data Link Connector, DLC).

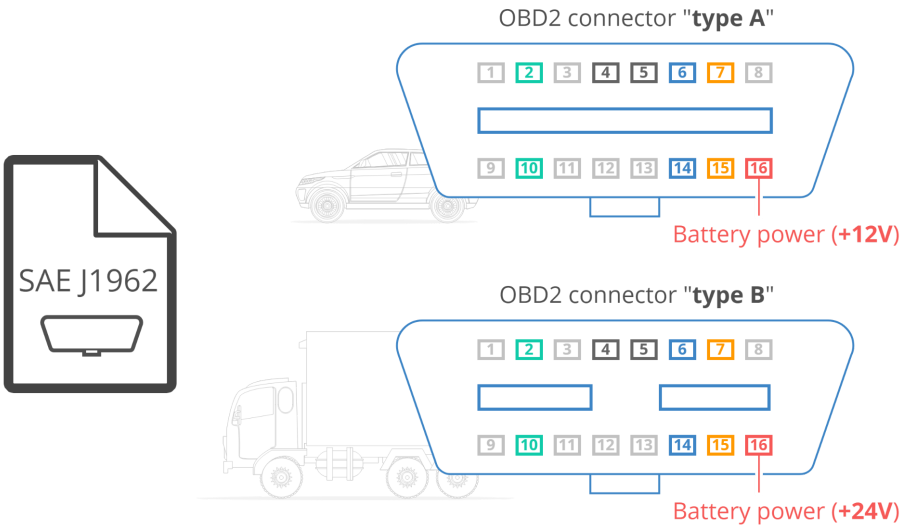



A few things to note:

- The OBD2 connector is near your steering wheel, but may be hidden behind covers/panels
- Pin 16 supplies battery power (often while the ignition is off)
- The OBD2 pinout depends on the communication protocol
- The most common protocol is CAN (via ISO 15765), meaning that pins 6 (CAN-H) and 14 (CAN-L) will typically be connected

## OBD2 connector - type A vs. B

In practice, you may encounter both the type A and type B OBD2 connector. Typically, type A will be found in cars, while type B is common in medium and heavy duty vehicles.



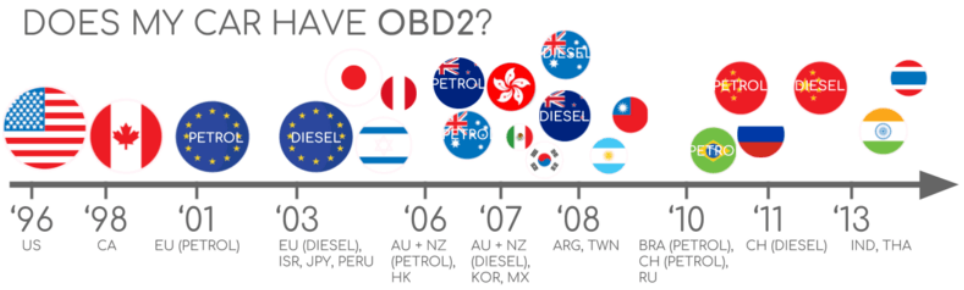
### Type A & B connector differences

As evident from the illustration, the two types share similar OBD2 pinouts, but provide two different power supply outputs (12V for type A and 24V for type B). Often the baud rate will differ as well, with cars typically using 500K, while most heavy duty vehicles use 250K (more recently with support for 500K).

To help physically distinguish between the two types of OBD2 sockets, note that the type B OBD2 connector has an interrupted groove in the middle. As a result, a type B OBD2 adapter cable will be compatible with both types A and B, while a type A will not fit into a type B socket.

# Does my car have OBD2?

In short: Probably! Almost all newer cars support OBD2 and most run on CAN (ISO 15765). For older cars, be aware that even if a 16 pin OBD2 connector is present, it may still not support OBD2. One way to determine compliance is to identify where & when it was bought new:



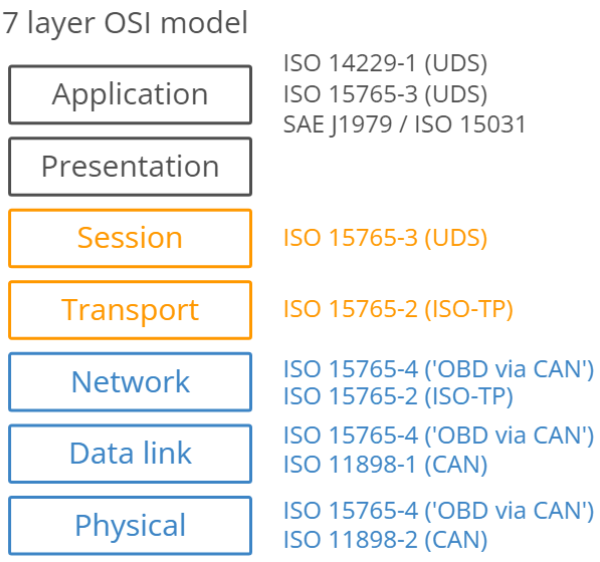

# Link between OBD2 and CAN bus

On board diagnostics, OBD2, is a 'higher layer protocol' (like a language). CAN is a method for communication (like a phone). In particular, the OBD2 standard specifies the OBD2 connector, incl. a set of five protocols that it can run on (see below). Further, since 2008, CAN bus (ISO 15765) has been the mandatory protocol for OBD2 in all cars sold in the US.

### What is the ISO 15765 standard?

ISO 15765 refers to a set of restrictions applied to the CAN standard (which is itself defined in ISO 11898). One might say that ISO 15765 is like "CAN for cars". In particular, ISO 15765-4 describes the physical, data link layer and network layers, seeking to standardize the CAN bus interface for external test equipment.

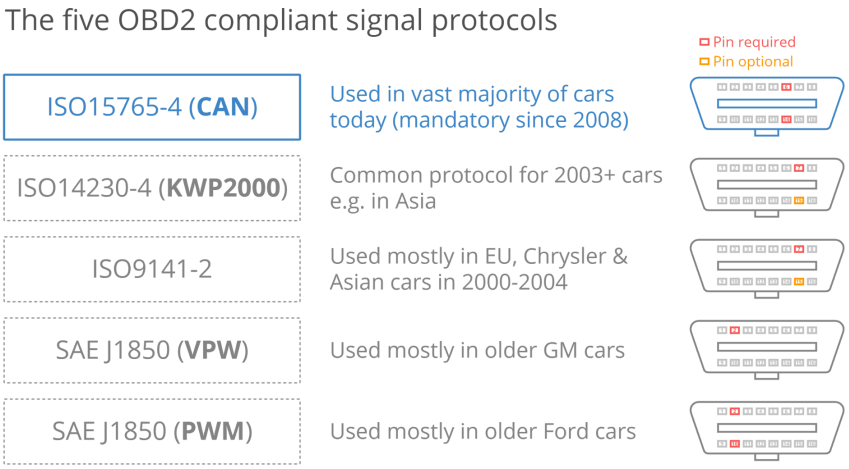
ISO 15765-2 in turn describes the transport layer (ISO TP) for sending CAN frames with payloads that exceed 8 bytes. This sub standard is also sometimes referred to as Diagnostic Communication over CAN (or DoCAN). See also the 7 layer OSI model illustration. OBD2 can also be compared to other higher layer protocols (e.g. J1939, CANopen).



### The five OBD2 protocols

As explained above, CAN bus today serves as the basis for OBD2 communication in the vast majority of cars through ISO 15765. However, if you're inspecting an older car (pre 2008), it is useful to know the other four protocols that have been used as basis for OBD2. Note also the pinouts, which can be used to determine which protocol may be used in your car.

- ISO 15765 (CAN bus): Mandatory in US cars since 2008 and is today used in the vast majority of cars
- ISO14230-4 (KWP2000): The Keyword Protocol 2000 was a common protocol for 2003+ cars in e.g. Asia
- ISO9141-2: Used in EU, Chrysler & Asian cars in 2000-04
- SAE J1850 (VPW): Used mostly in older GM cars
- SAE J1850 (PWM): Used mostly in older Ford cars

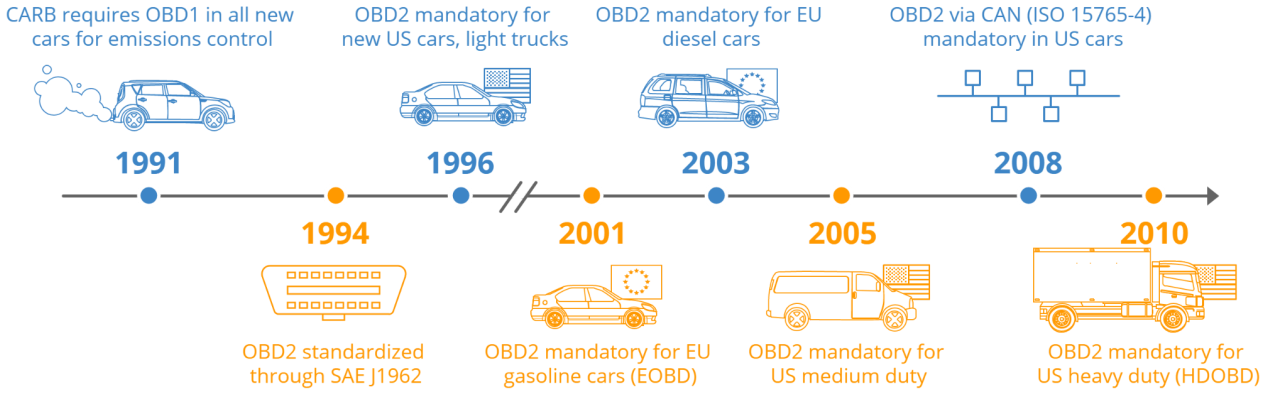



# OBD2 history & future

### History

OBD2 originates from California where the California Air Resources Board (CARB) required OBD in all new cars from 1991+ for emission control purposes. The OBD2 standard was recommended by the Society of Automotive Engineers (SAE) and standardized DTCs and the OBD connector across manufacturers (SAE J1962). From there, the OBD2 standard was rolled out step-by-step:

- 1996: OBD2 made mandatory in USA for cars/light trucks
- 2001: Required in EU for gasoline cars
- 2003: Required in EU also for diesel cars (EOBD)
- 2005: OBD2 was required in US for medium duty vehicles
- 2008: US cars must use ISO 15765-4 (CAN) as OBD2 basis
- 2010: Finally, OBD2 was required in US heavy duty vehicles




## Future

OBD2 is here to stay - but in what form? Two potential routes may radically change OBD2:

### OBD3/OBD-III - wireless emission testing

In today's world of connected cars, OBD2 tests can seem cumbersome: Manually doing emission control checks is time-consuming and expensive. The solution? OBD3 - adding telematics to all cars. Basically, OBD3 adds a small radio transponder (as in e.g. bridge tolls) to all cars. Using this, the car vehicle identification number (VIN) and DTCs can be sent via WiFi to a central server for checks.

Many devices today already facilitate transfer of CAN or OBD2 data via WiFi/cellular - e.g. the CANedge2 WiFi CAN logger. This saves cost and is convenient, but it is also politically a challenge due to surveillance concerns.

### Eliminating 3rd party OBD2 services

The OBD2 protocol was originally designed for stationary emission controls. Yet, today OBD2 is used extensively for generating real-time data by 3rd parties - via OBD2 dongles, CAN loggers etc. However, the German car industry is looking to change this:

***"OBD has been designed to service cars in repair shops. In no way has it been intended to allow third parties to build a form of data-driven economy on the access through this interface"***

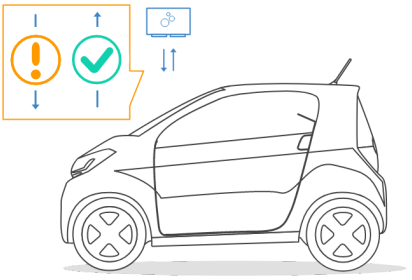
- Christoph Grote, SVP Electronics, BMW (2017)

The proposal is to "turn off" the OBD2 functionality while driving - and instead collect the data in a central server. This would effectively put the manufacturers in control of the automotive 'big data'. The argumentation is based in security (e.g. removing the risk of car hacking), though many see it as a commercial move. Whether this becomes a real trend is to be seen - but it may truly disrupt the market for OBD2 3rd party services.

# OBD2 parameter IDs (PID)

Why should you care about OBD2 data? Mechanics obviously care about OBD2 DTCs (maybe you do too), while regulatory entities need OBD2 to control emission. But the OBD2 protocol also supports a broad range of standard parameter IDs (PIDs) that can be logged across most cars.

This means that you can easily get human-readable OBD2 data from your car on speed, RPM, throttle position and more. In other words, OBD2 lets you analyze data from you car easily - in contrast to the OEM specific proprietary raw CAN data.



### Decoding OBD2 vs CAN bus data

In principle it is simple to log the raw CAN frames from your car. If you e.g. connect a CAN logger to the OBD2 connector, you'll start logging broadcasted CAN bus data out-the-box. However, the raw CAN messages need to be decoded via a database of conversion rules (DBC) and a suitable CAN software that supports DBC decoding (like e.g. asammdf). The challenge is that these CAN DBC files are typically proprietary, making the raw CAN data unreadable unless you're the automotive OEM.

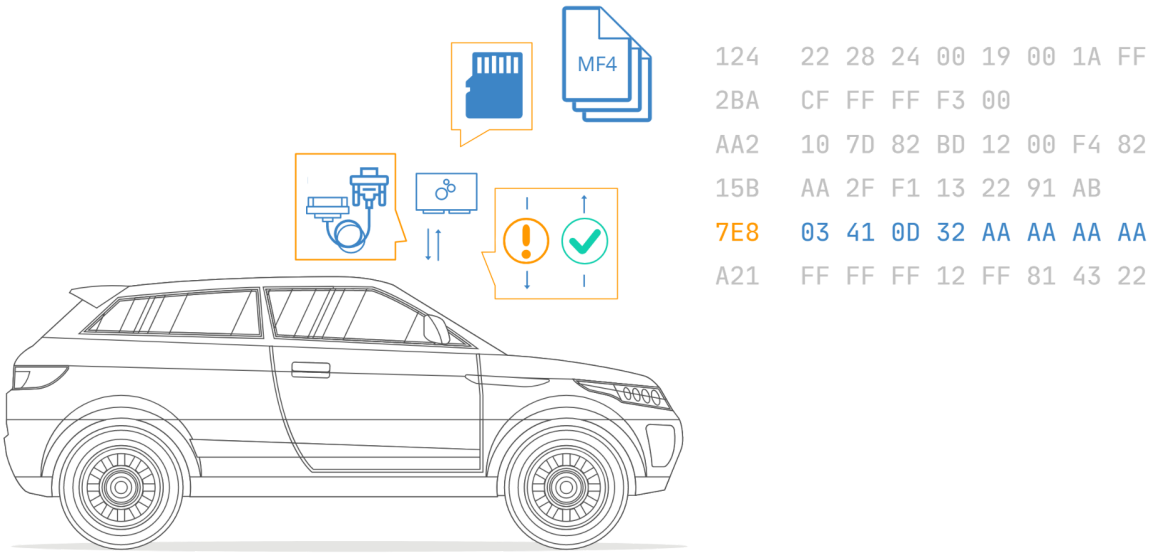
Car hackers may try to reverse engineer the rules, though this can be difficult. CAN is, however, still the only method to get "full access" to your car data - while OBD2 only provides access to a limited subset of data.

# How to log OBD2 data?

OBD2 data logging works as follows:

- You connect an OBD2 logger to the OBD2 connector
- Using the tool, you send 'request frames' via CAN
- The relevant ECUs send 'response frames' via CAN
- Decode the raw OBD2 responses via e.g. an OBD2 DBC

In other words, a CAN logger that is able to transmit custom CAN frames can also be used as an OBD2 logger.
Note that cars differ by model/year in what OBD2 PIDs they support. For details, see our OBD2 data logger guide.

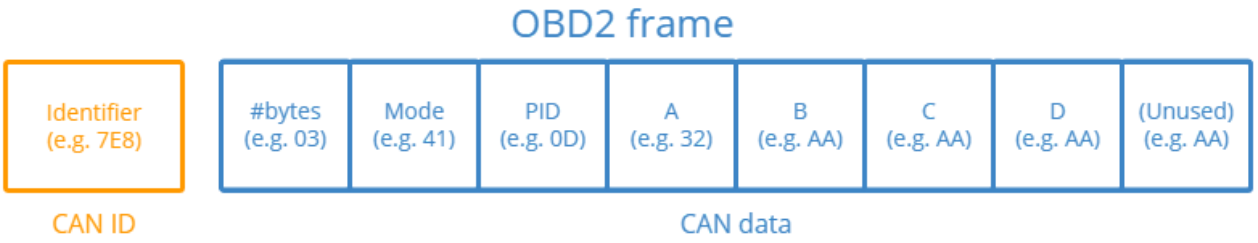



### CANedge OBD2 data logger

The CANedge lets you easily log OBD2 data to an 8-32 GB SD card. Simply specify what OBD2 PIDs you wish to request, then connect it to your car via an OBD2 adapter to start logging. Process the data via free software/APIs and our OBD2 DBC.

# Raw OBD2 frame details

To get started recording OBD2 data, it is helpful to understand the basics of the raw OBD2 message structure. In simplified terms, an OBD2 message consists of an identifier and data. Further, the data is split in Mode, PID and data bytes (A, B, C, D) as below.



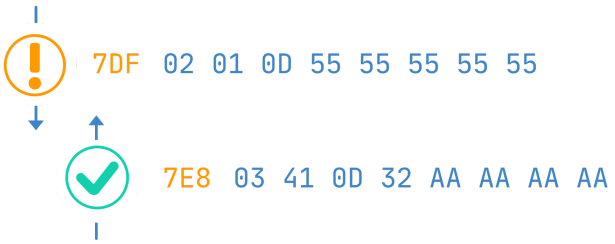

### OBD2 message fields explained

- **Identifier**: For OBD2 messages, the identifier is standard 11-bit and used to distinguish between "request messages" (ID 7DF) and "response messages" (ID 7E8 to 7EF). Note that 7E8 will typically be where the main engine or ECU responds at.
- **Length**: This simply reflects the length in number of bytes of the remaining data (03 to 06). For the Vehicle Speed example, it is 02 for the request (since only 01 and 0D follow), while for the response it is 03 as both 41, 0D and 32 follow.
- **Mode**: For requests, this will be between 01-0A. For responses the 0 is replaced by 4 (i.e. 41, 42, ... , 4A). There are 10 modes as described in the SAE J1979 OBD2 standard. Mode 1 shows Current Data and is e.g. used for looking at real-time vehicle speed, RPM etc. Other modes are used to e.g. show or clear stored diagnostic trouble codes and show freeze frame data.

- **PID**: For each mode, a list of standard OBD2 PIDs exist - e.g. in Mode 01, PID 0D is Vehicle Speed. For the full list, check out our OBD2 PID overview. Each PID has a description and some have a specified min/max and conversion formula. The formula for speed is e.g. simply A, meaning that the A data byte (which is in HEX) is converted to decimal to get the km/h converted value (i.e. 32 becomes 50 km/h above). For e.g. RPM (PID 0C), the formula is (256*A + B) / 4.
- **A, B, C, D**: These are the data bytes in HEX, which need to be converted to decimal form before they are used in the PID formula calculations. Note that the last data byte (after Dh) is not used.

### OBD2 request/response example

An example of a request/response CAN message for the PID 'Vehicle Speed' with a value of 50 km/h can be seen in the illustration. Note in particular how the formula for the OBD2 PID 0D (Vehicle Speed) simply involves taking the 4th byte (0x32) and converting it to decimal form (50).




### Extended OBD2 PID request/response

In some vehicles (e.g. vans and light/medium/heavy duty vehicles), you may find that the raw CAN data uses extended 29-bit CAN identifiers instead of 11-bit CAN identifiers.

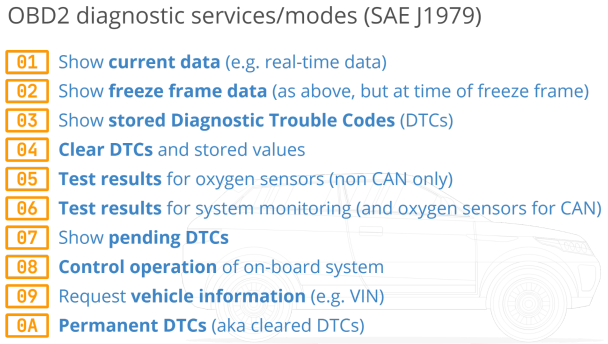
In this case, you will typically need to modify the OBD2 PID requests to use the CAN ID 18DB33F1 instead of 7DF. The data payload structure is kept identical to the examples for 11-bit CAN IDs.

If the vehicle responds to the requests, you'll typically see responses with CAN IDs 18DAF100 to 18DAF1FF (in practice, typically 18DAF110 and 18DAF11E). The response identifier is also sometimes shown in the 'J1939 PGN' form, specifically the PGN 0xDA00 (55808), which in the J1939-71 standard is marked as 'Reserved for ISO 15765-2'.

We provide an OBD2 DBC file for both the 11-bit and 29-bit responses, enabling simple decoding of the data in most CAN software tools.

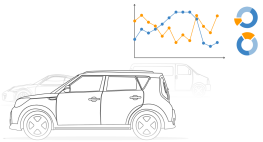
### The 10 OBD2 services (aka modes)

There are 10 OBD2 diagnostic services (or modes) as described in the SAE J1979 OBD2 standard. Mode 1 shows Current Data and is used for looking at real-time parameters like vehicle speed, RPM, throttle position etc. Other modes are e.g. used to show/clear diagnostic trouble codes (DTCs) and show freeze frame data. Manufacturers do not have to support all diagnostic services - and they may support modes outside these 10 services (i.e. manufacturer specific OBD2 services).



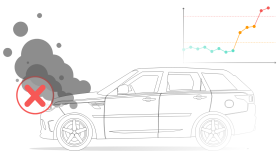

# OBD2 data logging - use case examples

OBD2 data from cars and light trucks can be used in various use cases:

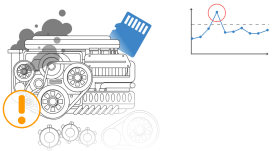


**Logging data from cars**
OBD2 data from cars can e.g. be used to reduce fuel costs, improve driving, test prototype parts and insurance
learn more

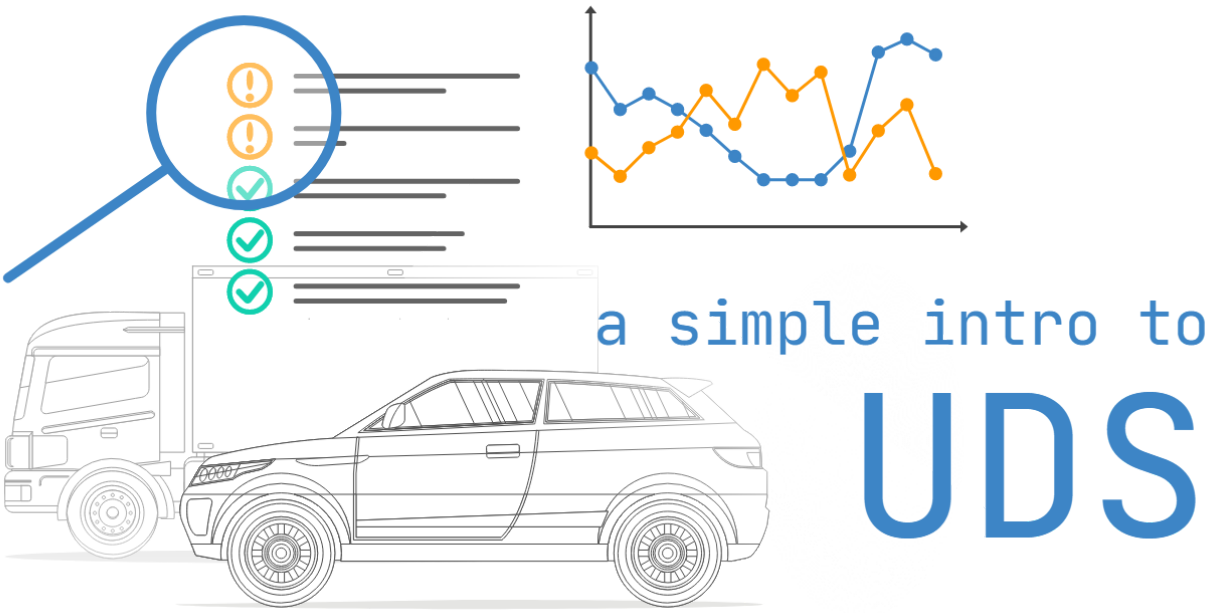
**Real-time car diagnostics**
OBD2 interfaces can be used to stream human-readable OBD2 data in real-time, e.g. for diagnosing vehicle issues
learn more



**Predictive maintenance**
Cars and light trucks can be monitored via IoT OBD2 loggers in the cloud to predict and avoid breakdowns
learn more



**Vehicle blackbox logger**
An OBD2 logger can serve as a 'blackbox' for vehicles or equipment, providing data for e.g. disputes or diagnostics
learn more




# UDS Explained (Unified Diagnostic Services)

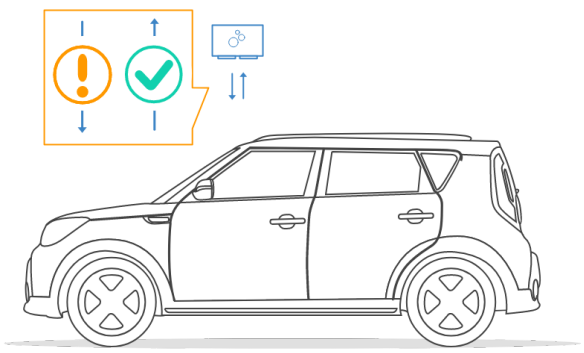
In this practical tutorial, we introduce the UDS basics with focus on UDS on CAN bus (UDSonCAN) and Diagnostics over CAN (DoCAN). We also introduce the ISO-TP protocol and explain the difference between UDS, OBD2, WWH-OBD and OBDonUDS. Finally, we'll explain how to request, record & decode UDS messages - with practical examples for logging EV State of Charge and the Vehicle Identification Number (VIN).

## What is the UDS protocol?

Unified Diagnostic Services (UDS) is a communication protocol used in automotive Electronic Control Units (ECUs) to enable diagnostics, firmware updates, routine testing and more.

The UDS protocol (ISO 14229) is standardized across both manufacturers and standards (such as CAN, KWP 2000, Ethernet, LIN). Further, UDS is today used in ECUs across all tier 1 Original Equipment Manufacturers (OEMs).

In practice, UDS communication is performed in a client-server relationship - with the client being a tester-tool and the server being a vehicle ECU. For example, you can connect a CAN bus interface to the OBD2 connector of a car and send UDS requests into the vehicle. Assuming the targeted ECU supports UDS services, it will respond accordingly.



In turn, this enables various use cases:

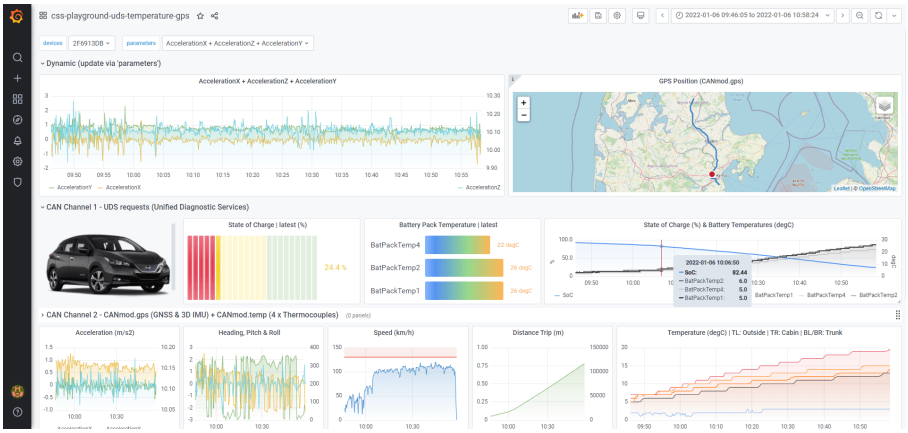
- Read/clear diagnostic trouble codes (DTC) for troubleshooting vehicle issues
- Extract parameter data values such as temperatures, state of charge, VIN etc
- Initiate diagnostic sessions to e.g. test safety-critical features
- Modify ECU behavior via resets, firmware flashing and settings modification

UDS is often referred to as 'vehicle manufacturer enhanced diagnostics' or 'enhanced diagnostics' - more on this below.

### Example: Nissan Leaf SoC%

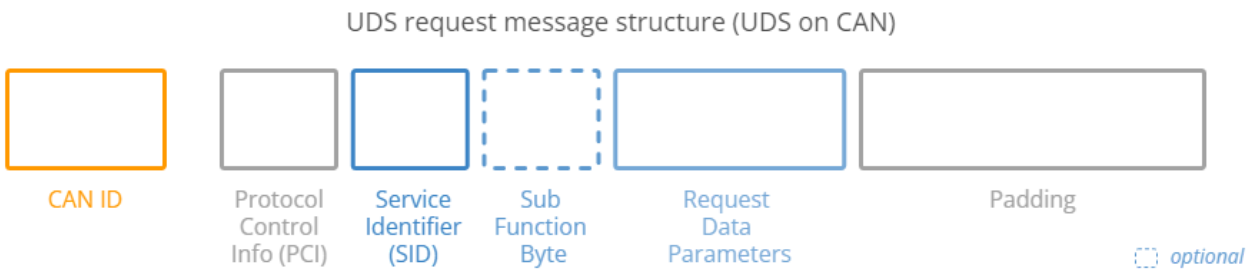
UDS and CAN ISO-TP are complex topics. As motivation, we've done a case study to show how it can be useful. Specifically, we use a CANedge2 to request data on State of Charge (SoC%) and battery temperatures from a Nissan Leaf EV. In the example, we also add a CANmod.gps and CANmod.temp to add GNSS, IMU and temperature data.

The multiframe ISO-TP responses and CANmod signals are DBC decoded via our Python API and written to a database for visualization in Grafana dashboards. Check it out: playground case study




# UDS message structure

UDS is a request based protocol. In the illustration we've outlined an example of an UDS request frame (using CAN bus ):




A diagnostic UDS request on CAN contains various fields that we detail below:

### Protocol Control Information (PCI)

The PCI field is not per se related to the UDS request itself, but is required for diagnostic UDS requests made on CAN bus. In short, the PCI field can be 1-3 bytes long and contains information related to the transmission of messages that do not fit within a single CAN frame. We will detail this more in the section on the CAN bus transport protocol (ISO-TP).

## UDS Service ID (SID)

The use cases outlined above relate to different UDS services. When you wish to utilize a specific UDS service, the UDS request message should contain the UDS Service Identifier (SID) in the data payload. Note that the identifiers are split between request SIDs (e.g. 0x22) and response SIDs (e.g. 0x62). As in OBD2, the response SIDs generally add 0x40 to the request SIDs. See also the overview of all standardized UDS services and SIDs. We will mainly focus on UDS service 0x22 in this article, which is used to read data (e.g. speed, SoC, temperature, VIN) from an ECU.

UDS service identifiers (SIDs)

| | UDS SID (request) | UDS SID (response) | Service | Details |
|---|---|---|---|---|
| Diagnostic and Communications Management | 0x10 | 0x50 | Diagnostic Session Control | Control which UDS services are available |
| | 0x11 | 0x51 | ECU Reset | Reset the ECU (“hard reset”, “key off”, “soft reset”) |
| | 0x27 | 0x67 | Security Access | Enable use of security-critical services via authentication |
| | 0x28 | 0x68 | Communication Control | Turn sending/receiving of messages on/off in the ECU |
| | 0x29 | 0x69 | Authentication | Enable more advanced authentication vs. 0x27 (PKI based exchange) |
| | 0x3E | 0x7E | Tester Present | Send a “heartbeat” periodically to remain in the current session |
| | 0x83 | 0xC3 | Access Timing Parameters | View/modify timing parameters used in client/server communication |
| | 0x84 | 0xC4 | Secured Data Transmission | Send encrypted data via ISO 15764 (Extended Data Link Security) |
| | 0x85 | 0xC5 | Control DTC Settings | Enable/disable detection of errors (e.g. used during diagnostics) |
| | 0x86 | 0xC6 | Response On Event | Request that an ECU processes a service request if an event happens |
| | 0x87 | 0xC7 | Link Control | Set the baud rate for diagnostic access |
| Data Transmission | 0x22 | 0x62 | Read Data By Identifier | Read data from targeted ECU - e.g. VIN, sensor data values etc. |
| | 0x23 | 0x63 | Read Memory By Address | Read data from physical memory (e.g. to understand software behavior) |
| | 0x24 | 0x64 | Read Scaling Data By Identifier | Read information about how to scale data identifiers |
| | 0x2A | 0x6A | Read Data By Identifier Periodic | Request ECU to broadcast sensor data at slow/medium/fast/stop rate |
| | 0x2C | 0x6C | Dynamically Define Data Identifier | Define data parameter for use in 0x22 or 0x2A dynamically |
| | 0x2E | 0x6E | Write Data By Identifier | Program specific variables determined by data parameters |
| | 0x3D | 0x7D | Write Memory By Address | Write information to the ECU’s memory |
| DTCs | 0x14 | 0x54 | Clear Diagnostic Information | Delete stored DTCs |
| | 0x19 | 0x59 | Read DTC Information | Read stored DTCs, as well as related information |
| | 0x2F | 0x6F | Input Output Control By Identifier | Gain control over ECU analog/digital inputs/outputs |
| | 0x31 | 0x71 | Routine Control | Initiate/stop routines (e.g. self-testing, erasing of flash memory) |
| Upload/ Download | 0x34 | 0x74 | Request Download | Start request to add software/data to ECU (incl. location/size) |
| | 0x35 | 0x75 | Request Upload | Start request to read software/data from ECU (incl. location/size) |
| | 0x36 | 0x76 | Transfer Data | Perform actual transfer of data following use of 0x74/0x75 |
| | 0x37 | 0x77 | Request Transfer Exit | Stop the transfer of data |
| | 0x38 | 0x78 | Request File Transfer | Perform a file download/upload to/from the ECU |
| | | 0x7F | Negative Response | Sent with a Negative Response Code when a request cannot be handled |

### UDS SIDs vs other diagnostic services

The standardized UDS services shown above are in practice a subset of a larger set of diagnostic services - see below overview. Note here that the SIDs 0x00 to 0x0F are reserved for legislated OBD services (more on this later).

Diagnostic service identifiers - overview (0x00 - 0xFF)

| Service Identifier (SID) | Service type | Further details |
|---|---|---|
| 0x00 - 0x0F | OBD service requests | ISO 15031-5 |
| **0x00 - 0x3E** | **ISO 14229 (requests)** | **ISO 14229** |
| 0x3F | Not applicable | Reserved |
| 0x40 - 0x4F | OBD service responses | ISO 15031-5 |
| **0x50 - 0x7E** | **ISO 14229 (responses)** | **ISO 14229** |
| 0x7F | Negative response SID | ISO 14229 |
| 0x80 | Not applicable | ISO 14229 (reserved) |
| 0x81 - 0x82 | Not applicable | ISO 14229 (reserved) |
| **0x83 - 0x88** | **ISO 14229 (requests)** | **ISO 14229** |
| 0x89 - 0x9F | Service requests | Reserved |
| 0xA0 - 0xB9 | Service requests | Defined by vehicle OEM |
| 0xBA - 0xBE | Service requests | Defined by systems OEM |
| 0xBF | Not applicable | Reserved |
| 0xC0 | Not applicable | ISO 14229 (reserved) |
| 0xC1 - 0xC2 | Not applicable | ISO 14229 (reserved) |
| **0xC3 - 0xC8** | **ISO 14229 (responses)** | **ISO 14229** |
| 0xC9 - 0xDF | Service responses | Reserved |
| 0xE0 - 0xF9 | Service responses | Defined by vehicle OEM |
| 0xFA - 0xFE | Service responses | Defined by systems OEM |
| 0xFF | Not applicable | Reserved |

UDS request SIDs  UDS positive response SIDs  UDS negative response SID

### UDS security via session-control (authentication)

As evident, UDS enables extensive control over the vehicle ECUs. For security reasons, critical UDS services are therefore restricted through an authentication process. Basically, an ECU will send a 'seed' to a tester, who in turn must produce a 'key' to gain access to security-critical services. To retain this access, the tester needs to send a 'tester present' message periodically.

In practice, this authentication process enables vehicle manufactures to restrict UDS access for aftermarket users and ensure that only designated tools will be able to utilize the security-critical UDS services.

Note that the switching between authentication levels is done through diagnostic session control, which is one of the UDS services available. Vehicle manufactures can decide which sessions are supported, though they must always support the 'default session' (i.e. which does not involve any authentication). With that said, they decide what services are supported within the default session as well. If a tester tool switches to a non-default session, it must send a 'tester present' message periodically to avoid being returned to the default session.

## UDS Sub Function Byte

The sub function byte is used in some UDS request frames as outlined below. Note, however, that in some UDS services, like 0x22, the sub function byte is not used. Generally, when a request is sent to an ECU, the ECU may respond positively or negatively. In case the response is positive, the tester may want to suppress the response (as it may be irrelevant). This is done by setting the 1st bit to 1 in the sub function byte. Negative responses cannot be suppressed.

The remaining 7 bits can be used to define up to 128 sub function values. For example, when reading DTC information via SID 0x19 (Read Diagnostic Information), the sub function can be used to control the report type - see also below table.

UDS services - sub function types

| UDS SID (request) | UDS SID (response) | Service | Sub function types |
|---|---|---|---|
| 0x10 | 0x50 | Diagnostic Session Control | Diagnostic session type |
| 0x11 | 0x51 | ECU Reset | Reset type |
| 0x27 | 0x67 | Security Access | Security access type |
| 0x28 | 0x68 | Communication Control | Control type |
| 0x3E | 0x7E | Tester Present | "Zero sub function" |
| 0x83 | 0xC3 | Access Timing Parameters | Timing parameter access type |
| 0x85 | 0xC5 | Control DTC Settings | DTC setting type |
| 0x86 | 0xC6 | Response On Event | Event type |
| 0x87 | 0xC7 | Link Control | Link control type |
| 0x2C | 0x6C | Dynamically Define Data Identifier | Definition type |
| 0x19 | 0x59 | Read DTC Information | Report type |
| 0x31 | 0x71 | Routine Control | Routine control type |

### Example: Service 0x19 sub functions

If we look specifically at service 0x19, we can see an example of the various sub functions below:

UDS service 0x19 - sub function byte values & types

| UDS SID (request) | UDS SID (response) | Report type (sub function value) | Report |
|---|---|---|---|
| 0x19 | 0x59 | 0x01 | Number of DTC by status mask |
| | | 0x02 | DTC by status mask |
| | | 0x03 | DTC snapshot identification |
| | | 0x04 | DTC snapshot record by DTC number |
| | | 0x05 | DTC stored data by record number |
| | | 0x06 | DTC extended data record by DTC number |
| | | 0x07 | Number of DTC by severity mask record |
| | | 0x08 | DTC by severity mask record |
| | | 0x09 | Severity information of DTC |
| | | 0x0A | Supported DTC |
| | | 0x0B | First failed DTC |
| | | 0x0C | First confirmed DTC |
| | | 0x0D | Most recent failed DTC |
| | | 0x0E | Most recent confirmed DTC |
| | | 0x0¤ | Mirror memory DTC by status mask |
| | | 0x10 | Mirror memory DTC by DTC number |
| | | 0x11 | Number of mirror memory DTC by status mask |
| | | 0x12 | Number of emissions OBD DTC by status mask |
| | | 0x13 | Emissions OBD DTC by status mask |
| | | 0x14 | DTC fault detection counter |
| | | 0x15 | DTC with permanent status |
| | | 0x16 | DTC extended data record by record number |
| | | 0x17 | User defined memory DTC by status mask |
| | | 0x18 | User defined memory DTC snapshot by number |
| | | 0x19 | User defined memory DTC record by number |
| | | 0x42 | WWH-OBD DTC by status mask record |
| | | 0x55 | WWH-OBD DTCs with permanent status |

## UDS 'Request Data Parameters' - incl. Data Identifier (DID)

In most UDS request services, various types of request data parameters are used to provide further configuration of a request beyond the SID and optional sub function byte. Here we outline two examples.

### Service 0x19 (Read DTC Information) - request configuration

For example, service 0x19 lets you read DTC information. The UDS request for SID 0x19 includes a sub function byte - for example, 0x02 lets you read DTCs via a status mask. In this specific case, the sub function byte is followed by a 1-byte parameter called DTC Status Mask to provide further information regarding the request. Similarly, other types of sub functions within 0x19 have specific ways of configuring the request.

### Service 0x22 (Read Data by Identifier) - Data Identifiers

Another example is service 0x22 (Read Data by Identifier). This service uses a Data Identifier (DID), which is a 2-byte value between 0 and 65535 (0xFFFF). The DID serves as a parameter identifier for both requests/responses (similar to how the parameter identifier, or PID, is used in OBD2).

For example, a request for reading data via a single DID in UDS over CAN would include the PCI field, the UDS service 0x22 and the 2-byte DID. Alternatively, one can request data for additional DIDs by adding them after the initial DID in the request. We will look further into this in the section on how to record and decode UDS communication.

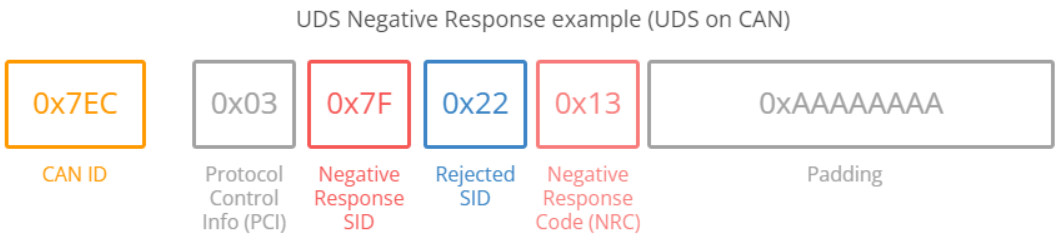
Data Identifiers can be proprietary and only known by OEMs, though some DIDs are standardized. This is for example the case for the WWH-OBD DIDs (more on this later) and the Vehicle Identification Number (VIN) is 0xF190. See the separate table for a list of standardized DIDs across UDS.

UDS - standardized data identifiers (DID)

| UDS DID (data identifier) | Description |
|---|---|
| 0xF180 | Boot software identification |
| 0xF181 | Application software identification |
| 0xF182 | Application data identification |
| 0xF183 | Boot software fingerprint |
| 0xF184 | Application software fingerprint |
| 0xF185 | Application data fingerprint |
| 0xF186 | Active diagnostic session |
| 0xF187 | Manufacturer spare part number |
| 0xF188 | Manufacturer ECU software number |
| 0xF189 | Manufacturer ECU software version |
| 0xF18A | Identifier of system supplier |
| 0xF18B | ECU manufacturing date |
| 0xF18C | ECU serial number |
| 0xF18D | Supported functional units |
| 0xF18E | Manufacturer kit assembly part number |
| 0xF190 | Vehicle Identification Number (VIN) |
| 0xF192 | System supplier ECU hardware number |
| 0xF193 | System supplier ECU hardware version number |
| 0xF194 | System supplier ECU software number |
| 0xF195 | System supplier ECU software version number |
| 0xF196 | Exhaust regulation/type approval number |
| 0xF197 | System name / engine type |
| 0xF198 | Repair shop code / tester serial number |
| 0xF199 | Programming date |
| 0xF19D | ECU installation date |
| 0xF19E | ODX file |

## Positive vs. negative UDS responses

When an ECU responds positively to an UDS request, the response frame is structured with similar elements as the request frame. For example, a 'positive' response to a service 0x22 request will contain the response SID 0x62 (0x22 + 0x40) and the 2-byte DID, followed by the actual data payload for the requested DID. Generally, the structure of a positive UDS response message depends on the service. However, in some cases an ECU may provide a negative response to an UDS request - for example if the service is not supported. A negative response is structured as in below CAN frame example:




## Details + Negative Response Code table

Below we briefly detail the negative response frame with focus on the NRC:

- The 1st byte is the PCI field
- The 2nd byte is the Negative Response Code SID, 0x7F
- The 3rd byte is the SID of the rejected request
- The 4th byte is the Negative Response Code (NRC)

In the negative UDS response, the NRC provides information regarding the cause of the rejection as per the table below.

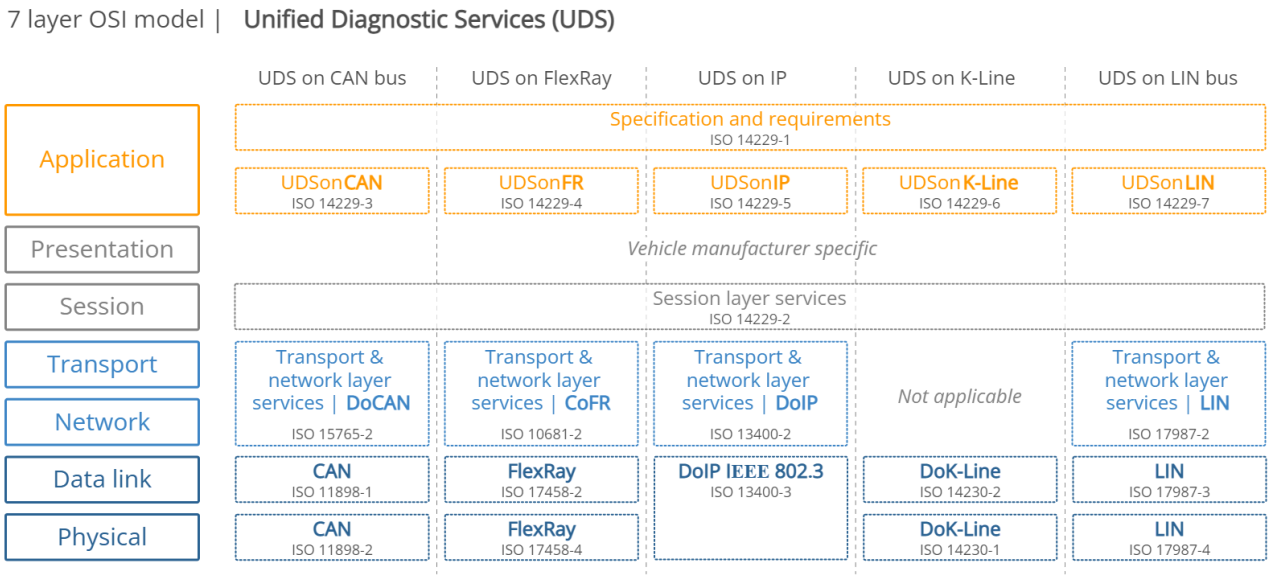
UDS SID 0x7F - Negative Response Codes (NRC)

| UDS NRC | Description |
|---|---|
| 0x10 | General reject |
| 0x11 | Service not supported |
| 0x12 | Sub-function not supported |
| 0x13 | Invalid message length/format |
| 0x14 | Response too long |
| 0x21 | Busy-repeat request |
| 0x22 | Conditions not correct |
| 0x24 | Request sequence error |
| 0x25 | No response from subnet component |
| 0x26 | Failure prevents execution of requested action |
| 0x31 | Request out of range |
| 0x33 | Security access denied |
| 0x35 | Invalid key |
| 0x36 | Exceeded number of attempts |
| 0x37 | Required time delay has not expired |
| 0x70 | Upload/download not accepted |
| 0x71 | Transfer data suspended |
| 0x72 | Programming failure |
| 0x73 | Wrong block sequence counter |
| 0x78 | Request received - response pending |
| 0x7E | Sub function not supported in active session |
| 0x7F | Service not supported in active session |
| 0x81/0x82 | RPM too high/low |
| 0x83/0x84 | Engine is running/not running |
| 0x85 | Engine run time too low |
| 0x86/0x87 | Temperature too high/low |
| 0x88/0x89 | Speed too high/low |
| 0x8A/0x8B | Throttle pedal too high/low |
| 0x8C/0x8D | Transmission range not in neutral/dear |
| 0x8F | Brake switches not closed |
| 0x90 | Shifter lever not in park |
| 0x91 | Torque converter clutch locked |
| 0x92/0x93 | Voltage too high/low |
| 0xF0-0xFE | Manufacturer specific conditions not correct |

# UDS vs CAN bus: Standards & OSI model

To better understand UDS, we will look at how it relates to CAN bus and the OSI model.

As explained in our CAN bus tutorial, the Controller Area Network serves as a basis for communication. Specifically, CAN is described by a data-link layer and physical layer in the OSI model (as per ISO 11898). In contrast to CAN, UDS (ISO 14229) is a 'higher layer protocol' and utilizes both the session layer (5th) and application layer (7th) in the OSI model as shown below:




## Overview of UDS standards & concepts

UDS refers to a large number of standards/concepts, meaning it can be a bit overwhelming. To give you an overview, we provide a high-level explanation of the most relevant ones below (with focus on CAN as the basis).

### Quick overview of the UDS OSI model layers

In the following we provide a quick breakdown of each layer of the OSI model:

- Application: This is described by ISO 14229-1 (across the various serial data link layers). Further, separate ISO standards describe the UDS application layer for the various lower layer protocols - e.g. ISO 14229-3 for CAN bus (aka UDSonCAN)
- Presentation: This is vehicle manufacturer specific
- Session: This is described in ISO 14229-2
- Transport + Network: For CAN, ISO 15765-2 is used (aka ISO-TP)
- Data Link: In the case of CAN, this is described by ISO 11898-1
- Physical: In the case of CAN, this is described by ISO 11898-2

As illustrated, multiple standards other than CAN may be used as the basis for UDS communication - including FlexRay, Ethernet, LIN bus and K-line. In this tutorial we focus on CAN, which is also the most common lower layer protocol.

### ISO 14229-1 (Application Layer)

The ISO 14229-1 standard describes the application layer requirements for UDS (independent of what lower layer protocol is used). In particular, it outlines the following:

- Client-server communication flows (requests, responses, ...)
- UDS services (as per the overview described previously)
- Positive responses and negative response codes (NRCs)
- Various definitions (e.g. DTCs, parameter data identifiers aka DIDs, ...)

### ISO 14229-3 (Application Layer for CAN)

The purpose of 14229-3 is to enable the implementation of Unified Diagnostic Services (UDS) on Controller Area Networks (CAN) - also known as UDSonCAN. This standard describes the application layer requirements for UDSonCAN.

This standard does not describe any implementation requirements for the in-vehicle CAN bus architecture. Instead, it focuses on some additional requirements/restrictions for UDS that are specific to UDSonCAN.

Specifically, 14229-3 outlines which UDS services have CAN specific requirements. The affected UDS services are ResponseOnEvent and ReadDataByPeriodicIdentifier, for which the CAN specific requirements are detailed in 14229-3. All other UDS services are implemented as per ISO 14229-1 and ISO 14229-2.

ISO 14229-3 also describes a set of mappings between ISO 14229-2 and ISO 15765-2 (ISO-TP) and describes requirements related to 11-bit and 29-bit CAN IDs when these are used for UDS and legislated OBD as per ISO 15765-4.

### ISO 14229-2 (Session Layer)

This describes the session layer in the UDS OSI model. Specifically, it outlines service request/confirmation/indication primitives. These provide an interface for the implementation of UDS (ISO 14229-1) with any of the communication protocols (e.g. CAN).

### ISO 15765-2 (Transport + Network Layer for CAN)

For UDS on CAN, ISO 15765-2 describes how to communicate diagnostic requests and responses. In particular, the standard describes how to structure CAN frames to enable communication of multi-frame payloads. As this is a vital part of understanding UDS on CAN, we go into more depth in the next section.

### ISO 11898 (Physical + Data Link Layer for CAN)

When UDS is based on CAN bus, the physical and data link layers are described in ISO 11898-1 and ISO 11898-2. When UDS is based on CAN, it can be compared to a higher layer protocol like J1939, OBD2, CANopen, NMEA 2000 etc. However, in contrast to these protocols, UDS could alternatively be based on other communication protocols like FlexRay, Ethernet, LIN etc.

### UDSonCAN vs DoCAN

When talking about UDS based on CAN bus, you'll often see two terms used: UDSonCAN (UDS on CAN bus) and DoCAN (Diagnostics on CAN bus). Some UDS tutorials use these terms interchangeably, which may cause confusion.

In ISO 14229-1 the terms are used as in our OSI model illustration. In other words, UDSonCAN is used to refer to ISO 14229-3, while DoCAN is used to refer to ISO 15765-2 aka ISO-TP.

However, part of the confusion may arise because ISO 14229-3 also provides an OSI model where DoCAN is both used in relation to ISO 15765-2 and as an overlay across OSI model layers 2 to 7. In ISO 14229-2, DoCAN is referred to as the

communication protocol on which UDS (ISO 14229-1) is implemented. This is in sync with the illustration from ISO 14229-3. In this context, DoCAN can be viewed as a more overarching term for the implementation of UDS on CAN, whereas UDSonCAN seems consistently to refer to ISO 14229-3 only.

### ISO 15765-3 vs. ISO 14229-3

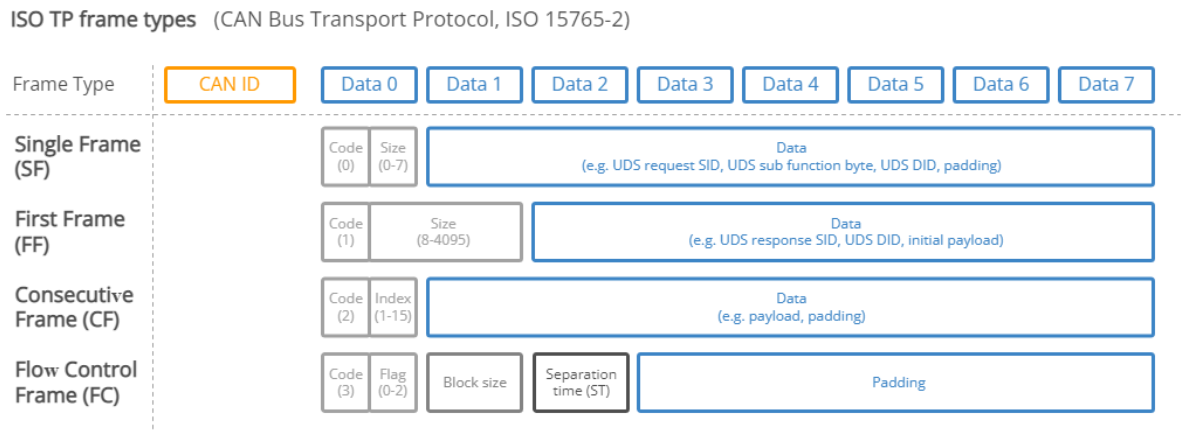
UDS on CAN bus (UDSonCAN) is sometimes referred to through ISO 15765-3. However, this standard is now obsolete and has been replaced by ISO 14229-3.

# CAN ISO-TP - Transport Protocol (ISO 15765-2)

When implementing diagnostics on CAN, one challenge is the size of the CAN frame payload: For Classical CAN frames, this is limited to 8 bytes and for CAN FD the payload is limited to 64 bytes. Vehicle diagnostics often involve communication of far larger payloads.

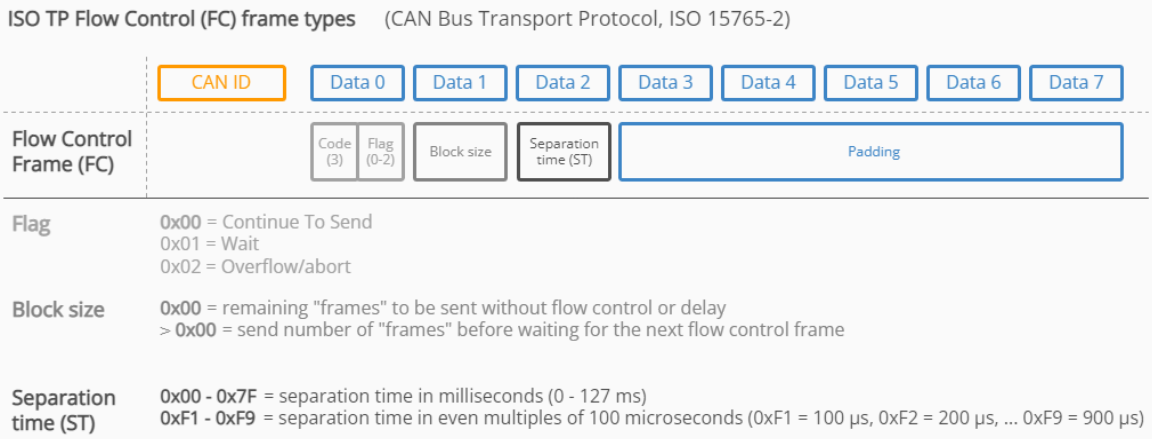
ISO 15765-2 was established to solve the challenge of large payloads for CAN based vehicle diagnostics.
The standard specifies a transport protocol and network layer services for use in CAN based vehicle networks. The most common use cases include UDS (ISO 14229-1), OBD (SAE J1979, ISO 15031-5) and world-wide harmonized OBD aka WWH-OBD (ISO 27145).

The ISO-TP standard outlines how to communicate CAN data payloads up to 4095 bytes through segmentation, flow control and reassembly. ISO-TP defines specific CAN frames for enabling this communication as shown below:




### Regarding the Flow Control frame

The flow control frame is used to 'configure' the subsequent communication. It can be constructed as below:




A few comments:

- In the simplest case, the FC payload can be set to 30 00 00 00 00 00 00 00 (all remaining frames to be sent without delay)
- Alternatively, one can decide to perform more granular control over the communication by e.g. alternating between the Wait and Continue commands, as well as specifying a specific separation time (in milliseconds) between frames

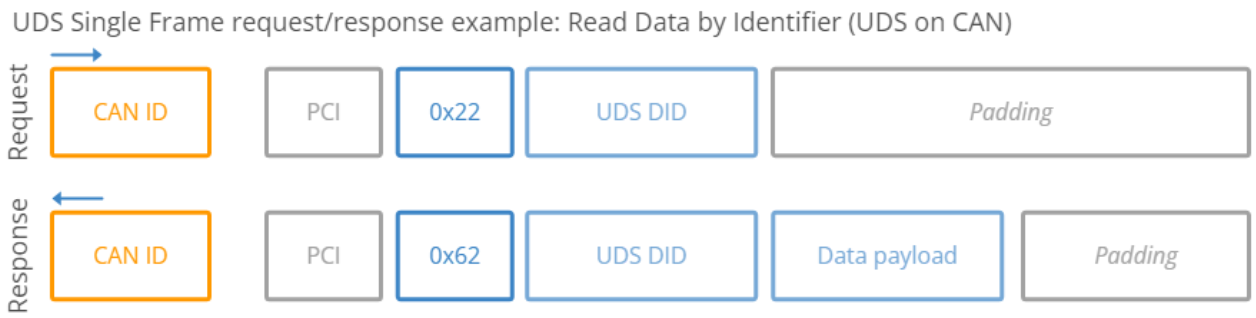
### Other ISO-TP frame comments

- The ISO-TP frame type can be identified from the first nibble of the first byte (0x0, 0x1, 0x2, 0x3)
- The total frame size can be up to 4095 bytes (0xFFF) as evident from the FF frame
- The CF index runs from 1 to 15 (0xF) and is then reset if more data is to be sent
- Padding (e.g. 0x00, 0xAA, ...) is used to ensure the frame payloads equal 8 bytes in length

Below we outline how the ISO-TP protocol works for single-frame and multi-frame communication:

## ISO-TP: Single-frame communication

In vehicle diagnostics, communication is initiated by a tester tool sending a request. This request frame is a Single Frame (SF). In the simplest case, a tester tool sends a Single Frame to request data from an ECU. If the response can be contained in a 7-byte payload, the ECU provides a Single Frame response.



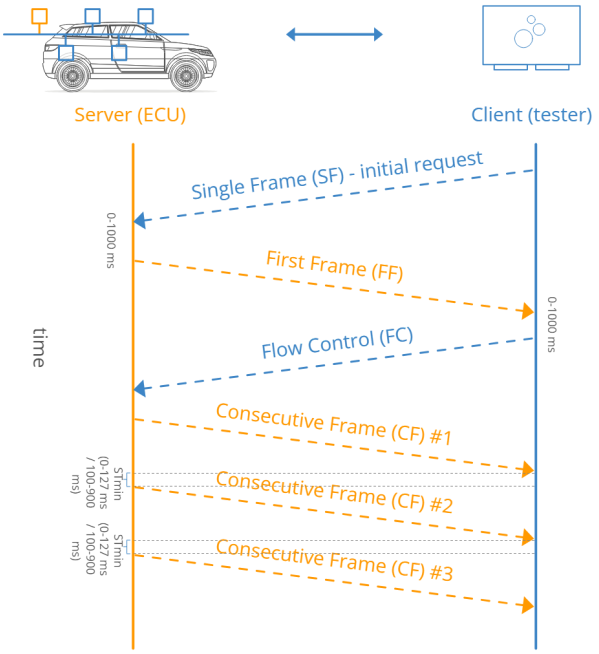
### ISO-TP: Multi-frame communication

When the payload exceeds 7 bytes, it needs to be split across multiple CAN frames.

As before, a tester starts by sending a Single Frame (SF) request to an ECU (sender). However, in this case the response exceeds 7 bytes. Because of this, the ECU sends a First Frame (FF) that contains information on the total packet length (8 to 4095 bytes) as well as the initial chunk of data. When the tester receives the FF, it will send a Flow Control (FC) frame, which tells the ECU how the rest of the data transfer should be transmitted.

Following this, the ECU will send Consecutive Frames (CF) that contain the remaining data payload.

ISO-TP plays an important role in most CAN based diagnostics protocols. Before we show practical examples of such communication flows, it is useful to get an overview of the most common vehicle diagnostic protocols.

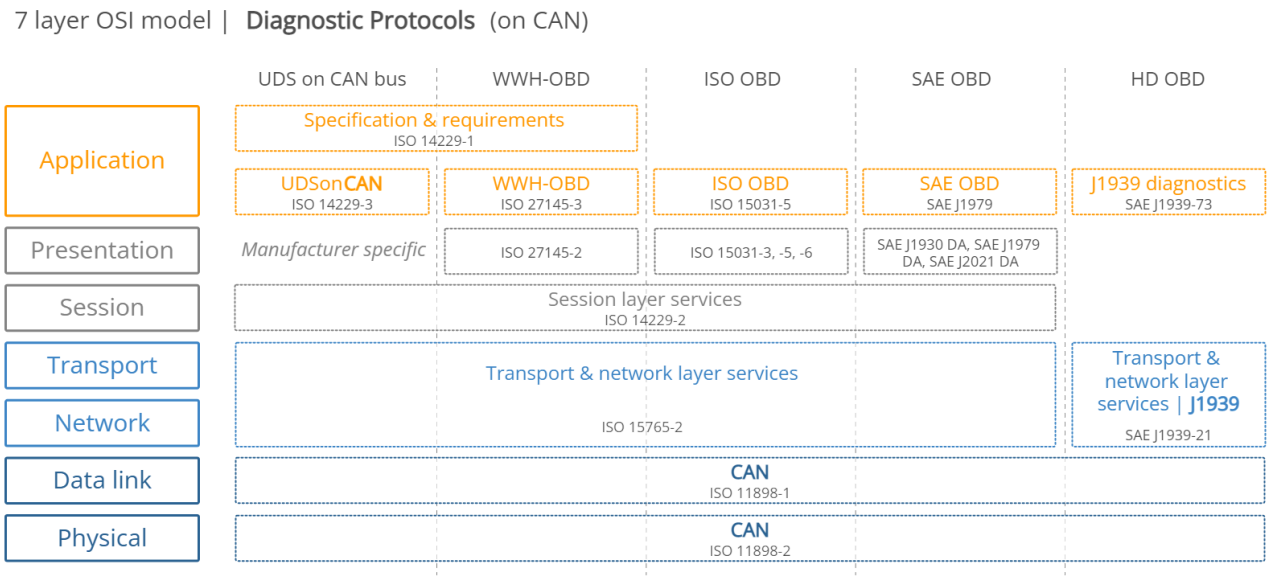



# UDS vs. OBD2 vs. WWH-OBD vs. OBDonUDS

A common question is how UDS relates to On-Board Diagnostics (OBD2), World-Wide Harmonized OBD (WWH-OBD) and OBDonUDS. To understand this, it is important to first note the following:

**OBD (On-Board Diagnostics) is today implemented in different ways across countries and vehicles.**

This is illustrated via the below OSI model comprising CAN based vehicle diagnostic protocols in use today:



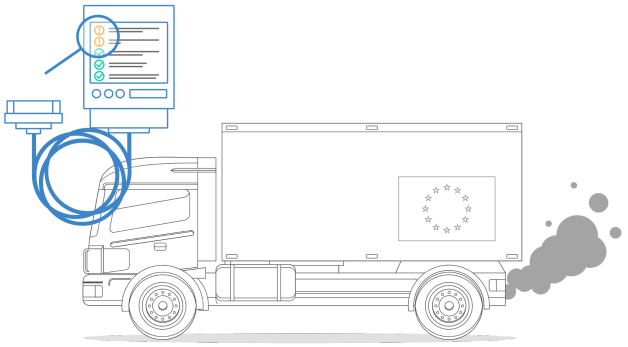

Let's look at each diagnostic protocol:

- ISO OBD (or EOBD) refers to the OBD protocol specification legislated for use in EU cars, while SAE OBD refers to the OBD protocol specification legislated for use in US. The two are technically equivalent and hence often referred to simply as OBD or OBD2
- HD OBD (SAE J1939) typically refers to heavy duty OBD and is commonly implemented through the J1939 protocol in both US and EU produced vehicles with J1939-73 specifying diagnostic messages
- UDS (ISO 14229) has been implemented by vehicle manufacturers to serve the need for richer diagnostics data/functionality - beyond the limits of the emissions-focused OBD protocols. It is implemented in most ECUs today, across markets and vehicle types - though in itself, UDS does not offer the necessary standardization required to serve as an alternative to OBD
- WWH-OBD (and/or possibly OBDonUDS) provide an updated version of OBD2 for emissions-related diagnostics - based on UDS

To understand UDS, it is useful to better understand WWH-OBD and OBDonUDS:

## What is WWH-OBD (ISO 27145)?

WWH-OBD is a global standard for vehicle diagnostics, developed by the UN under the Global Technical Regulations (GTR) mandate. It aims to provide a single, future-proof alternative to the existing OBD protocols (ISO OBD, SAE OBD, HD OBD). Furthermore, WWH-OBD is based on UDS in order to suit the enhanced diagnostics functionality already deployed by most automotive OEMs today.



## Advantages of WWH-OBD

Moving from OBD2 to WWH-OBD will involve a number of benefits, primarily derived from using the UDS protocol as the basis. First of all, the data richness can be increased. OBD2 parameter identifiers (PID) are limited to 1 byte, restricting the number of unique data types to 255, while the UDS data identifier (DID) is 2 bytes, enabling 65535 parameters.

For diagnostic trouble codes (DTCs), OBD2 would allow for 2-byte DTCs. Here, WWH-OBD allows for 'extended DTCs' of 3 bytes. This allows for grouping DTCs by 2-byte types and using the 3rd byte as a failure mode indicator to specify the DTC sub type. Further, WWH-OBD enables a classification of DTCs based on how severe an issue is in regards to the exhaust emissions quality.

WWH-OBD also seeks to take potential future requirements into account by allowing for the Internet Protocol (IP) to be used as an alternative to CAN, meaning that UDSonIP will also be possible in future implementations of WWH-OBD. One potential benefit from this will be the ability to one day perform remote diagnostics through the same protocol.

## What is the status on WWH-OBD roll-out?

The intent of WWH-OBD is to serve as a global standard, across all markets and across all vehicle types (cars, trucks, buses, ...). Further, the aim is to potentially expand the standardized functionality beyond just emissions-control.

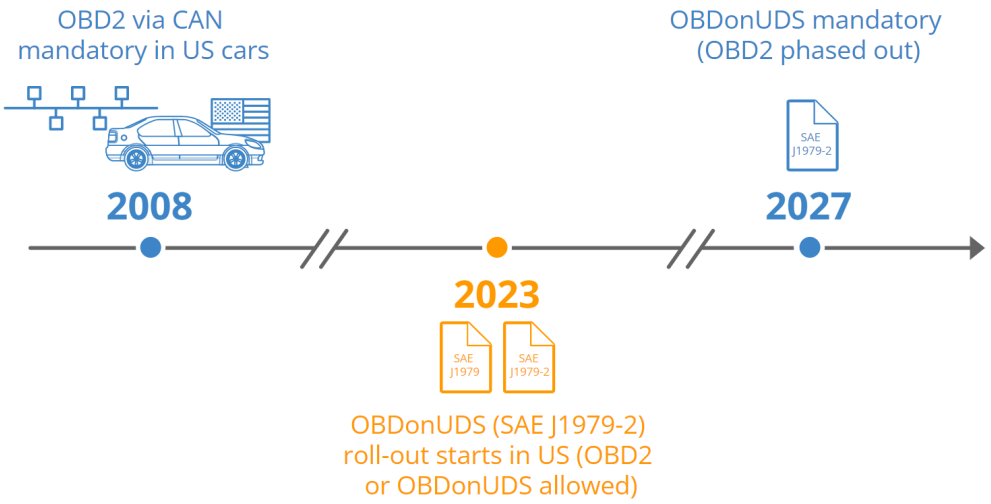
In practice, WWH-OBD has been required in EU since 2014 for newly developed heavy duty vehicles (as per the Euro-VI standards). Note in this case that HD OBD (as per J1939) remains allowed in these vehicles.

Beyond this, however, the roll-out of WWH-OBD has been limited. One challenge is that WWH-OBD is currently not accepted by EPA/CARB in USA. See e.g. this discussion for potential motivations. However, recently OBDonUDS (SAE J1979-2) is being adopted in US.

### What is OBDonUDS (SAE J1979-2)?

Similar to how OBD2 has been split into 'SAE OBD' (SAE J1979) for US and 'ISO OBD' (ISO 15031) for EU, the 'next generation' of OBD2 may again be regionally split.

Specifically, WWH-OBD (ISO 21745) has been adopted in EU for heavy duty vehicles already - but not yet in the US. Instead, it has recently been decided to adopt OBD on UDS in US vehicles in the form of the SAE J1979-2 standard, which serves as an update to the SAE J1979. The new SAE J1979-2 standard is also referred to as OBDonUDS. The aim is to initiate a transition phase starting in 2023, where ECUs are allowed to support either OBD2 or OBDonUDS. From 2027, OBDonUDS will be a mandatory requirement for all vehicles produced in the US.




### Looking ahead: WWH-OBD vs. OBDonUDS

To recap, WWH-OBD and OBDonUDS both serve as possible solutions for creating a 'next generation" protocol for emissions-related on-board diagnostics. It remains to be seen if the two will exist in parallel (like ISO/SAE OBD), or if one of the protocols will become the de facto standard across both US, EU and beyond.

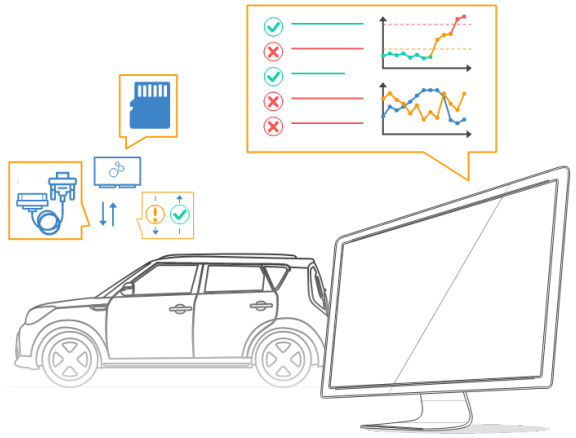
In either case, the basis for emissions-related diagnostics will be UDS, which will serve to simplify ECU programming as the emissions-related diagnostics can increasingly be implemented within the same UDS based structure as the manufacturer specific enhanced diagnostics.

# FAQ: How to request/record UDS data

We have now gone through the basics of UDS and the CAN based transport protocol.

With this in place, we can provide some concrete guidance on how you can work with UDS data in practice. In particular, we will focus on how UDS can be used to log various data parameters - like state of charge (SoC) in electric vehicles.

Before the examples, we'll cover frequently asked questions on UDS data logging:

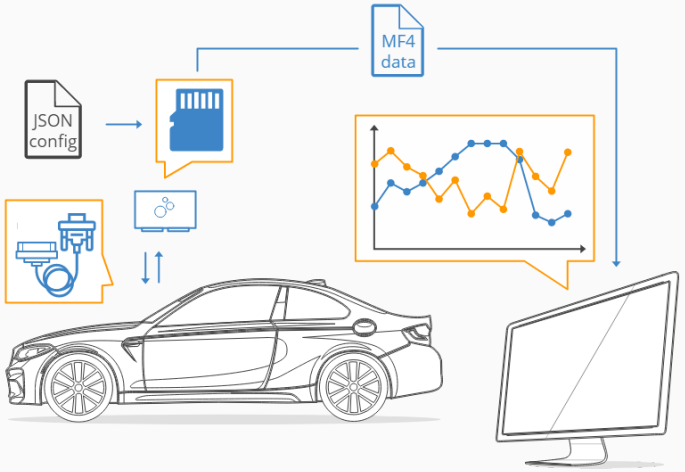


### Can the CANedge record UDS data?

Yes, as we'll show further below, the CANedge can be configured to request UDS data. Effectively, the device can be configured to transmit up to 64 custom CAN frames as periodic or single shot frames. You can control the CAN ID, CAN data payload, period time and delay.

For single-frame UDS communication, you simply configure the CANedge with the request frame, which will trigger a single response frame from the ECU.

For multi-frame communication, you can again configure the CANedge with a request frame and then add the Flow Control frame as a separate frame to be transmitted X milliseconds after the request frame. By adjusting the timing, you can set this up so that the Flow Control is sent after the ECU has sent the First Frame response.




Note that the CANedge will record the UDS responses as raw CAN frames. You can then process and decode this data via your preferred software (e.g. Vector tools) or our CAN bus Python API to reassemble and decode the frames.

Note: In future firmware updates, we may enhance the transmit functionality to enable the CANedge to transmit custom CAN frames based on a trigger condition, such as receiving a specific frame. This would allow for sending the Flow Control frame with a set delay after receiving the First Frame, providing a simpler and more robust

implementation. With that said, the current functionality will serve to support most UDS communicated related to services 0x22 (Read Data by Identifier) and 0x19 (Read DTC Information).

## What data can I log via UDS?

A very common use case for recording UDS data via 'standalone' data loggers will be to acquire diagnostic trouble code values, e.g. for use in diagnosing issues.

In addition to the trouble codes, UDS lets you request the 'current value" of various sensors related to each ECU. This allows e.g. vehicle fleet managers, researchers etc. to collect data of interest such as speed, RPM, state of charge, temperatures etc. from the car (assuming they know how to request/decode the data, as explained below).

Beyond the above, UDS can of course also be used for more low-level control of ECUs, e.g. resets and flashing of firmware, though such use cases are more commonly performed using a CAN bus interface - rather than a 'standalone' device.

## Is UDS data proprietary - or are there public parameters?

Importantly, UDS is a manufacturer specific diagnostic protocol. In other words, while UDS provides a standardized structure for diagnostic communication, the actual 'content" of the communication remains proprietary and is in most cases only known to the manufacturer of a specific vehicle/ECU.

For example, UDS standardizes how to request parameter data from an ECU via the 'Read Data By Identifier" service (0x22). But it does not specify a list of standardized identifiers and interpretation rules. In this way, UDS differs from OBD2, where a public list of OBD2 PIDs enable almost anyone to interpret OBD2 data from their car.

With that said, vehicles that support WWH-OBD or OBDonUDS may support some of the usual OBD2 PIDs like speed, RPM etc via the usual PID values - but with a prefix of 0xF4 as shown in Example 1 below.

Generally, only the manufacturer (OEM) will know how to request proprietary parameters via UDS - and how to interpret the result. Of course, one exception to this rule is cases where companies or individuals successfully reverse engineer this information. Engaging in such reverse engineering is a very difficult task, but you can sometimes find public information and DBC files where others have done this exercise. Our intro to DBC files contain a list of public DBC/decoding databases.

## Who benefits from logging UDS data?

Because of the proprietary nature of UDS communication, it is typically most relevant to automotive engineers working at OEMs. Tools like the CANedge CAN bus data logger allow these users to record raw CAN traffic from a vehicle - while at the same time requesting diagnostic trouble codes and specific parameter values via UDS.

Further, some after market users like vehicle fleet managers and even private persons can benefit from UDS assuming they are able to identify the reverse engineered information required to request and decode the UDS parameters of interest.

Logging UDS data will also become increasingly relevant assuming WWH-OBD gets rolled out as expected. Already today, WWH-OBD is used in EU heavy duty vehicles produced after 2014, meaning UDS communication will be relevant for use cases related to on-board diagnostics in these vehicles.

## Central Gateway (CGW): Why log sensor data via UDS vs. CAN?

If you're looking to request UDS-based diagnostic trouble codes (DTC), you'll of course have to use UDS communication for this purpose. However, if your aim is to record current sensor values it is less clear.
Typically, data parameters of interest for e.g. vehicle telematics (speed, state of charge etc) will already be communicated between ECUs on the CAN bus in the form of raw CAN frames - without the need for a diagnostic tool requesting this information. That is because ECUs rely on communicating this information as part of their operation (as explained in our intro to CAN bus).
If you have direct access to the CAN bus, it would thus appear easier to simply log this raw CAN traffic and process it. If you are the vehicle manufacturer, you will know how to interpret this raw CAN data either way - and it'll be simpler to perform your device configuration and post processing in most cases. If you're in the aftermarket, it'll also be simpler to reverse engineer the raw CAN frames as you can focus on single frames - and avoid the request/response layer of complexity.

However, one key reason why UDS is frequently used for extracting sensor values despite the above is due to 'gateways'. Specifically, an increasing share of modern cars have started to block the access to the raw CAN bus data via the OBD2 connector. This is particularly often the case for German vehicles, as well as electric vehicles.
To record the existing CAN traffic in such a car, you would need to e.g. use a CANCrocodile adapter and 'snap' it onto the CAN low/high wiring harness. This in turn will require exposing the wiring harness by removing a panel, which is often prohibitive for many use cases. In contrast, the OBD2 connector gateways typically still allow for UDS communication - incl. sensor value communication.

A secondary - and more subtle - reason is that most reverse engineering work is done by 'OBD2 dongle manufacturers'. These develop tools that let you extract data across many different cars through the OBD2 connector. Increasingly, the only way for these dongles to get useful information through the OBD2 connector is through UDS communication, which drives a proportionally higher availability of information/databases related to UDS parameters vs. raw CAN parameters.

## Does my vehicle support UDS?

Since most ECUs today support UDS communication, the answer is in "yes, most likely".

If you're the vehicle manufacturer, you will in most cases have the information required to construct UDS requests for whatever data you need - and you'll also know how to decode it.

For the specific case of recording WWH-OBD data in EU trucks, standardized DID information can be recorded by both OEMs and after-market users - similar to how you can record public OBD2 PIDs from cars/trucks.

Beyond the above, if you are in the after market and wish to record proprietary UDS information from a car/truck, it will be difficult. In this case, you would either have to contact the OEM (e.g. as a system integrator/partner) or identify the request/decoding information through reverse engineering. The latter is in practice impossible for most people.

In select cases you may be able to utilize public information shared on e.g. github to help in constructing UDS requests - and decoding the responses. Just keep in mind that public resources are based on reverse engineering efforts - and may risk being incorrect or outdated. You should therefore take all information with a significant grain of salt.

## Why is UDS increasingly important?

If your use case involves recording data from cars produced between 2008 and 2018, you will most often be interested in data that can be collected via OBD2 data logging. This is because most ICE cars after 2008 support a large share of the public OBD2 parameter identifiers like speed, RPM, throttle position, fuel level etc.
However, the availability of OBD2 data is expected to decrease over time for multiple reasons.

First of all, as we explained in the previous section, WWH-OBD (based on UDS) or OBDonUDS are expected to gradually replace OBD2 as the de facto standard for vehicle diagnostics.

Second, with the rise of electric vehicles, legislated OBD2 is not necessarily supported at all. And even if an EV supports some OBD2 PIDs, you'll note from our OBD2 PID list that some of the most relevant EV parameters like State of Charge (SoC) and State of Health (SoH) are not available via OBD2. In contrast, UDS remains supported in most EVs and will provide access to a far broader range of data - although without the after-market convenience of a public list of UDS parameters (at least yet). It is expected that EV sales will overtake ICE car sales between 2030 and 2040 - and thus UDS communication will become increasingly relevant.

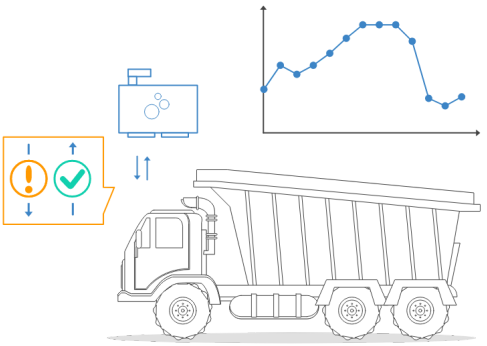
### About the CANedge CAN logger

The CANedge lets you easily record CAN/UDS data to an 8-32 GB SD card. You can customize what CAN frames to send, incl. custom UDS requests and flow control frames. Data can be processed via free software/API tools.


# Example 1: Record single frame UDS data (Speed via WWH-OBD)

To show how UDS works in practice, we will start with a basic example. As outlined before, WWH-OBD is based on UDS - and is mandated in all EU trucks after 2014.

As part of this, many EU heavy duty trucks will let you request parameters like speed, RPM, fuel level etc in a way similar to how you'd request this information via OBD2 PID requests in a car - see our OBD2 intro and OBD2 data logger intro for details. However, under WWH-OBD (ISO 21745-2), the OBD2 PIDs are replaced by the WWH-OBD DIDs.



For service 01, WWH-OBD PIDs are equivalent to the OBD2 PIDs, except that 0xF4 is added in front. For example, the OBD2 PID Vehicle Speed is 0x0D - which becomes 0xF40D in the WWH-OBD context.

In this case, we will use a CANedge2 CAN bus data logger as our "tester" tool. This tool lets you record raw CAN bus data, as well as transmit custom CAN frames. To request WWH-OBD Vehicle Speed, we will use the UDS service 0x22 (Read Data by Identifier) and the Data Identifier 0xF40D. The request/response looks as below:

UDS on CAN - single frame communication example

| Time | CAN ID (HEX) | DataBytes (HEX) | Sender | Frame type |
|---|---|---|---|---|
| 4.0435 | 18DB33F1 | 03 22 F4 0D AA AA AA AA | CANedge (client) | Single Frame (SF) |
| 4.0468 | 18DAF100 | 04 62 F4 0D 32 AA AA AA | ECU (server) | First Frame (FF) |

Legend
PCI field
UDS SID (request)
UDS DID
UDS SID (response)
padding/unused
payload (1 byte)

### Communication flow details

Note how the request is sent with CAN ID 0x18DB33F1. This is the same 29-bit CAN ID that would be used to perform a functionally addressed OBD2 PID request in heavy duty vehicles and can be compared with the 11-bit 0x7DF CAN ID used for OBD2 requests in cars.

The response has CAN ID 0x18DAF100, an example of a physical response ID matching the IDs you'd see in regular OBD2 responses from heavy duty vehicles.

Let's break down the communication flow message payloads:

First, the CANedge2 sends a Single Frame (SF) request:

- The initial 4 bits of the PCI field equal the frame type (0x0 for SF)
- The next 4 bits of the PCI field equal the the length of the request (3 bytes)
- The 2nd byte contains the Service Identifier (SID), in this case 0x22
- The 3rd and 4th bytes contain the DID for Vehicle Speed in WWH-OBD (0xF40D)
- The remaining bytes are padded

In response to this request, the truck responds with a Single Frame (SF) response:

- The 1st byte again reflects the PCI field (now with a length of 4 bytes)
- The 2nd byte is the response SID for Read Data by Identifier (0x62, i.e. 0x22 + 0x40)
- The 3rd and 4th bytes again contain the DID 0xF40D
- The 5th byte contains the value of Vehicle Speed, 0x32

Here we can use the same decoding rules as for ISO/SAE OBD2, meaning that the physical value of Vehicle Speed is simply the decimal form of 0x32 - i.e. 50 km/h. See also our OBD2 PID conversion tool.
If you are familiar with logging OBD2 PIDs, it should be evident that WWH-OBD requests are very similar, except for using the UDSonCAN payload structure for requests/responses.

# Example 2: Record & decode multi frame UDS data (SoC)

In this section, we illustrate how multi frame UDS communication works in the context of CAN ISO-TP.

Specifically, we will use the CANedge2 and the UDS service SID 0x22 (Read Data By Identifier) to request the current value of State of Charge (SoC%) from a Hyundai Kona electric vehicle.


First, the CANedge is configured to send two CAN frames:

1. A Single Frame (SF) request (period: 5000 ms, delay: 0 ms)
2. A Flow Control (FC) frame (period: 5000 ms, delay: 100 ms)

A subset of the resulting communication flow looks as below:

UDS on CAN - multiframe communication example

| Time | CAN ID (HEX) | DataBytes (HEX) | Sender | Frame type |
|---|---|---|---|---|
| 1.0135 | 7E4 | 03 22 01 01 AA AA AA AA | CANedge (client) | Single Frame (SF) |
| 1.0228 | 7EC | 10 3E 62 01 01 FF F7 E7 | ECU (server) | First Frame (FF) |
| 1.0235 | 7E4 | 30 00 00 00 00 00 00 00 | CANedge (client) | Flow Control (FC) |
| 1.0426 | 7EC | 21 FF 96 3E 11 42 90 83 | ECU (server) | Consecutive Frame (CF) |
| 1.0486 | 7EC | 22 00 12 0E F3 17 16 16 | ECU (server) | Consecutive Frame (CF) |
| 1.0586 | 7EC | 23 16 17 16 00 00 18 C3 | ECU (server) | Consecutive Frame (CF) |
| 1.0687 | 7EC | 24 02 C2 0B 00 00 92 00 | ECU (server) | Consecutive Frame (CF) |
| 1.0787 | 7EC | 25 01 04 50 00 01 02 0E | ECU (server) | Consecutive Frame (CF) |
| 1.0886 | 7EC | 26 00 00 63 F3 00 00 60 | ECU (server) | Consecutive Frame (CF) |
| 1.0986 | 7EC | 27 74 00 3D A5 07 0D 01 | ECU (server) | Consecutive Frame (CF) |
| 1.1086 | 7EC | 28 7F 00 00 00 00 03 E8 | ECU (server) | Consecutive Frame (CF) |

Reassembled UDS frame

| | | |
|---|---|---|
| 1.0135 | 7EC | 62 01 01 FF F7 E7 00 00 00 ... 7F 00 00 00 00 03 E8 |

Legend

PCI field
UDS SID (request)
UDS DID
UDS SID (response)
padding/unused
FC block size, ST
payload (59 bytes)

## Communication flow details

In the following we explore this communication between the CANedge and ECU in detail. First of all, the initial Single Frame (SF) request is constructed via the same logic as in our previous example - containing the PCI field, the SID 0x22 and the DID. In this case, we use the DID 0x0101. In response to the initial SF request, the targeted ECU sends a First Frame (FF) response:

- The initial 4 bits equal the frame type (0x1 for FF)
- The next 12 bits equal the data payload size, in this case 62 bytes (0x03E)
- The 3rd byte is the response SID for Read Data by Identifier (0x62, i.e. 0x22 + 0x40)
- The 4th and 5th bytes contain the Data Identifier (DID) 0x0101
- The remaining bytes contain the initial part of the data payload for the DID 0x0101

Following the FF, the tester tool now sends the Flow Control (FC) frame:

- The initial 4 bits equal the frame type (0x3 for FC)
- The next 4 bits specifies that the ECU should "Continue to Send" (0x0)
- The 2nd byte sets remaining frames to be sent without flow control or delay
- The 3rd byte sets the minimum consecutive frame separation time (ST) to 0

Once the ECU receives the FC, it sends the remaining Consecutive Frames (CF):

- The initial 4 bits equal the frame type (0x2 for CF)
- The next 4 bits equal the index counter, incremented from 1 up to 8 in this case
- The remaining 7 bytes of each CF contain the rest of the payload for the DID

## Regarding proprietary UDS data

Part of the information used here is proprietary. In particular, it is generally not known what Data Identifier (DID) to use in order to request e.g. State of Charge from a given electric vehicle, unless you're the vehicle manufacturer (OEM). Further, as explained in the next section, it is not known how to decode the response payload.

However, various online resources exist e.g. on github, where enthusiasts create open source databases for specific parameters and certain cars (based on reverse engineering). The information we use for this specific communication is taken from one such database.

## Regarding the CAN IDs used

In this case we use the CAN ID 0x7E4 to request data from a specific ECU, which in turn responds with CAN ID 0x7EC. This is known as a physically addressed request.

In contrast, functionally addressed request would use the CAN ID 0x7DF (or 0x18DB33F1 in heavy duty vehicles). Generally, request/response CAN IDs are paired (as per the table below) and you can identify the physical request ID corresponding to a specific physical response ID by subtracting the value 8 from the response ID. In other words, if an ECU responds via CAN ID 0x7EC, the physical request ID targeting that ECU would be 0x7E4 (as in our EV example).

Since you may not know what address to target initially, you can in some cases start by sending out a functional request using the CAN ID 0x7DF, in which case the relevant ECU should provide a positive First Frame response if the initial request payload is structured correctly. In some vehicles, you may be able to also send the subsequent Flow Control frame using the same CAN ID, 0x7DF, in order to trigger the ECU to send the remaining Consecutive Frames. However, some implementations may require that you instead utilize the physical addressing request ID for the Flow Control frame.

Implementing a request structure with dynamically updating CAN IDs may be difficult. If you're the manufacturer, you will of course know the relevant CAN IDs to use for sending physically addressed service requests. If not, you may perform an analysis using e.g. a CAN bus interface to identify what response CAN IDs appear when sending functionally addressed service requests - and using this information to construct your configuration.

On a separate note, ISO 15765-4 states that enhanced diagnostics requests/responses may utilize the legislated OBD2 CAN ID range as long as it does not interfere - which is what we are seeing in this specific Hyundai Kona example where the IDs 0x7EC/0x7E4 are used for proprietary data. See also the table from ISO 15765-4 for an overview of the legislated OBD CAN identifiers for use in functional and physical OBD PID requests.

Legislated OBD CAN identifiers (11-bit)

| CAN ID | Description |
|---|---|
| 0x7DF | Functionally addressed request sent by tester |
| 0x7E0 to 0x7E7 | Physical request from tester to ECU #1 to #8 |
| 0x7E8 to 0x7EF | Physical response from ECU #1 to #8 to tester |

Legislated OBD CAN identifiers (29-bit)

| CAN ID | Description |
|---|---|
| 0x18DB33F1 | Functionally addressed request sent by tester |
| 0x18DAxxF1 | Physical request from tester to ECU #xx |
| 0x18DAF1xx | Physical response from ECU #xx to tester |

## Regarding timing parameters

In the above example, we generally focus on the sequence of CAN frames. The sequence is important: For example, if your tester tool sends the Flow Control frame before receiving the First Frame, the Flow Control frame will either be ignored (thus not triggering the Consecutive Frames) or cause an error.

However, in addition to this, certain timing thresholds will also need to be satisfied. For example, if your tester tool receives the First Frame from an ECU of a multi frame response, the ECU will 'time out' if the Flow Control frame is not sent within a set time period.

As a rule of thumb, you should configure your tester (e.g. the CANedge) so that the Flow Control frame is always sent after the First Frame response is received from the ECU (typically this happens within 10-50 ms from sending the initial request) - but in a way so that it is sent within a set time after receiving the First Frame (e.g. within 0-50 ms). For details on this, feel free to contact us.

### How to reassemble and decode multi-frame UDS data?

We've now shown how you can request/record a multi-frame UDS response to collect proprietary ECU sensor data. In order to extract 'physical values' like State of Charge, you need to know how to interpret the response CAN frames. As explained, the 'decoding' information is typically proprietary and only known to the OEM. However, in the specific case of the Hyundai Kona EV, we know the following about the SoC signal from online resources:

- The signal is in the 8th byte of the data payload
- The signal is Unsigned
- The signal has a scale 0.5, offset 0 and unit "%"

So how do we use this knowledge to decode the signal?

First, we need to reassemble the segmented CAN frames. The result of this is shown in the previous communication example. Via reassembly, we get a "CAN frame" with ID 0x7EC and a payload exceeding 8 bytes. The payload in this case contains the SID in the 1st byte and DID in the 2nd and 3rd bytes.

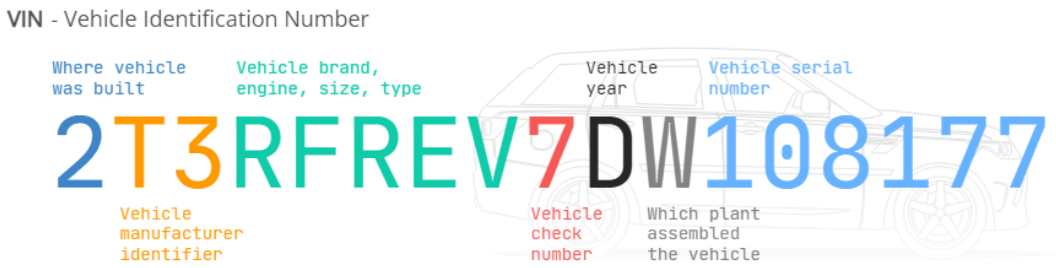

You could process the reassembled CAN frame manually in e.g. Excel. However, we generally recommend to use CAN databases (DBC files) to store decoding rules. In this particular case, you can treat the reassembled CAN frame as a case of extended multiplexing. We provide an example UDS DBC file for the Hyundai Kona incl. State of Charge and temperature signals, which can be useful as inspiration.

Our CAN bus Python API enables reassembly & DBC decoding of multi-frame UDS responses - see our API examples repository for more details incl. the Hyundai Kona sample data.

```
BO_ 2028 Battery: 62 Vector__XXX
 SG_ M_SID_0x220101_StateOfChargeBMS m257 : 56|8@1+ (0.5,0) [0|0] "%" Vector__XXX
 SG_ response m98M : 15|16@0+ (1,0) [0|0] "unit" Vector__XXX
 SG_ service M : 7|8@0+ (1,0) [0|0] "" Vector__XXX

BO_ 1979 Temperature: 54 Vector__XXX
 SG_ M_SID_0x220100_IndoorTemp m256 : 64|8@1+ (0.5,-40) [0|0] "degC" Vector__XXX
 SG_ response m98 : 15|16@0+ (1,0) [0|0] "unit" Vector__XXX
 SG_ service M : 7|8@0+ (1,0) [0|0] "" Vector__XXX
 SG_ M_SID_0x220100_OutdoorTemp : 79|8@0+ (0.5,-40) [0|0] "" Vector__XXX
 SG_ M_SID_0x220100_Speed : 255|8@0+ (0.5,0) [0|0] "" Vector__XXX


BA_DEF_ BO_  "VFrameFormat" ENUM  "StandardCAN","ExtendedCAN","StandardCAN_FD","ExtendedCAN_FD","J1939PG";
BA_DEF_  "ProtocolType" STRING ;
BA_DEF_DEF_  "VFrameFormat" "";
BA_DEF_DEF_  "ProtocolType" "";
BA_ "ProtocolType" "";
BA_ "VFrameFormat" BO_ 2028 0;

SG_MUL_VAL_ 2028 M_SID_0x220101_StateOfChargeBMS response 257-257;
SG_MUL_VAL_ 2028 response service 98-98;
```

# Example 3: Record the Vehicle Identification Number

The Vehicle Identification Number (aka VIN, chassis number, frame number) is a unique identifier code used for road vehicles. The number has been standardized and legally required since the 1980s - for details see the VIN page on Wikipedia.




A VIN consists of 17 ASCII characters and can be extracted on-request from a vehicle. This is useful in e.g. data logging or telematics use cases where a unique identifier is required for association with e.g. CAN bus log files.

CAN data bytes can be converted from HEX to ASCII via tables, online HEX to ASCII converters, Python packages etc. For example, the byte 0x47 corresponds to the letter "G". Since a VIN is 17 bytes (17 ASCII characters) long, it does not fit into a single CAN frame, but has to be extracted via a multi frame diagnostic request/response as in Example 2. Further, the VIN is extracted differently depending on the protocol used.

Below we provide three examples on how to record the VIN.

### 3.1: How to record the VIN via OBD2 (SAE J1979)

To extract the Vehicle Identification Number from e.g. a passenger car using OBD2 requests, you use Service 0x09 and the PID 0x02:

VIN - Vehicle Identification Number request/response (OBD2)

| Time | CAN ID (HEX) | DataBytes (HEX) | Sender | Frame type |
|---|---|---|---|---|
| 1.0135 | 7E0 | 02 09 02 AA AA AA AA AA | CANedge (client) | Single Frame (SF) |
| 1.0228 | 7E8 | 10 14 49 02 01 32 54 33 | ECU (server) | First Frame (FF) |
| 1.0235 | 7E0 | 30 00 00 00 00 00 00 00 | CANedge (client) | Flow Control (FC) |
| 1.0426 | 7E8 | 21 52 46 52 45 56 37 44 | ECU (server) | Consecutive Frame (CF) |
| 1.0486 | 7E8 | 22 57 31 30 38 31 37 37 | ECU (server) | Consecutive Frame (CF) |

Reassembled OBD2 frame

| Time | CAN ID (HEX) | DataBytes (HEX) |
|---|---|---|
| 1.0135 | 7E8 | 49 02 01 32 54 33 52 46 52 45 56 37 44 57 31 30 38 31 37 37 |

VIN = 2T3RFREV7DW108177

Legend
- PCI field
- OBD service (request)
- OBD PID
- OBD service (response)
- NODI
- padding/unused
- FC block size, ST
- payload (17 bytes)

#### Communication flow details

The logic of the frame structure is identical to Example 2, with the tester tool sending a Single Frame request with the PCI field (0x02), request service identifier (0x09) and data identifier (0x02).

The vehicle responds with a First Frame containing the PCI, length (0x014 = 20 bytes), response SID (0x49, i.e. 0x09 + 0x40) and data identifier (0x02). Following the data identifier is the byte 0x01 which is the Number Of Data Items (NODI), in this case 1 (see SAE J1979 or ISO 15031-5 for details).

The remaining 17 bytes equal the VIN and can be translated from HEX to ASC via the methods previously discussed.

### 3.2: How to record the VIN via UDS (ISO 14229-2)

To read the Vehicle Identification Number via UDS, you can use the UDS SID 0x22 and the DID 0xF190:

VIN - Vehicle Identification Number request/response (UDS on CAN)

| Time | CAN ID (HEX) | DataBytes (HEX) | Sender | Frame type |
|---|---|---|---|---|
| 1.0135 | 7E0 | 03 22 F1 90 AA AA AA AA | CANedge (client) | Single Frame (SF) |
| 1.0228 | 7E8 | 10 14 62 F1 90 32 54 33 | ECU (server) | First Frame (FF) |
| 1.0235 | 7E0 | 30 00 00 00 00 00 00 00 | CANedge (client) | Flow Control (FC) |
| 1.0426 | 7E8 | 21 52 46 52 45 56 37 44 | ECU (server) | Consecutive Frame (CF) |
| 1.0486 | 7E8 | 22 57 31 30 38 31 37 37 | ECU (server) | Consecutive Frame (CF) |

**Reassembled UDS frame**

1.0135 7E8 62 F1 90 32 54 33 52 46 52 45 56 37 44 57 31 30 38 31 37 37

VIN = 2T3RFREV7DW108177

**Legend**

PCI field
UDS SID (request)
UDS DID
UDS SID (response)
padding/unused
FC block size, ST
payload (17 bytes)

### Communication flow details

As evident, the request/response communication flow looks similar to the OBD2 case above. The main changes relate to the use of the UDS service 0x22 instead of the OBD2 service 0x09 - and the use of the 2-byte UDS DID 0xF190 instead of the 1 byte OBD2 PID 0x02. Further, the UDS response frame does not include the Number of Data Items (NODI) field after the DID, in contrast to what we saw in the OBD2 case.

## 3.3: How to record the VIN via WWH-OBD (ISO 21745-3)

If you need to request the Vehicle Identification Number from an EU truck after 2014, you can use the WWH-OBD protocol. The structure is identical to the UDS example, except that WWH-OBD specifies the use of the DID 0xF802 for the VIN.

VIN - Vehicle Identification Number request/response (WWH-OBD on CAN)

| Time | CAN ID (HEX) | DataBytes (HEX) | Sender | Frame type |
|---|---|---|---|---|
| 1.0135 | 18DB33F1 | 03 22 F8 02 AA AA AA AA | CANedge (client) | Single Frame (SF) |
| 1.0228 | 18DAF100 | 10 14 62 F8 02 32 54 33 | ECU (server) | First Frame (FF) |
| 1.0235 | 18DB33F1 | 30 00 00 00 00 00 00 00 | CANedge (client) | Flow Control (FC) |
| 1.0426 | 18DAF100 | 21 52 46 52 45 56 37 44 | ECU (server) | Consecutive Frame (CF) |
| 1.0486 | 18DAF100 | 22 57 31 30 38 31 37 37 | ECU (server) | Consecutive Frame (CF) |

**Reassembled WWH-OBD frame**

1.0135 18DAF100 49 F8 02 32 54 33 52 46 52 45 56 37 44 57 31 30 38 31 37 37

VIN = 2T3RFREV7DW108177

**Legend**

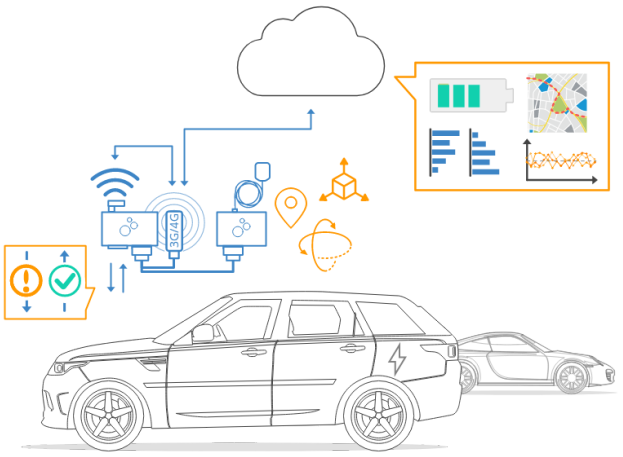
PCI field
UDS SID (request)
UDS DID
UDS SID (response)
padding/unused
FC block size, ST
payload (17 bytes)

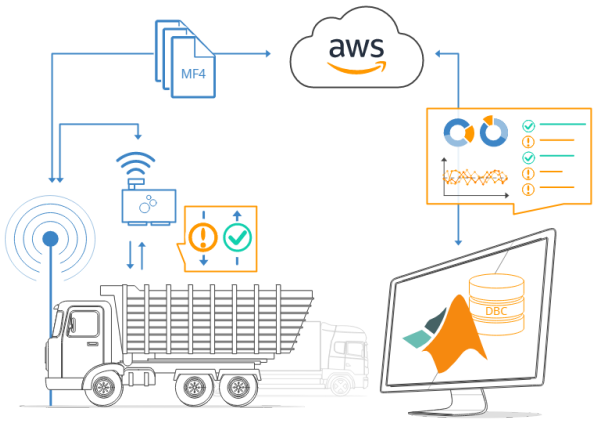
# UDS data logging - applications

In this section, we outline example use cases for recording UDS data.

## UDS telematics for prototype electric vehicles

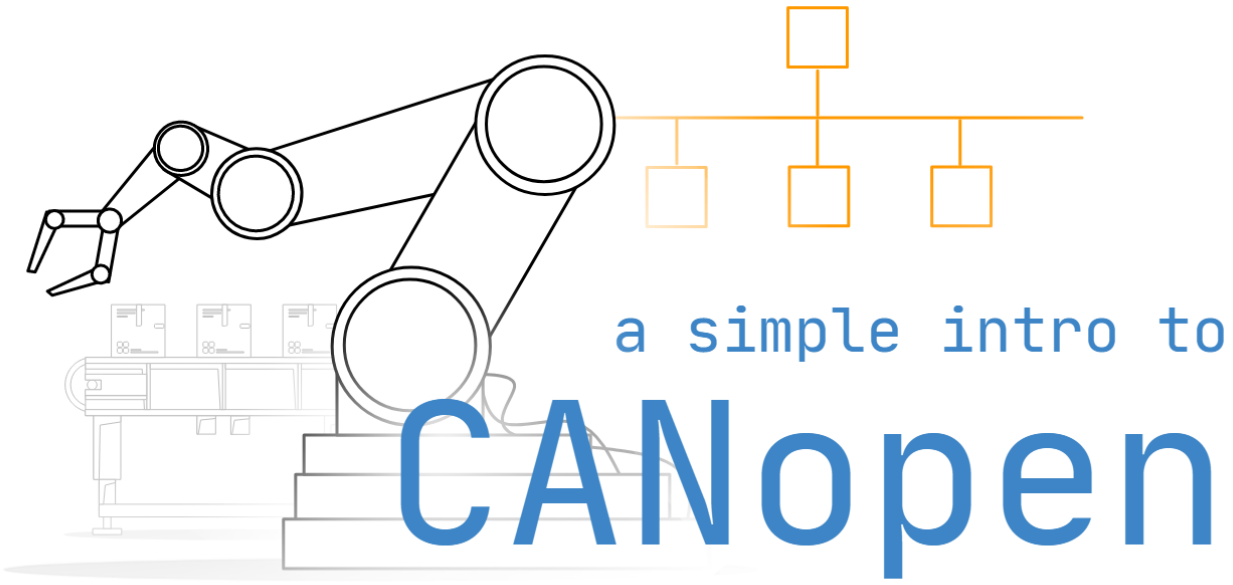
As an OEM, you may need to get data on various sensor parameters from prototype EVs while they are operating in the field. Here, the CANedge2 can be deployed to request data on e.g. state of charge, state of health, temperatures and more by transmitting UDS request frames and flow control frames periodically. The data can e.g. be combined with GNSS/IMU data from a CANmod.gps and sent via a 3G/4G access point to your own cloud server for analysis via Vector tools, Python or MATLAB.




## Training a predictive maintenance model

If you're looking to implement predictive maintenance across fleets of heavy duty vehicles, the first step is typically to "train your model". This requires large amounts of training data to be collected, including both sensor data (speed, RPM, throttle position, tire pressures etc) and "classification results" (fault / no fault). One way to obtain the latter is by periodically requesting diagnostic trouble codes from the vehicle, providing you with log files that combine both types of data over time. You can use the CANedge1 to collect this data offline onto SD cards, or the CANedge2 to automatically offload the data - e.g. when the vehicles return to stationary WiFi routers in garages.



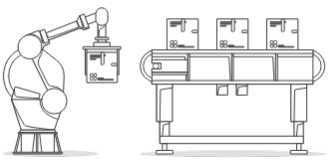

# CANopen Explained - A Simple Intro

In this guide we introduce the CANopen protocol basics incl. the object dictionary, services, SDO, PDO and master/slave nodes. CANopen can seem complex - so this tutorial is a visual intro in layman's terms.

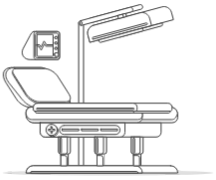
## What is CANopen?

CANopen is a CAN based communication protocol.

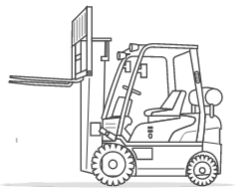
The CANopen standard is useful as it enables off-the-shelf interoperability between devices (nodes) in e.g. industrial machinery. Further, it provides standard methods for configuring devices - also after installation. CANopen was originally designed for motion-oriented machine control systems. Today, CANopen is extensively used in motor control (stepper/servomotors) - but also a wide range of other applications:



**Robotics**
Automated robotics, conveyor belts & other industrial machinery



**Medical**
X-ray generators, injectors, patient tables & dialysis devices



**Automotive**
Agriculture, railway, trailers, heavy duty, mining, marine & more

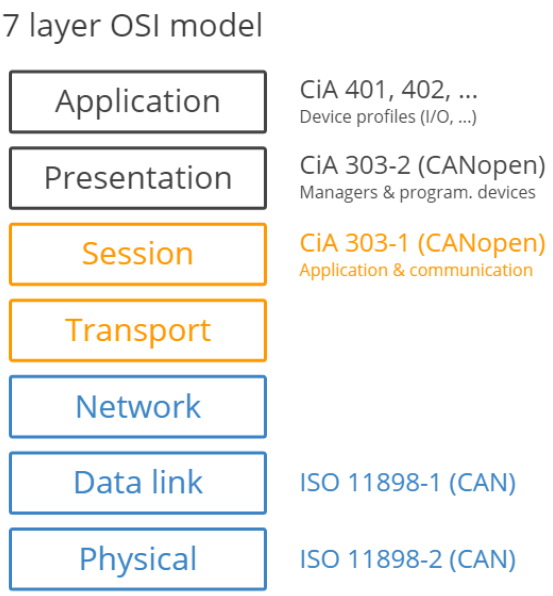
### CANopen - higher layer protocol

The following is important to understand:

**CANopen is a "higher layer protocol" based on CAN bus.**

This means that CAN bus (ISO 11898) serves as the 'transport vehicle' (like a truck) for CANopen messages (like containers).

You can view CANopen from a 7-layer OSI model.




### CANopen in OSI model context

The OSI model is a conceptual model standardizing communication functions across diverse communication technologies. Lower layers describe basic communication (e.g. raw bit streams), while higher layers describe things like segmentation of long messages and services like initiating, indicating, responding, and confirming of messages.
CAN bus represents the two lowest layers (1: Physical, 2: Data Link). This means that CAN simply enables the transmission of frames with an 11 bit CAN ID, a remote transmission (RTR) bit and 64 data bits (fields relevant to higher-layer protocols). In other words, CAN bus plays the same role in CANopen as it does in e.g. the J1939 protocol.
As evident above, CANopen implements the 7th layer of the OSI model (Application) via a set of standards. As part of this, it adds several important concepts that we detail below. It's worth noting, that CANopen could also be adapted to other data link layer protocols than CAN (e.g. EtherCAT, Modbus, Powerlink). To fully understand CAN bus vs. CANopen, see also our CAN bus intro tutorial.

### CANopen FD

In this article we primarily focus on CANopen based on Classical CAN. However, it is worth noting that as CAN FD is being rolled out, CANopen FD may play an increasingly important role as the next generation of CANopen. For details, see the overview by CAN in Automation on CANopen FD.

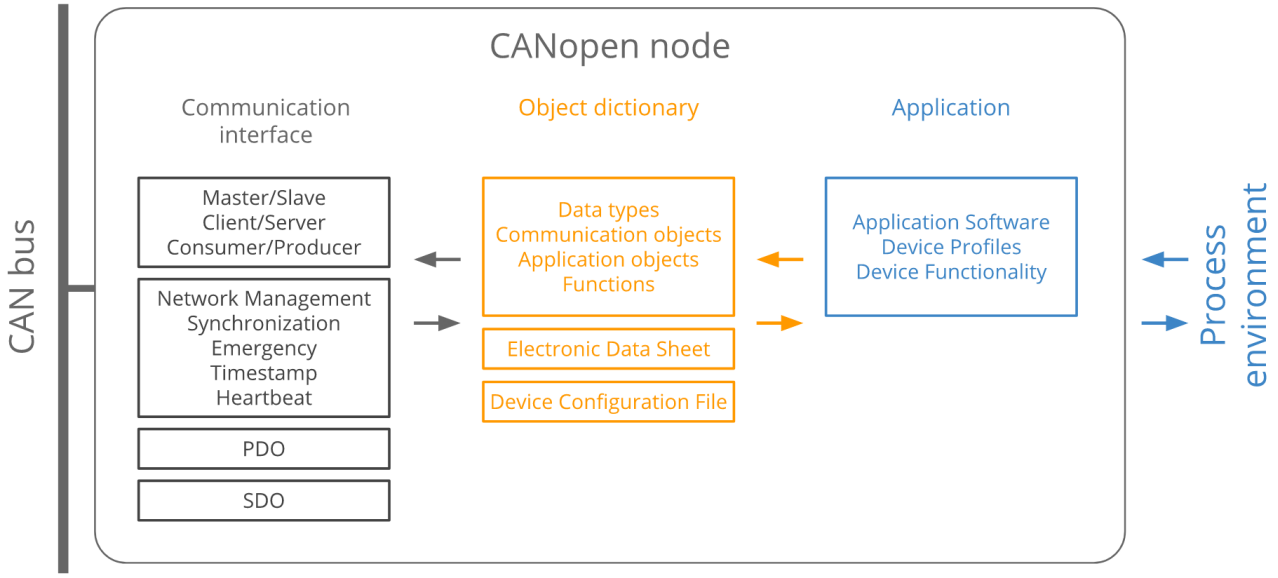
# Six core CANopen concepts

Even if you're familiar with CAN bus and e.g. J1939, CANopen adds a range of important new concepts:


**Communication Models** | **Communication Protocols** | **Device States** | **Object Dictionary** | **Electronic Data Sheet** | **Device Profiles Standards** describe e.g. I/O

| | | | | | |
|---|---|---|---|---|---|
| There are 3 models for device/node communication: Master/slave, client/server and producer/consumer | Protocols are used in communication, e.g. configuring nodes (SDOs) or transmitting real-time data (PDOs) | A device supports different states. A 'master' node can change state of a 'slave' node - e.g. resetting it | Each device has an OD with entries that specify e.g. the device config. It can be accessed via SDOs | The EDS is a standard file format for OD entries - allowing e.g. service tools to update devices | modules (CiA 401) and motion-control (CiA 402) for vendor independence |

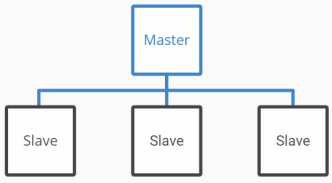
The below illustration shows how the CANopen concepts link together - and we will detail each below:



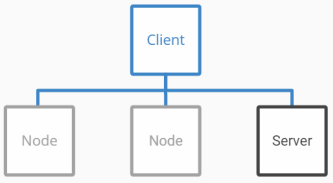

# CANopen communication basics

In a CANopen network, several devices need to communicate. For example, in an industrial automation setup you may have a robot arm with multiple servomotor nodes and a control interface/PC node. To facilitate communication, three models exist within CANopen - each closely linked to the CANopen protocols that we look at shortly. See below for a brief introduction:

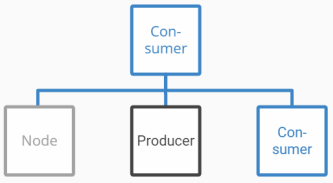
**CANopen communication models**




**Master/Slave**
One node (e.g. the control interface) acts as application master or host controller. It sends/requests data from the slaves (e.g. the servo motors). This is used in e.g. diagnostics or state management.




**Client/Server**
A client sends a data request to a server, which replies with the requested data. Used e.g. when an application master needs data from the OD of a slave. A read from a server is an "upload", while a write is



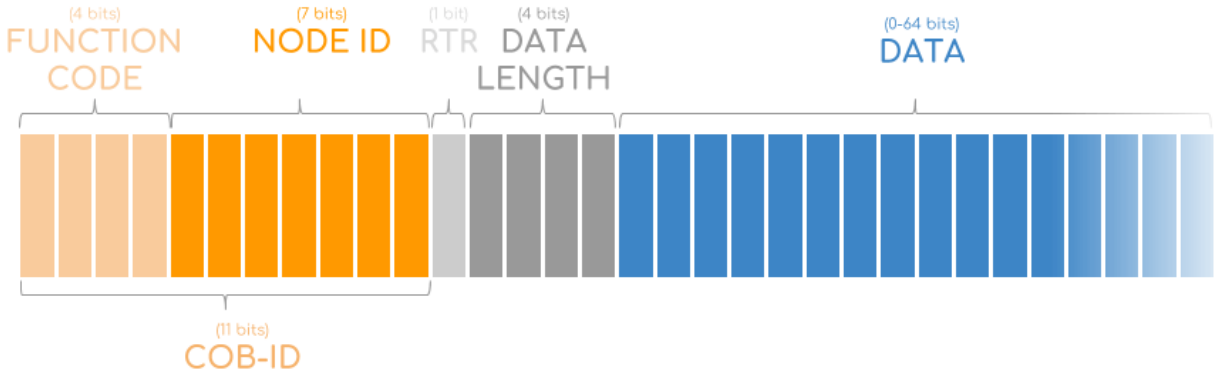

**Consumer/Producer**
Here, the producer node broadcasts data to the network, which is consumed by the consumer node. The producer either sends this data on request (pull model) or without a specific request (push model).

| | | |
|---|---|---|
| There can be 0-127 slaves in standard applications. Note that in a single CANopen network, there can be different host controllers sharing the same data link layer.<br>Service example: NMT | a "download" (the terminology takes a "server side" perspective).<br>Service example: SDO | Service example: Heartbeat |

As evident, the models are practically identical, but we distinguish between them for terminology consistency.

## The CANopen frame

To understand CANopen communication, it is necessary to break down the CANopen CAN frame:



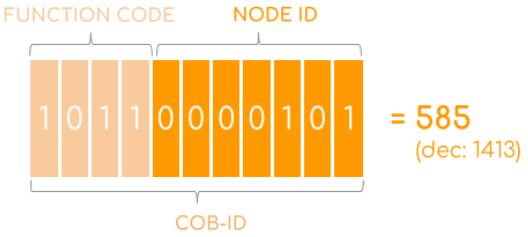

The 11-bit CAN ID is referred to as the Communication Object Identifier (COB-ID) and is split in two parts: By default, the first 4 bits equal a function code and the next 7 bits contain the node ID.

To understand how the COB-ID works, let's take outset in the pre-defined allocation of identifiers used in simple CANopen networks (see the table). Note: We'll refer to COB-IDs and Node IDs in HEX below. As evident, the COB-IDs (e.g. 381, 581, ...) are linked to the communication services (transmit PDO 3, transmit SDO, ...). As such, the COB-ID details which node is sending/receiving data - and what service is used.

| | COMMUNICATION OBJECT | FUNCTION CODE (4 bit, bin) | NODE IDs (7 bit, bin) | COB-IDs (hex) | COB-IDs (dec) | # |
|---|---|---|---|---|---|---|
| 1 | NMT | 0000 | 0000000 | 0 | 0 | 1 |
| 2 | SYNC | 0001 | 0000000 | 80 | 128 | 1 |
| 3 | EMCY | 0001 | 0000001-1111111 | 81 - FF | 129 - 255 | 127 |
| 4 | TIME | 0010 | 0000000 | 100 | 256 | 1 |
| 5 | Transmit PDO 1 | 0011 | 0000001-1111111 | 181 - 1FF | 385 - 511 | 127 |
| | Receive PDO 1 | 0100 | 0000001-1111111 | 201 - 27F | 513 - 639 | 127 |
| | Transmit PDO 2 | 0101 | 0000001-1111111 | 281 - 2FF | 641 - 767 | 127 |
| | Receive PDO 2 | 0110 | 0000001-1111111 | 301 - 37F | 769 - 895 | 127 |
| | Transmit PDO 3 | 0111 | 0000001-1111111 | 381 - 3FF | 897 - 1023 | 127 |
| | Receive PDO 3 | 1000 | 0000001-1111111 | 401 - 47F | 1025 - 1151 | 127 |
| | Transmit PDO 4 | 1001 | 0000001-1111111 | 481 - 4FF | 1153 - 1279 | 127 |
| | Receive PDO 4 | 1010 | 0000001-1111111 | 501 - 57F | 1281 - 1407 | 127 |
| 6 | Transmit SDO | 1011 | 0000001-1111111 | 581 - 5FF | 1409 - 1535 | 127 |
| | Receive SDO | 1100 | 0000001-1111111 | 601 - 67F | 1537 - 1693 | 127 |
| 7 | HEARTBEAT | 1110 | 0000001-1111111 | 701 - 77F | 1793 - 1919 | 127 |

### Example

A CANopen device with node ID 5 would transmit an SDO via the 11-bit CAN ID 585.
This corresponds to a binary function code of 1011 and a node ID of 5 (binary: 0000101) - see the illustration.



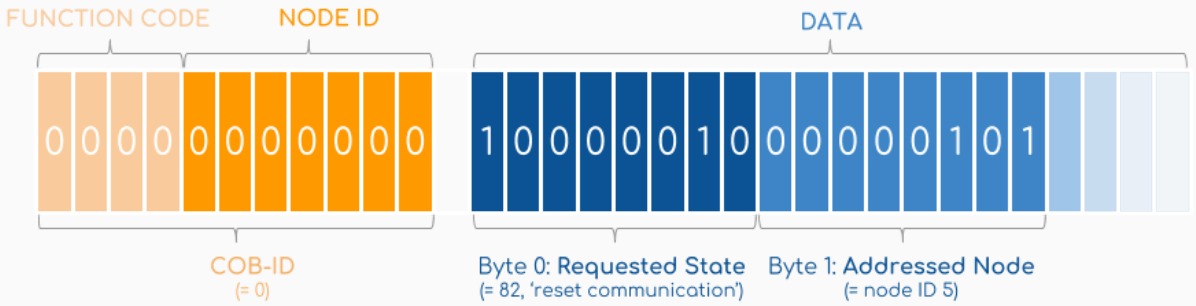

## CANopen communication protocols/services

Below we briefly outline the 7 service types mentioned, incl. how they utilize the 8 CAN frame data bytes.

### #1 Network Management (NMT)

**What is it?** The NMT service is used for controlling the state of CANopen devices (e.g. pre-operational, operational, stopped) by means of NMT commands (e.g. start, stop, reset).

**How does it work?** To change state, the NMT master sends a 2-byte message with CAN ID 0 (i.e. function code 0 and node ID 0). All slave nodes process this message. The 1st CAN data byte contains the requested state - while the 2nd CAN data byte contains the node ID of the targeted node. The node ID 0 indicates a broadcast command.




Possible commands include transition to operational (state 01), to stopped (state 02), pre-operational (state 80) as well as reset application (81) and reset communication (82).

### #2 Synchronization (SYNC)

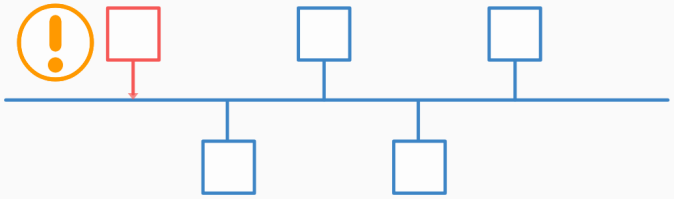
**What is it?** The SYNC message is used e.g. to synchronize the sensing of inputs and actuation of several CANopen devices - typically triggered by the application master.

**How does it work?** The application master sends the SYNC message (COB ID 080) to the CANopen network (with or without SYNC counter). Multiple slave nodes may be configured to react to the SYNC and respond by transmitting input data captured at the very same time or by setting the output at the very same time as the nodes participating in the synchronous operation. Using the SYNC counter several groups of synchronously operating devices can be configured.

### #3 Emergency (EMCY)

**What is it?** The emergency service is used in case a device experiences a fatal error (e.g. a sensor failure), allowing it to indicate this to the rest of the network.

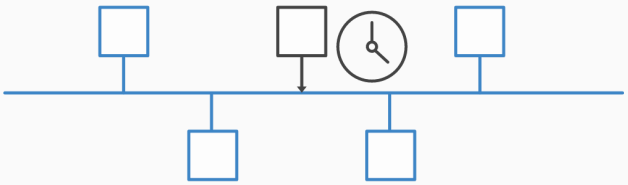
**How does it work?** The affected node sends a single EMCY message (e.g. with COB-ID 085 for node 5) to the network with high priority. The data bytes contain information about the error, which can be looked up for details.



### #4 Timestamp (TIME) [PDO]

**What is it?** With this communication service a global network time can be distributed. The TIME service contains a 6-byte date & time information.

**How does it work?** An application master sends out the TIME message with CAN ID 100, where the initial 4 data bytes contain time in ms after midnight and the next 2 bytes contain the number of days since January 1, 1984.



### #5 Process Data Object [PDO]

**What is it?** The PDO service is used to transmit real-time data between devices - e.g. measured data such as position or command data such as torque requests. In this respect it is similar to e.g. broadcasted data parameters in J1939.

**How does it work?** We'll deep dive on this further below.

### #6 Service Data Object [SDO]

**What is it?** The SDO services are used to access/change values in the object dictionary of a CANopen device - e.g. when an application master needs to change certain configurations of a CANopen device.

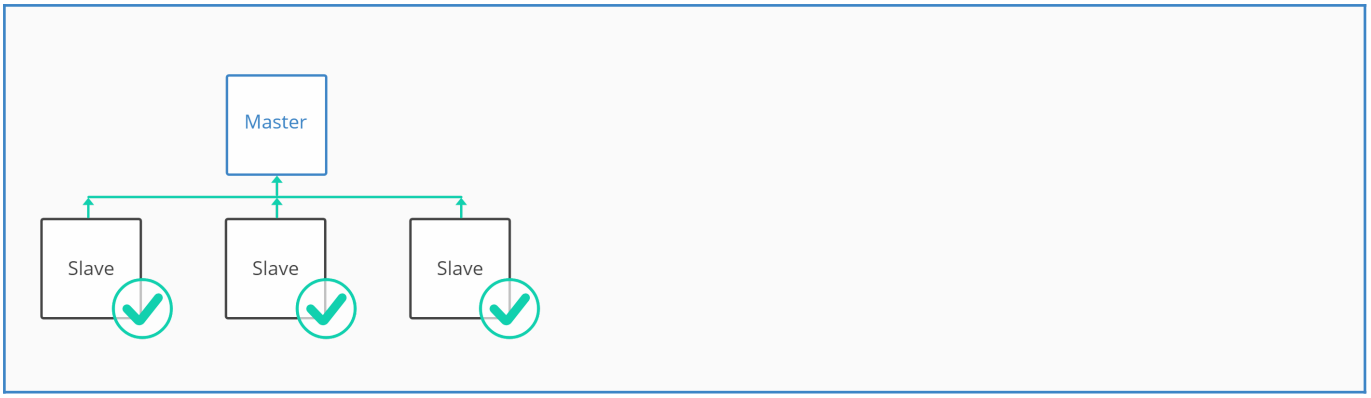
**How does it work?** We'll deep dive on this further below.

### #7 Node monitoring (Heartbeat) [SDO]

**What is it?** The Heartbeat service has two purposes: To provide an 'alive' message and to confirm the NMT command.

**How does it work?** An NMT slave device periodically sends (e.g. every 100ms) the Heartbeat message (e.g. with CAN ID 705 for node 5) with the node's "state" in the 1st data byte

The "consumer" of the Heartbeat message (e.g. the NMT master and optionally any other device) then reacts if no message is received in a certain time limit.




The PDO and SDO services are particularly important as they form the basis for most CANopen communication. Below we deep-dive on each of these - but first we need to introduce a core concept of CANopen: The object dictionary.

# CANopen Object Dictionary

All CANopen nodes must have an object dictionary (OD) - but what is it? The object dictionary is a standardized structure containing all parameters describing the behavior of a CANopen node. OD entries are looked up via a 16-bit index and 8-bit subindex. For example, index 1008 (subindex 0) of a CANopen-compliant node OD contains the node *device name*.

Specifically, an entry in the object dictionary is defined by attributes:

- Index: 16-bit base address of the object
- Object name: Manufacturer device name
- Object code: Array, variable, or record
- Data type: E.g. VISIBLE_STRING, or UNSIGNED32 or Record Name
- Access: rw (read/write), ro (read-only), wo (write-only)
- Category: Indicates if this parameter is mandatory/optional (M/O)

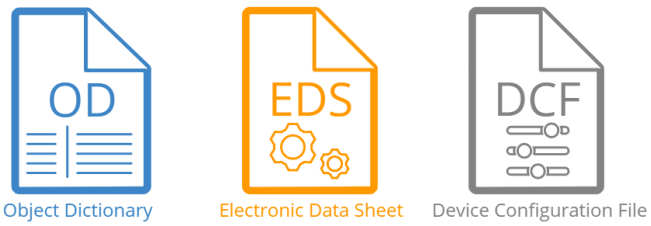
### OD standardized sections

The object dictionary is split into standardized sections where some entries are mandatory and others are fully customizable. Importantly, OD entries of a device (e.g. a slave) can be accessed by another device (e.g. a master) via CAN using e.g. SDOs. For example, this might let an application master change whether a slave node logs data via a specific input sensor - or how often the slave sends a heartbeat.

| OD INDEX (16 bits, hex) | DESCRIPTION |
|---|---|
| 0000 | Reserved |
| 0001 - 025F | Data types |
| 0260 - 0FFF | Reserved |
| 1000 - 1FFF | Communication object area |
| 2000 - 5FFF | Manufacturer specific area |
| 6000 - 9FFF | Device profile specific area |
| A000 - BFFF | Interface profile specific area |
| C000 - FFFF | Reserved |

### Link to Electronic Data Sheet and Device Configuration File

To understand the OD, it is helpful to look at the 'human-readable form': The Electronic Data Sheet and Device Configuration File.




**The Electronic Data Sheet (EDS)**
In practice, configuring/managing complex CANopen networks will be done using adequate software tools.
To simplify this, the CiA 306 standard defines a human-readable (and machine friendly) INI file format, acting as a "template" for the OD of a device - e.g. the "ServoMotor3000". This EDS is typically provided by the vendor and contains info on all device objects (but not values).

**Device Configuration File (DCF)**
Assume a factory has bought a ServoMotor3000 to integrate into their conveyor belt. In doing so, the operator edits the device EDS and adds specific parameter values and/or changes the names of each object described in the EDS. In doing so, the operator effectively creates what is known as a Device Configuration File (DCF). With this in place, the ServoMotor3000 is ready for integration into the specific CANopen network on-site.

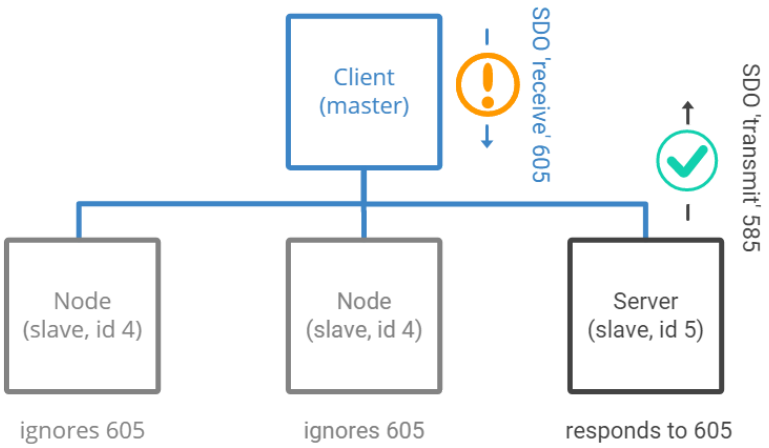
### EDS and DCF example

Reviewing real EDS/DCF examples is one of the best ways to really understand the object dictionary of CANopen - see e.g. the difference between an EDS and DCF object entry below. We recommend checking out the CiA 306 standard to gain a deeper understanding of the OD, EDS and DCF with practical examples.


As mentioned, the DCF is typically created upon device integration. However, often it will be necessary to read and/or change the object values of a node after initial configuration - this is where the CANopen SDO service comes into play.

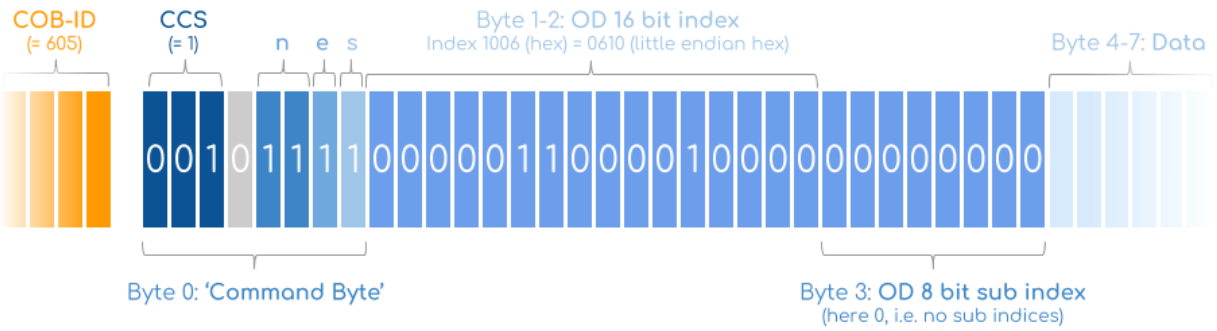
# SDO - configuring the CANopen network

What is the SDO service? The SDO service allows a CANopen node to read/edit values of another node's object dictionary over the CAN network. As mentioned under 'communication models', the CANopen SDO services utilize a "client/server" behavior. Specifically, an SDO "client" initiates the communication with one dedicated SDO "server". The purpose can be to update an OD entry (called an "SDO download") or read an entry ("SDO upload"). In simple master/slave networks, the node with NMT master functionality acts as the client for all NMT slave nodes reading or writing to their ODs.




### Example: Client node SDO download

The client node can initiate an SDO download to node 5 by broadcasting below CAN frame - which will trigger node 5 (and be ignored by other nodes, see above illustration). The SDO 'receive' (i.e. request) CAN frame looks as below:




### SDO message variables explained

- First, COB-ID 605 reflects the use of an 'SDO receive' (COB-ID 600 + node ID).
- The CCS (client command specifier) is the transfer type (e.g. 1: Download, 2: Upload)
- n is the #bytes in data bytes 4-7 that do not contain data (valid if e & s are set)
- If set, e indicates an "expedited transfer" (all data is in a single CAN frame)
- If set, s indicates that data size is shown in n
- Index (16 bits) and subindex (8 bits) reflect the OD address to be accessed
- Finally, bytes 4-7 contain the data to be downloaded to node 5

### CANopen SDO example comments

Once the CAN frame is sent by the master (client), the slave node 5 (server) responds via an 'SDO transmit' with COB-ID 585. The response contains the index/subindex and 4 empty data bytes. Naturally, if the client node requested an upload instead (i.e. reading data from the node 5 OD), node 5 would respond with the relevant data contained in bytes 4-7. A few comments:

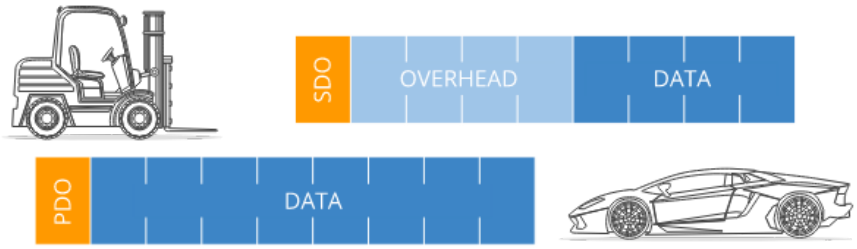
- As evident, each SDO uses 2 identifiers, creating an "SDO channel"
- The example is simplified as it's "expedited" (data is contained in the 4 bytes)
- For larger data scenarios, SDO segmentation/block transfers can be used

SDOs are flexible, but carry a lot of overhead - making them less ideal for real-time operational data. This is where the PDO comes in.

# PDO - operating the CANopen network

First of all: What is the CANopen PDO service? The CANopen PDO service is used for effectively sharing real-time operational data across CANopen nodes. For example, the PDO would carry pressure data from a pressure transducer - or temperature data from a temperature sensor. But wait: Can't the SDO service just do this?

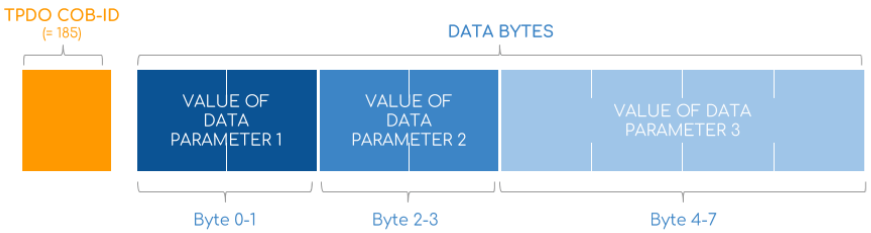
Yes, in principle the SDO service could be used for this. However, a single SDO response can only carry 4 data bytes due to overhead (command byte and OD addresses). Further, let's say a master node needs two parameter values (e.g. "SensTemp2" and "Torque5") from Node 5 - to get this via SDO, it would require 4 full CAN frames (2 requests, 2 responses).




In contrast, a PDO message can contain 8 full bytes of data - and it can contain multiple object parameter values within a single frame. Thus, what would require at least 4 frames with SDO could potentially be done with 1 frame in the PDO service. The PDO is often seen as the most important CANopen protocol as it carries the bulk of information.

## How does the CANopen PDO service work?

For PDOs, the consumer/producer terminology is used. Thus, a producer 'produces data', which it transmits to a 'consumer' (master) using a transmit PDO (TPDO). Conversely, it may receive data from the consumer via a receive PDO (RPDO). Producer nodes may e.g. be configured to respond to a SYNC trigger broadcasted by the consumer every 100 ms. Node 5 may then e.g. broadcast below transmit PDO with COB-ID 185:




Note how the data bytes are packed with 3 parameter values. These values reflect real-time data of specific OD entries of node 5. The nodes that use this information (the consumers) of course need to know how to interpret the PDO data bytes.

### PDO service vs. J1939 PGNs and SPNs

Isn't the PDO service a bit similar to J1939 PGNs & SPNs? Yes, to some extent this is similar to how a specific J1939 parameter group (PG) will contain multiple SPNs/signals (aka data parameters) in the 8 data bytes. The J1939 CAN frame does not need to waste data bytes on "decoding" information because this is known by the relevant nodes (and by external tools via e.g. J1939 DBC files or the J1939 PDF standards). The wrinkle is that in CANopen, these 'PDO mappings' are often configurable and can be changed during the creation of the DCF and/or via the SDO service. For more details on PDOs, see this article (p. 5).

# CANopen data logging - use case examples

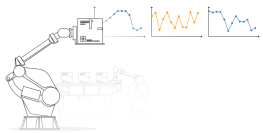
Since CANopen is a CAN-based protocol, it is possible to record raw CANopen frames using a CAN bus data logger. As an example, the CANedge lets you record CANopen data to an 8-32 GB SD card.

Simply connect it to your application to start logging - and process the data via free software/APIs. Learn more!

### Raw data decoding via CANopen DBC files

As CANopen is based on CAN bus, you can store your CANopen decoding rules in the standardized CAN database format, a CAN DBC file. With this, you can directly decode your raw CANopen data in open source software/API tools for the CANedge, including the asammdf GUI, telematics dashboards and Python API tools. Note that you may not have a CANopen DBC file readily available, but rather your CANopen frame decoding rules may be stored in your EDS/DCF or in a PDF. In such a case you can take outset in our DBC intro to learn how to construct a CANopen DBC file from scratch using various free editor tools.

Solutions like the CANedge enable several CANopen logging use cases:



**Logging CANopen node data**

Generally, logging CANopen data can be used to e.g. analyze operational data. WiFi CAN loggers can also be used for e.g. over-the-air SDOs

learn more

**Warehouse fleet management**

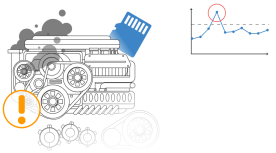
CANopen is often used in EV forklifts/AGVs in warehouses, where monitoring e.g. SoC helps reduce breakdowns and improve battery life

learn more

**Predictive maintenance**

Industrial machinery can be monitored via IIoT CAN loggers in the cloud to predict and avoid breakdowns based on the CANopen data

learn more



**Machinery diagnostic blackbox**

A CAN logger can serve as a 'blackbox' for industrial machinery, providing data for e.g. disputes or rare issue diagnostics

learn more


# CAN FD Explained - A Simple Intro

In this guide we introduce CAN FD (CAN Flexible Data-rate) - incl. CAN FD frames, overhead & efficiency, example applications and logging use cases.

## Why CAN FD?

The CAN protocol has been around since 1986 and it's popular: Practically any machine that moves utilizes CAN today - whether it's cars, trucks, boats, planes or robots.

But with the rise of modern technology, the "Classical" CAN protocol (official term used in ISO 11898-1:2015) is pressured:

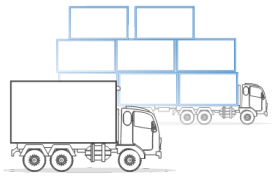
- A rise in vehicle functionality is driving an explosion in data
- Networks are increasingly limited by the 1-Mbit/s bandwidth
- To cope, OEMs create complex & costly workarounds

Specifically, Classical CAN struggles with substantial overhead (>50%) as each CAN data frame can only contain 8 data bytes. Further, the network speed is limited to 1 Mbit/s, restricting the implementation of data-producing features. CAN FD resolves these issues - making it future-proof.

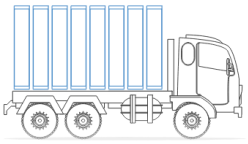
## What is CAN FD?

The CAN FD protocol was pre-developed by Bosch (with industry experts) and released in 2012. It was improved through standardization and is now in ISO 11898-1:2015. The original Bosch CAN FD version (non-ISO CAN FD) is incompatible with ISO CAN FD.

**CAN FD offers four major benefits:**

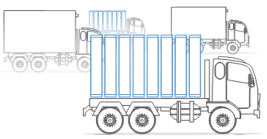


**#1 Increased length**
CAN FD supports up to 64 data bytes per data frame vs. 8 data bytes for Classical CAN. This reduces the protocol overhead and leads to an improved protocol efficiency.



**#2 Increased speed**
CAN FD supports dual bit rates: The nominal (arbitration) bit-rate limited to 1 Mbit/s as in Classical CAN - and the data bit-rate, which depends on the network topology/transceivers. In practice, data bit-rates up to 5 Mbit/s are achievable.

**#3 Better reliability**
CAN FD uses an improved cyclic redundancy check (CRC) and the "protected stuff-bit counter", which lower the risk of undetected errors. This is e.g. vital in safety-critical applications like vehicles and industrial automation.



**#4 Smooth transition**
CAN FD and Classical CAN only ECUs can be mixed under certain conditions. This allows for a gradual introduction of CAN FD nodes, greatly reducing costs and complexity for OEMs.

In practice, CAN FD can improve network bandwidth by 3-8x vs Classical CAN, creating a simple solution to the rise in data.

# How does CAN FD work?

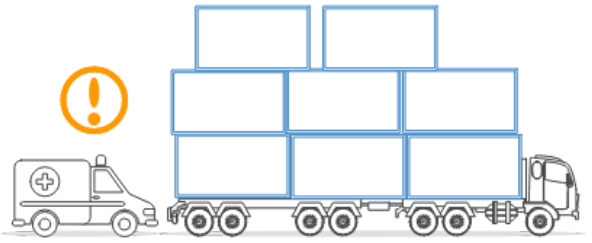
So CAN FD seems pretty simple: Speed up the data transmission and pack more data into each message, right? In practice, however, it's not that straightforward. Below we outline the main challenges that the CAN FD solution had to solve.

## Two key challenges

Before looking at the CAN FD data frame, it's key to understand two core parts of Classical CAN that we want to maintain:

### #1 Avoid critical message delays

Why not simply pack Classical CAN frames with 64 bytes of data? Doing so would reduce overhead and simplify message interpretation. However, if the bit-rate is unchanged, this would also block the CAN bus for longer, potentially delaying mission-critical higher-priority data frames.



### #2 Maintain practical CAN wire lengths

So, more speed is needed to send more data per message. But why not speed up the entire CAN message (rather than just the data phase)? This is due to "arbitration": If 2+ nodes transmit data simultaneously, arbitration determines which node takes priority. The "winner" continues sending (without delay), while the other nodes "back off" during the data transmission.

### Regarding bit time

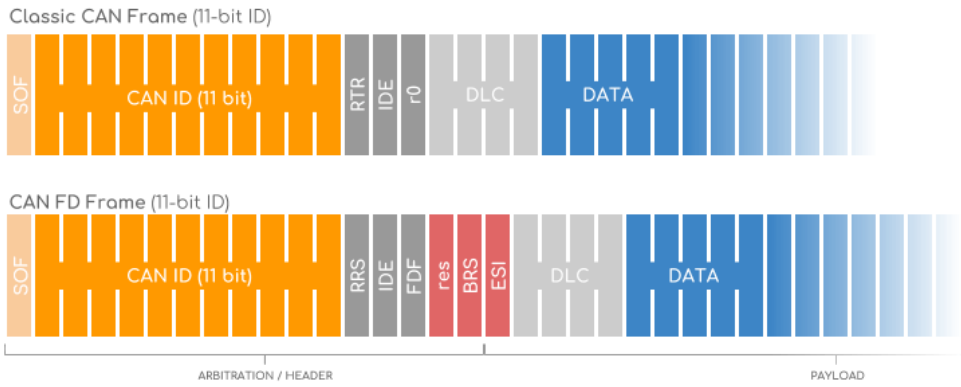
During arbitration, a "bit time" provides sufficient delay between each bit to allow every node on the network to react. To be certain that every node is reached within the bit time, a CAN network running at 1 Mbit/s needs to have a maximum length of 40 metres (in practice 25 metres). Speeding up the arbitration process would reduce the maximum length to unsuitable levels.

On the other hand, after arbitration there's an "empty highway" - enabling high speed during the data transmission (when there is just one node driving the bus-lines). Before the ACK slot - when multiple nodes acknowledge the correct reception of the data frame - the speed needs to be reduced to the nominal bit-rate.

In short, it is necessary to find a way to only increase the speed during the data transmission.

## Solution: The CAN FD frame

The CAN FD protocol introduces an adjusted CAN data frame to enable the extra data bytes and flexible bit-rates. Below we compare an 11-bit Classical CAN frame vs. an 11-bit CAN FD frame (29-bit is also supported):




Below we go through the differences step-by-step:

### CAN FD frame fields explained

**RTR vs. RRS:** The Remote Transmission Request (RTR) is used in Classical CAN to identify data frames and corresponding remote frames. In CAN FD, remote frames are not supported at all - the Remote Request Substitution (RRS) is always dominant (0).

**r0 vs. FDF**: In Classical CAN, r0 is reserved and dominant (0). In CAN FD, it's named FDF and recessive (1).
After the r0/FDF bit, the CAN FD protocol adds "3 new bits". Note that nodes that are not CAN FD capable produce an error frame after the FDF bit.

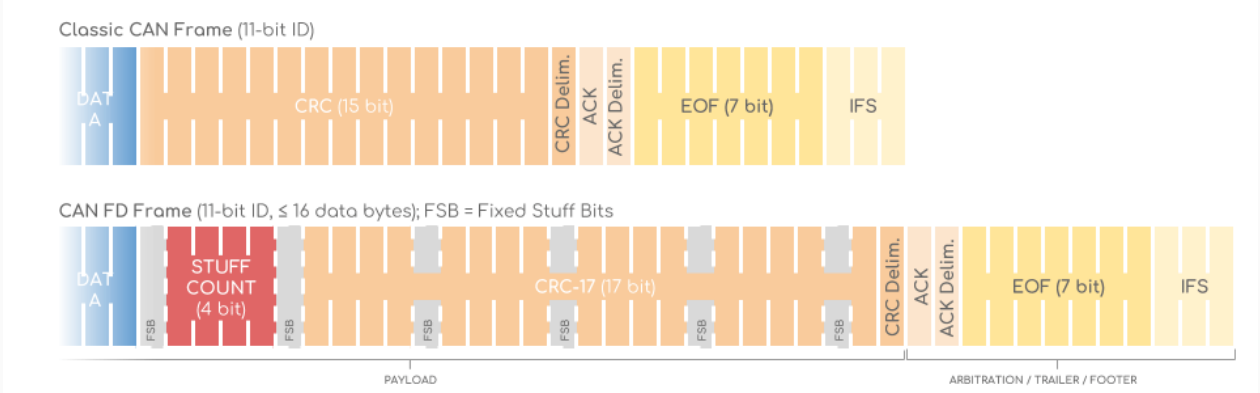
**res:** This new reserved bit plays the same role as r0 - i.e. it may in the future be set to recessive (1) to denote a new protocol.

**BRS:** The Bit Rate Switch (BRS) can be dominant (0), meaning that the CAN FD data frame is sent at the arbitration rate (i.e. up to max 1 Mbit/s). Setting it to recessive (1) means that the remaining part of the data frame is sent at a higher bit rate (up to 5 Mbit/s).

**ESI:** The Error Status Indicator (ESI) bit is by default dominant (0), i.e.'error active'. If the transmitter becomes 'error passive' it'll be recessive (1) to indicate it is in error passive mode.

| DLC (bin) | 0000 | 0001 | 0010 | 0011 | 0100 | 0101 | 0110 | 0111 | 1000 | 1001 | 1010 | 1011 | 1100 | 1101 | 1110 | 1111 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DLC (dec) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Classic CAN | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| CAN FD | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 12 | 16 | 20 | 24 | 32 | 48 | 64 |

DLC: Like in Classical CAN, the CAN FD DLC is 4 bits and denotes the number of data bytes in the frame. The above table shows how the two protocols use the DLC consistently up to 8 data bytes. To maintain a 4-bit DLC, CAN FD uses the remaining 7 values from 9 to 15 to denote the number of data bytes used (12, 16, 20, 24, 32, 48, 64).




**SBC:** The Stuff Bit Count (SBC) precedes the CRC and consists of 3 gray-coded bits and a parity bit. The following Fixed Stuff-Bit can be regarded as a second parity bit. The SBC is added to improve communication reliability.

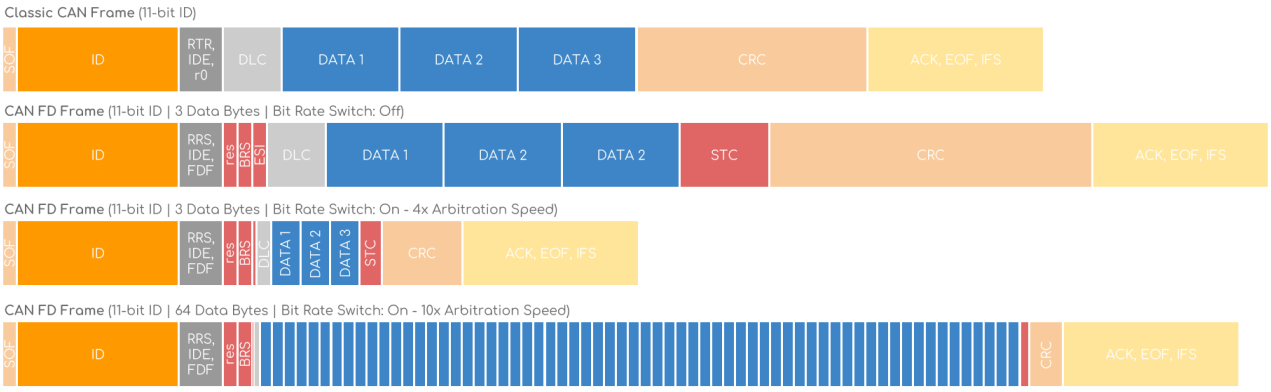
**CRC:** The Cyclic Redundancy Check (CRC) is 15 bit in the Classical CAN, while in CAN FD it's 17 bits (for up to 16 data bytes) or 21 bits (for 20-64 data bytes). In Classical CAN, there can be 0 to 3 stuff bits in the CRC, while in CAN FD there are always four fixed stuff bits to improve communication reliability.

**ACK**: The data phase (aka payload) of the CAN FD data frame stops at the ACK bit, which also marks the end of the potentially increased bit rate.

# Overhead and data efficiency of CAN FD vs. CAN

As evident, the added functionality of CAN FD adds a lot of extra bits vs. Classical CAN - how can this lead to less overhead?

The answer is that it doesn't - see the below visualization of Classical CAN vs. CAN FD for 3 data bytes. In fact, the efficiency of CAN FD does not exceed Classical CAN until crossing 8 data bytes. However, by moving towards 64 data bytes, the efficiency can go from ~50% up towards ~90% (more on this below).



## Need for speed: Turning on bit rate switching

As mentioned, sending 64 data bytes at regular speed would block the CAN bus, reducing the real-time performance. To solve this, bit rate switching can be enabled to allow the payload to be sent at a higher rate vs the arbitration rate (e.g. 5 Mbit/s vs 1 Mbit/s). Above we illustratively visualize the effect for the 3 data byte and 64 data byte scenarios. Note that the higher speed applies to the data frame section starting in the BRS bit and ending in the CRC delimiter. Further, most vehicles today use 0.25-0.5 Mbit/s, meaning that with 5 Mbit/s CAN FD would 10x the speed of the payload transmission.

## Mixing Classical CAN and CAN FD nodes

As mentioned earlier, Classical CAN and CAN FD nodes can be mixed under certain conditions. This allows for a step-by-step migration towards CAN FD, rather than having to switch every ECU in one go. Two scenarios exist:

**100% CAN FD system:** Here, the CAN FD controllers can freely mix Classical CAN and CAN FD data frames.

**Some nodes are legacy Classical CAN:** Here, the CAN FD controllers can switch to Classical CAN communication to avoid error frame reactions from the Classical CAN nodes. Also, during e.g. ECU flashing, the Classical CAN nodes may be turned off to allow a temporary shift to CAN FD communication.

## What is the max bit rate of CAN FD?

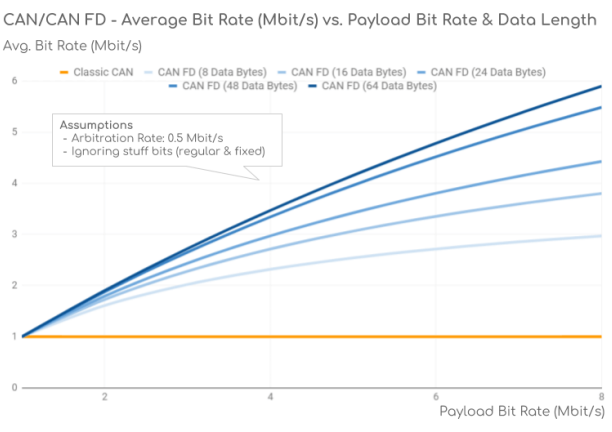
A confusing aspect of CAN FD is the max bit rate during the payload phase - as different articles mention different levels. Some state that practical applications enable up to 8 Mbit/s and theoretically 15 Mbit/s. Others state up to 12 Mbit/s. Further, Daimler state that beyond 5 Mbit/s is doubtful - both as there's no standard for this and because low-cost automotive Ethernet (10 BASE-T1) is expected to limit the demand for CAN FD at higher speed. So what is correct?

It depends. Looking at ISO 11898-2 (the transceiver chip standard), it specifies two symmetry parameter sets. It is recommended to use those with improved symmetry parameters, often advertised as 5 Mbit/s transceivers. The achievable data phase bit-rate depends on many things. One of the most important is the desired temperature range. Flashing of an ECU does not require the support of low temperatures. This implies that for ECU flashing, it is possible to go up to 12 Mbit/s. Another important bit-rate limitation is caused by the chosen topology. Bus-line topology with very short stubs allows significantly higher bit-rates versus hybrid topologies with long stubs or even stars. Most multi-drop bus-line networks are limited to 2 Mbit/s for a temperature range of -40 degC to +125 degC. CiA provides appropriate rules of thumb in the CiA 601-3 network design recommendation. This includes recommendations to set the sample-points in the data-phase.

## CAN FD calculator: Efficiency & baud rate

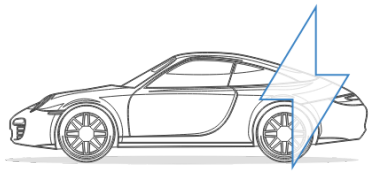
For a detailed understanding of CAN FD efficiency and bit rates, see our CAN FD calculator.

The calculator compares Classical CAN vs. CAN FD in regards to frames and visualizes the frame structures in response to the settings you provide.

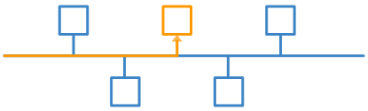


# Examples: CAN FD applications

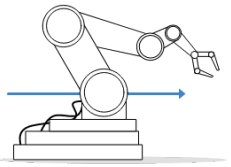
In short, CAN FD enables more data at faster rates. This is key for multiple increasingly relevant use cases:



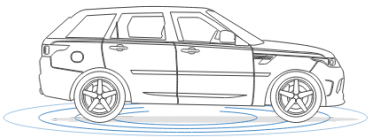
**Electric vehicles**
EVs and hybrids use new powertrain concepts that require far higher bit rates. Added complexity comes from new control units related to the DC/DC inverter, battery, charger, range extender etc. By 2025 it is expected that the required bit rate exceeds CAN - and with the explosive rise in EVs, this may be the spearhead of the CAN FD roll-out.



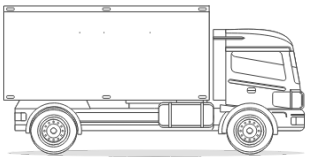
**ECU flashing**
Vehicle software is becoming increasingly complex. As such, performing ECU updates via e.g. the OBD2 port can take hours today. With CAN FD, such processes can be made >4x faster. This use case has been one of the original drivers behind the demand for CAN FD by automotive OEMs.



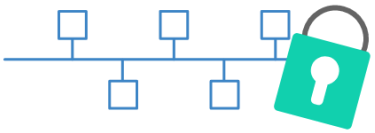
**Robotics**
Several applications rely on time-synced behaviour - e.g. robot arms with multiple axles. Such devices often use CANopen and require multiple CAN frames (PDOs) to be sent by each controller time-synced (without interruption from higher-priority frames). By shifting to CAN FD, the data can be sent in a single frame for efficiency.



**ADAS & safe driving**
Increasingly, advanced driver assistance systems (ADAS) are being introduced in passenger cars and commercial vehicles. This pressures the bus load of Classical CAN, yet ADAS is key to improving safety. Here, CAN FD will be key to enhancing safe driving in the near future.



**Trucks & buses**
Trucks & buses utilize long CAN buses (10-20 meters). As a result, they rely on slow bit rates (250 kbit/s or 500 kbit/s as per J1939-14). Here, the upcoming J1939 FD protocol is expected to enable a significant improvement in commercial vehicle features, incl. e.g. ADAS.



**Secure CAN bus**
As shown in recent CAN hacker attacks, Classical CAN is vulnerable. If hackers gain access to the CAN bus (e.g. over-the-air), they could e.g. turn off critical functions. CAN FD authentication via the Secure Onboard Communication (SecOC) module may be a key roll-out driver.

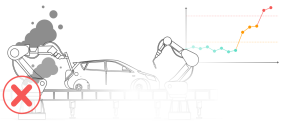
# Logging CAN FD data - use case examples

With the rise of CAN FD there will be several use cases for logging CAN FD data:

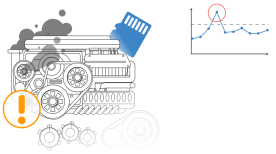
**Logging data from cars**
As CAN FD gets rolled out in new cars, CAN FD data loggers will be key for OEM R&D and diagnostics

learn more

**Heavy duty fleet telematics**
IoT CAN FD loggers compatible with J1939 FD (flexible data-rate) will be key to future heavy duty telematics
learn more



**Predictive maintenance**
As CANopen FD rolls out, new industrial machinery will need CAN FD IoT loggers to help predict and avoid breakdowns
learn more



**Vehicle/machine blackbox**
A CAN FD logger can serve as a 'blackbox' for e.g. new prototype vehicles, providing data for diagnostics and R&D
learn more

### CAN FD logging - practical considerations

When logging CAN FD data the following considerations are relevant:

#### #1 ISO CAN FD vs. non-ISO CAN FD

Before the ISO 11898-1:2015 update, the CAN FD standard had a weakness related to error checking. Controllers adhering to the updated standard are sometimes referred to as "ISO CAN FD". When recording data from an early prototype CAN FD system you may therefore need to turn on "NON-ISO CAN FD" mode if your device supports this.

#### #2 Bit rate switch - on/off?

By default, your CAN FD data logger will be able to handle both Classical CAN and CAN FD data messages - without having to be pre-configured between them. Similarly, you won't have to pre-specify whether bit rate switching is on/off for pure logging purposes. However, when you transmit data to the CAN bus, you'll need to specify whether to use bit rate switching or not. If enabled, your data payloads are transmitted at the system's 2nd bit rate, which will typically be 2 or 4 Mbit/s.

#### #3 Conversion & CAN FD DBC files

CAN FD minimizes the need for handling multi-packet messages. This can greatly simplify the software development for converting raw CAN FD data to human-readable form, to the benefit of end users of CAN FD analyzers. Further, the standard CAN database format, DBC, also supports CAN FD conversion rules. As such, it's always recommended that you collect your scaling rules in a DBC file to enable easy transition between various CAN software like e.g. asammdf etc.

## CAN FD - outlook

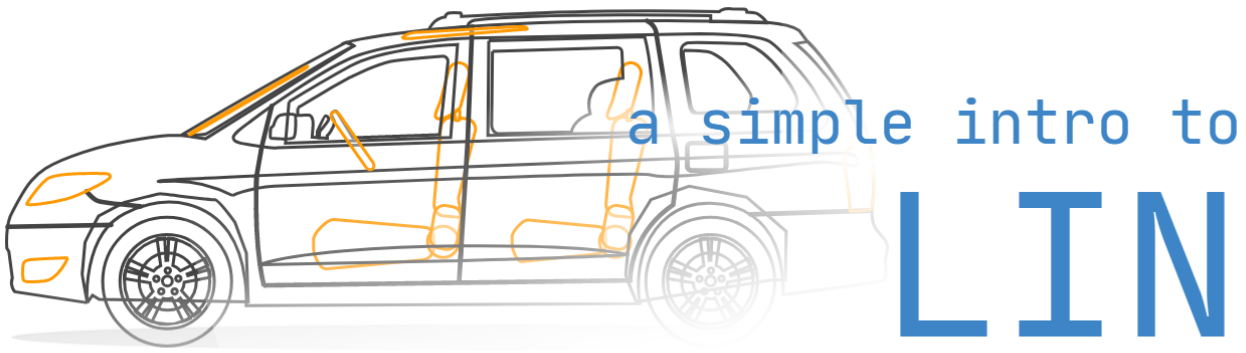
CAN FD is predicted to take over Classical CAN in the coming years:

- The first CAN FD capable cars are expected to be sold in 2019/20
- Initial roll-out will likely use 2 Mbit/s, gradually transitioning to 5 Mbit/s
- CANopen FD has been adapted via CiA 1301 1.0
- J1939-22 uses CAN FD data frames

- CAN is still a growing technology, but recently mainly due to CAN FD
- It's anticipated that in the future, CAN FD will be used in most new development

### CAN FD vs. other protocols

Of course, legacy applications with no bandwidth and payload requirements will still use Classical CAN. Further, the CAN community is already developing the next generation of a CAN data link layer supporting payloads up to 2048 bytes. This approach can be regarded as an alternative to 10 Mbit/s Ethernet. As such, it is still to be determined exactly what role CAN FD will play in the future - but it will definitely be on the rise.




# LIN Bus Explained - A Simple Intro

In this guide we introduce the Local Interconnect Network (LIN) protocol basics incl. LIN vs. CAN, use cases, how LIN works and the six LIN frame types.

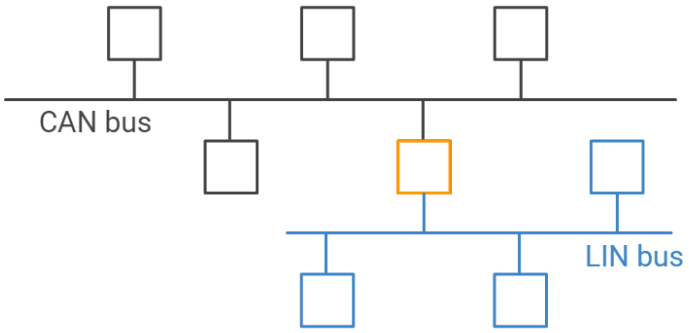
# What is LIN bus?

LIN bus is a supplement to CAN bus. It offers lower performance and reliability - but also drastically lower costs. Below we provide a quick overview of LIN bus and a comparison of LIN bus vs. CAN bus.

- Low cost option (if speed/fault tolerance are not critical)
- Often used in vehicles for windows, wipers, air condition etc..
- LIN clusters consist of 1 master and up to 16 slave nodes
- Single wire (+ground) with 1-20 kbit/s at max 40 m bus length
- Time triggered scheduling with guaranteed latency time
- Variable data length (2, 4, 8 bytes)
- LIN supports error detection, checksums & configuration
- Operating voltage of 12V
- Physical layer based on ISO 9141 (K-line)
- Sleep mode & wakeup support
- Most newer vehicles have 10+ LIN nodes

### LIN bus vs CAN bus

- LIN is lower cost (less harness, no license fee, cheap nodes)
- CAN uses twisted shielded dual wires 5V vs LIN single wire 12V
- A LIN master typically serves as gateway to the CAN bus
- LIN is deterministic, not event driven (i.e. no bus arbitration)
- LIN clusters have a single master - CAN can have multiple
- CAN uses 11 or 29 bit identifiers vs 6 bit identifiers in LIN
- CAN offers up to 1 Mbit/s vs. LIN at max 20 kbit/s



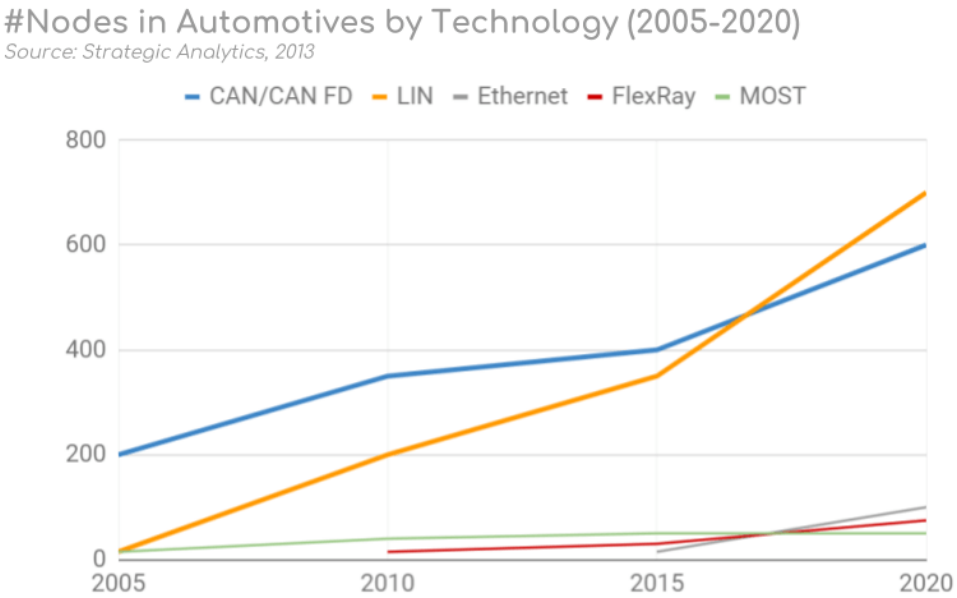

## LIN bus history

Below we briefly recap the history of the LIN protocol:

- 1999: LIN 1.0 released by the LIN Consortium (BMW, VW, Audi, Volvo, Mercedes-Benz, Volcano & Motorola)
- 2000: The LIN protocol was updated (LIN 1.1, LIN 1.2)
- 2002: LIN 1.3 released, mainly changing the physical layer
- 2003: LIN 2.0 released, adding major changes (widely used)
- 2006: LIN 2.1 specification released
- 2010: LIN 2.2A released, now widely implemented versions
- 2010-12: SAE standardized LIN as SAE J2602, based on LIN 2.0
- 2016: CAN in Automation standardized LIN (ISO 17987:2016)


## LIN bus future

The LIN protocol serves an increasingly important role in providing low cost feature expansion in modern vehicles. As such, LIN bus has exploded in popularity in the last decade with >700 million nodes expected in automotives by 2020 vs ~200 million in 2010.



### Cybersecurity & new protocols

However, with the rise of LIN also comes increased scrutiny in regards to cyber security. LIN faces similar risk exposures as CAN - and since LIN plays a role in e.g. the seats and steering wheel, a resolution to these risks may be necessary. The future automotive vehicle networks are seeing a rise in CAN FD, FlexRay and automotive Ethernet. While there's uncertainty regarding the role each of these systems will play in future automotives, it's expected that LIN bus clusters will remain vital as the low cost solution for an ever increasing demand for features in modern vehicles.

### Master/slave vs. commander/responder

As part of designing a more inclusive wording for LIN bus, the CiA/ISO/SAE agreed wording will transition to commander/responder. As such, this will be the de facto standard wording used in most guidelines and LIN bus specifications going forward.

# LIN bus applications

Today, LIN bus is a de facto standard in practically all modern vehicles - with examples of automotive use cases below:

- Steering wheel: Cruise control, wiper, climate control, radio
- Comfort: Sensors for temperature, sun roof, light, humidity
- Powertrain: Sensors for position, speed, pressure
- Engine: Small motors, cooling fan motors
- Air condition: Motors, control panel (AC is often complex)
- Door: Side mirrors, windows, seat control, locks
- Seats: Position motors, pressure sensors
- Other: Window wipers, rain sensors, headlights, airflow

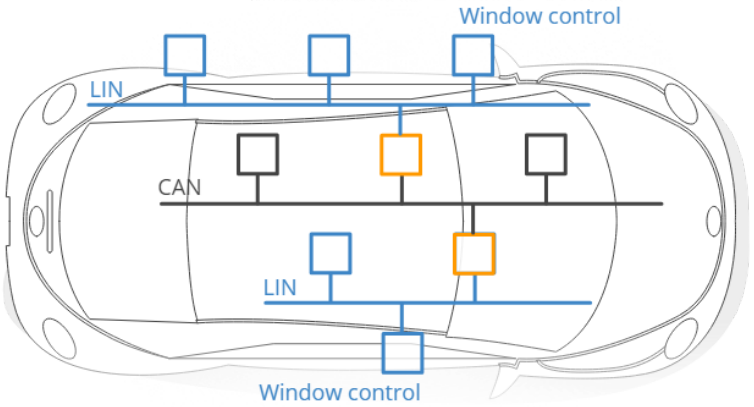
Further, LIN bus is also being used in other industries:

- Home appliances: Washing machines, refrigerators, stoves
- Automation: Manufacturing equipment, metal working

### Example: LIN vs CAN window control

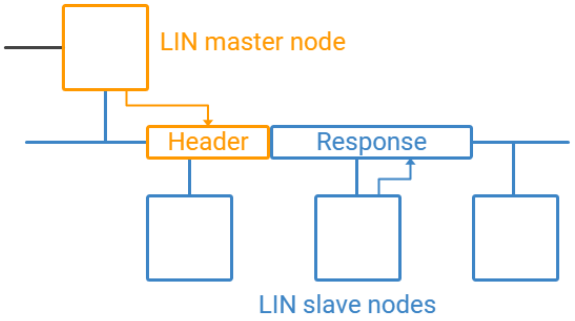
LIN nodes are typically bundled in clusters, each with a master that interfaces with the backbone CAN bus.

Example: In a car's right seat you can roll down the left seat window. To do so, you press a button to send a message via one LIN cluster to another LIN cluster via the CAN bus. This triggers the second LIN cluster to roll down the left seat window.



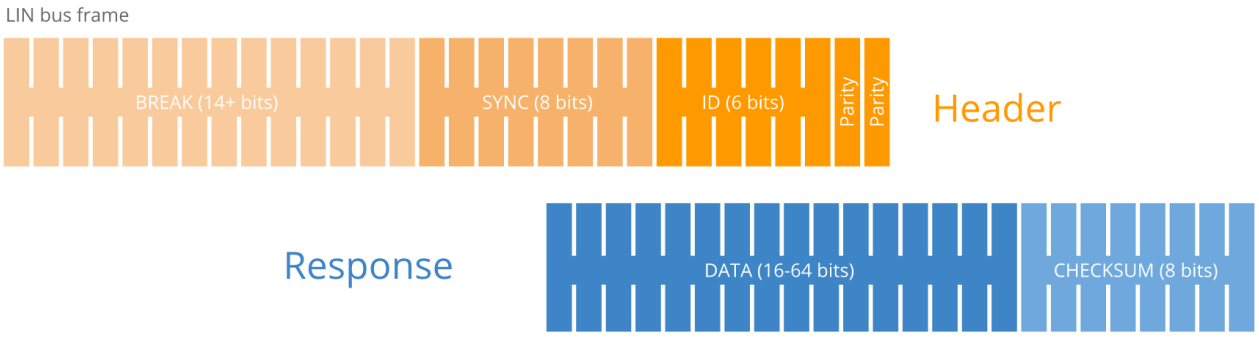

# How does LIN bus work?

LIN communication at its core is relatively simple: A master node loops through each of the slave nodes, sending a request for information - and each slave responds with data when polled. The data bytes contain LIN bus signals (in raw form). However, with each specification update, new features have been added to the LIN specification - making it more complex. Below we cover the basics: The LIN frame & six frame types.




## The LIN frame format

In simple terms, the LIN bus message frame consists of a header and a response. Typically, the LIN master transmits a header to the LIN bus. This triggers a slave, which sends up to 8 data bytes in response. This overall LIN frame format can be illustrated as below:



### LIN frame fields

**Break**: The Sync Break Field (SBF) aka Break is minimum 13 + 1 bits long (and in practice most often 18 + 2 bits). The Break field acts as a “start of frame" notice to all LIN nodes on the bus.

**Sync**: The 8 bit Sync field has a predefined value of 0x55 (in binary, 01010101). This structure allows the LIN nodes to determine the time between rising/falling edges and thus the baud rate used by the master node. This lets each of them stay in sync.

**Identifier**: The Identifier is 6 bits, followed by 2 parity bits. The ID acts as an identifier for each LIN message sent and which nodes react to the header. Slaves determine the validity of the ID field (based on the parity bits) and act via below:

1. Ignore the subsequent data transmission
2. Listen to the data transmitted from another node
3. Publish data in response to the header

Typically, one slave is polled for information at a time - meaning zero collision risk (and hence no need for arbitration). Note that the 6 bits allow for 64 IDs, of which ID 60-61 are used for diagnostics (more below) and 62-63 are reserved.

**Data**: When a LIN slave is polled by the master, it can respond by transmitting 2, 4 or 8 bytes of data. The data length can be customized, but it is typically linked to the ID range (ID 0-31: 2 bytes, 32-47: 4 bytes, 48-63: 8 bytes). The data bytes contain the actual information being communicated in the form of LIN signals. The LIN signals are packed within the data bytes and may be e.g. just 1 bit long or multiple bytes.

**Checksum:** As in CAN, a checksum field ensures the validity of the LIN frame. The classic 8 bit checksum is based on summing the data bytes only (LIN 1.3), while the enhanced checksum algorithm also includes the identifier field (LIN 2.0).

### Logging LIN bus data

The CANedge lets you easily log LIN bus data to an 8-32 GB SD card. Simply connect it to your LIN application to start logging - and process the data via free software/APIs.

For example, the free asammdf GUI/API lets you DBC decode your LIN data to physical values and e.g. plot your LIN signals. Learn more

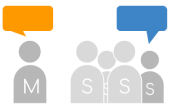

# Six LIN frame types

Multiple types of LIN frames exist, though in practice the vast majority of communication is done via “unconditional frames".

Note also that each of the below follow the same basic LIN frame structure - and only differ by timing or content of the data bytes. Below we briefly outline each LIN frame type:

| ID (dec) | ID (hex) | LIN Frame Type |
|---|---|---|
| 0-59 | 00-3B | Unconditional |
| 0-59 | 00-3B | Event Triggered |
| 0-59 | 00-3B | Sporadic |
| 60-61 | 3C-3D | Diagnostic |
| 62 | 3E | User Defined |
| 63 | 3F | Reserved |

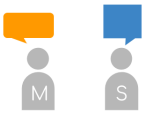

**Unconditional Frames**
The default form of communication where the master sends a header, requesting information from a specific slave. The relevant slave reacts accordingly



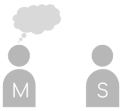

**Event Trigger Frames**
The master polls multiple slaves. A slave responds if its data has been updated, with its protected ID in the 1st data byte. If multiple respond, a collision occurs and the master defaults to unconditional frames


**Sporadic Frames**
Only sent by the master if it knows a specific slave has updated data. The master "acts as a slave" and provides the response to its own header - letting it provide slave nodes with "dynamic" info


**Diagnostic Frames**
Since LIN 2.0, IDs 60-61 are used for reading diagnostics from master or slaves. Frames always contain 8 data bytes. ID 60 is used for the master request, 61 for the slave response




**User Defined Frames**
ID 62 is a user-defined frame which may contain any type of information




**Reserved Frames**
Reserved frames have ID 63 and must not be used in LIN 2.0 conforming LIN networks

# Advanced LIN topics

Below we include two advanced topics - click to expand.

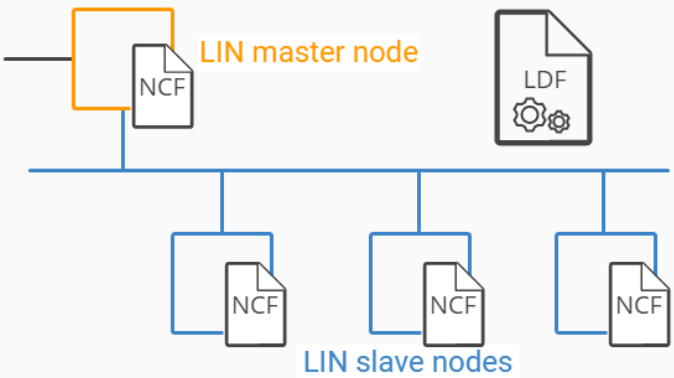
### The LIN Node Configuration File (NCF) and LIN Description File (LDF)

To quickly set up LIN bus networks, off-the-shelf LIN nodes come with Node Configuration Files (NCF). The NCF details the LIN node capabilities and is a key part of the LIN topology.

An OEM will then combine these node NCFs into a cluster file, referred to as a LIN Description File (LDF). The master then sets up and manages the LIN cluster based on this LDF - e.g. the time schedule for headers.

Note that the LIN bus nodes can be re-configured by using the diagnostic frames described earlier. This type of configuration could be done during production - or e.g. everytime the network is started up. For example, this can be used to change node message IDs.

If you're familiar with CANopen, you may see parallels to the Device Configuration File used to pre-configure CANopen nodes - and the role of Service Data Objects in updating these configurations.

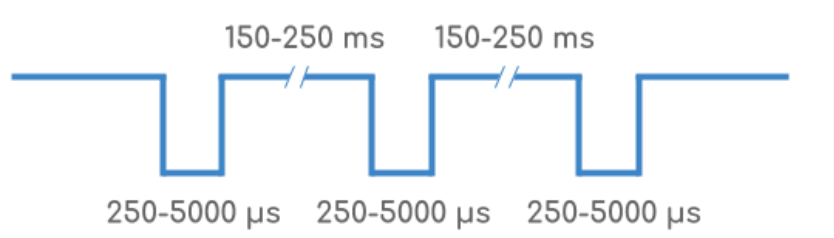


### LIN Sleep & Wakeup

A key aspect of LIN is not only saving costs, but also power.

To achieve this, each LIN slave can be forced into sleep mode by the master sending a diagnostic request (ID 60) with the first byte equal to 0. Each slave also automatically sleeps after 4 seconds of bus inactivity.

The slaves can be woken up by either the master or slave nodes sending a wake up request. This is done by forcing the bus to be dominant for 250-5000 microseconds, followed by a pause for 150-250 ms. This is repeated up to 3 times if no header is sent by the master. After this, a pause of 1.5 seconds is required before sending a 4th wake up request. Typically nodes wake up after 1-2 pulses.

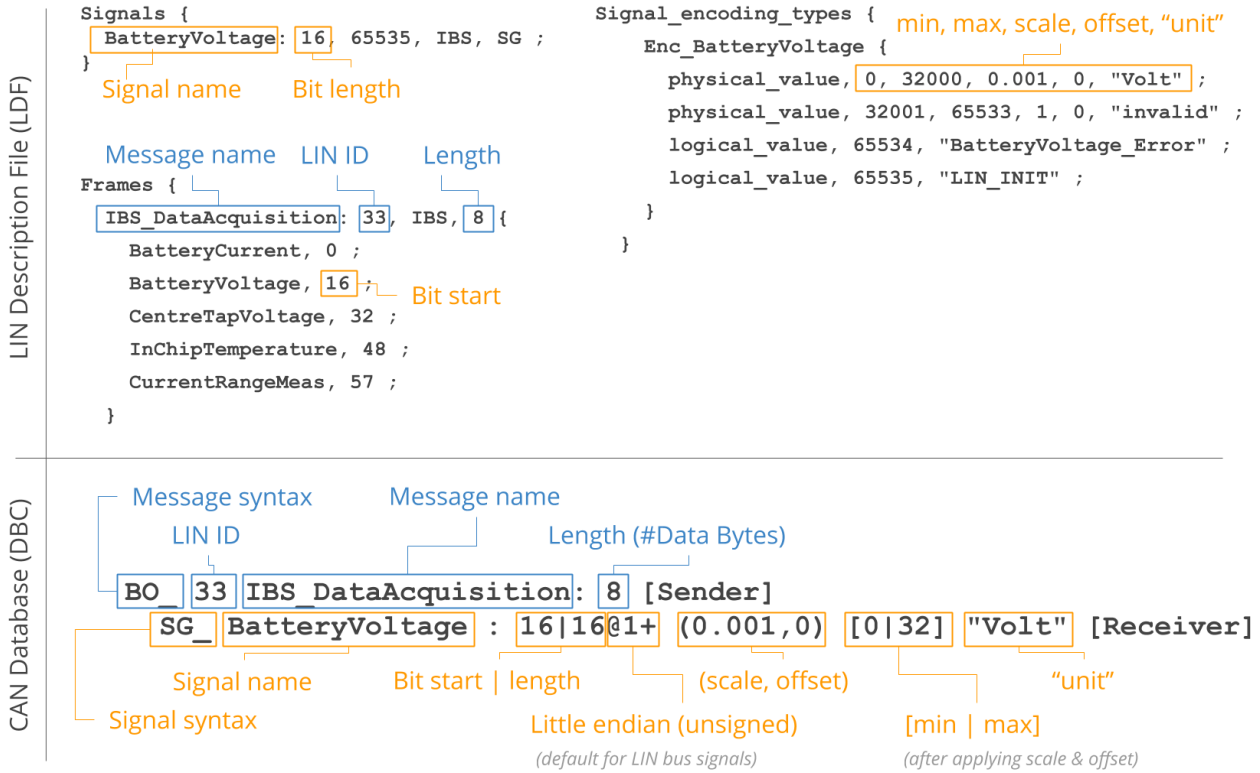



# LIN Description File (LDF) vs. DBC files

As part of your LIN data logger workflow, you may need to decode your raw LIN bus data to physical values. Specifically, this involves extracting LIN signals from the LIN frame payload and decoding these to human-readable form.

This process of LIN bus decoding is similar to CAN bus decoding and requires the same information:

- ID: Which LIN frame ID contains the LIN bus signal
- Name: The LIN signal name should be known
- Start bit: Start position of the LIN signal in the payload
- Length: Length of the LIN bus signal
- Endianness: LIN signals are little endian (Intel byte order)
- Scale: How to multiply the decimal value of the LIN signal bits
- Offset: By what constant should the LIN signal value be offset
- Unit/Min/Max: Additional supporting information (optional)




This information is typically available as part of the LIN Description File (LDF) for a local interconnect network. However, since many software tools do not natively support the LDF format, we explain below how to use DBC files as an alternative.

### LIN Description File (LDF) vs. DBC files

As evident from our CAN bus intro and DBC file intro, the above entries are equivalent to the information stored in a CAN DBC file. This means that a simple method for storing LIN bus decoding rules is to use the DBC file format, which is supported by many software and API tools (incl. the CANedge software tools like asammdf). For example, you can load a LIN DBC file and your raw LIN bus data from the CANedge in asammdf to extract LIN bus signals from the data, which you can then plot, analyze or export.

In many cases, you may not have a LIN DBC file directly available, but instead you may have a LIN description file (LDF). Below we therefore focus on how you can convert the relevant LIN signal information into the DBC format.

Note: The LDF typically contains various other information relevant to the operation of the LIN bus, which we do not focus on here. For a full deep-dive on the LIN protocol and the a detailed description of the LDF specification, see the LIN protocol PDF standard.

### How to convert a LIN Description File (LDF) to DBC [incl. Examples]

Below we provide an example to showcase how you can extract LIN signal information from an LDF and enter it into a DBC file. We use a very simplified LIN description file (with only one signal and excluding some sections).
You can expand the below examples to see the LIN signal, BatteryVoltage, in the LDF format and in the DBC format.
You can also download a raw LIN bus log file (MF4) from the CANedge2 with data for this signal, which you can open and DBC decode in asammdf:

**Example: BatteryVoltage signal (LDF)**

download .ldf | download .dbc

**Guide to LDF to DBC conversion**

In short, to convert an LDF file to DBC, you'll go through the following steps for each LIN signal:

- Get the LIN signal name and length from the Signals section
- Get the LIN signal message name, ID and length from the Frames section
- Get the LIN signal bit start from the Frames section
- Go to the LDF Signal_encoding_types section and find "Enc_[signal_name]"
- Get remaining info via the syntax: 'physical_value, [min], [max], [scale], [offset], "[unit]" ;'

If you're looking to create your own LIN DBC file, we suggest you review our DBC file introduction for details on the syntax, as well as DBC editor tools.

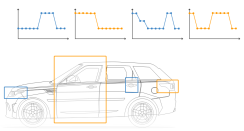
**Minor pitfalls**

The conversion from LDF to DBC is not entirely 1-to-1. In particular, note how the LIN signal BatteryVoltage has 2 entries for the physical value, one for the decimal range 0 to 32000 and one for 32001 to 65533. In this specific case, only the data in the first range are valid (the unit is "invalid" for the 2nd range). However, in some cases there can be multiple ranges that require separate scaling factors - something which is not possible to handle in the DBC file format. In this case, you will need to choose one of the ranges and e.g. treat results outside this range as invalid.

This is also the simplest way to handle the LIN signal 'logical_value' entries in the Signal_encoding_types section. These typically reflect how specific values of the LIN signal should be treated (e.g. as errors). One way of treating these entries would be to ignore them and possibly exclude them as part of your data post processing - similar to how FF byte values in CAN bus are often excluded as they represent invalid or N/A data.

# LIN bus data logging - use case examples

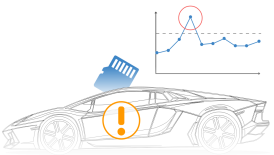
LIN bus data logging is relevant across various use cases:



**Vehicle CAN/LIN development**
Logging CAN/LIN data via a hybrid logger is key to OEM vehicle development and can be used in optimization or diagnostics
learn more

**Field prototype telematics**
CAN/LIN data from automotive prototype equipment can be collected at scale using IoT CAN/LIN hybrid loggers to speed up R&D
learn more

**Predictive maintenance**
Industrial machinery can be monitored via IoT CAN/LIN loggers in the cloud to predict and avoid breakdowns via prediction models
learn more



**Rare LIN issue diagnostics**
A LIN bus logger can serve as a 'blackbox' for industrial machinery, providing data for e.g. disputes or rare issue diagnostics
learn more

# Practical considerations for LIN data logging

Below we list key considerations for your LIN bus data logging:

### LIN logger vs. LIN interface

To record LIN bus data, you'll need a LIN bus data logger and/or interface. A LIN bus data logger with SD card has the advantage of letting you record data in standalone mode - i.e. during actual usage of the vehicle. An interface, on the other hand, is helpful during e.g. dyno testing of the vehicle functionality.

For standalone LIN loggers, it's key that the device is plug & play, compact and low cost - so as to allow it to be used in scale applications across e.g. vehicle fleets.

### CAN vs. LIN support

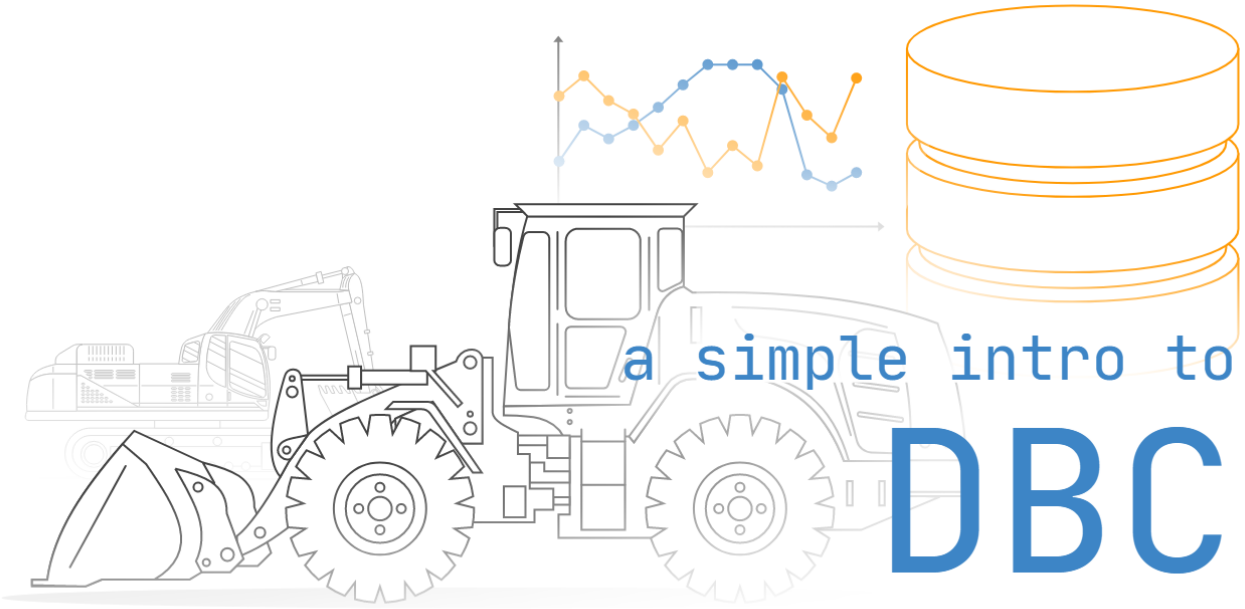
Often, you'll want to combine LIN data with CAN data to get a holistic perspective of the vehicle in use - for example:

- How is driving behavior correlated with use of various LIN bus features?
- Do issues arise in the interaction between LIN masters and the CAN bus?
- Are LIN related issues correlated with certain CAN based events?

To combine this data, you'll want a hybrid CAN/LIN logger with multiple channels. Further, CAN FD support is also key as it's expected to increasingly be rolled out in new vehicles.

### WiFi

Collecting logged LIN bus data can be a hassle if you need to physically extract the data from e.g. large vehicle test fleets. Here, a WiFi enabled CAN/LIN logger can be a powerful solution. You simply specify a WiFi hotspot that the vehicle will get in range of from time-to-time - and the data will then be uploaded automatically from the SD card when in range. It's also possible to add a cellular hotspot within the vehicle for near real-time data transfer.




# CAN DBC File Explained - A Simple Intro

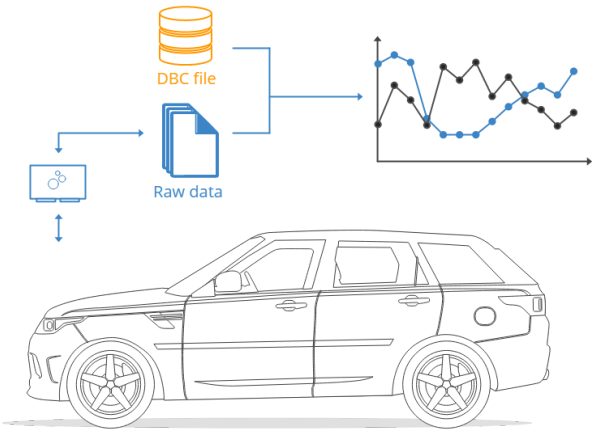
In this tutorial we explain DBC files (CAN bus databases), incl. structure, syntax, examples - and a cool DBC editor playground. To get practical, we also include real J1939/OBD2 data and DBC files - which you can load in free open source CAN tools.

## What is a CAN DBC file?

A CAN DBC file (CAN database) is a text file that contains information for decoding raw CAN bus data to 'physical values'.

To understand what 'raw CAN data' looks like, see the below example CAN frame from a truck:

```
CAN ID    Data bytes
0CF00400  FF FF FF 68 13 FF FF FF
```




If you have a CAN DBC that contains decoding rules for the CAN ID, you can 'extract' parameters (signals) from the data bytes. One such signal could be EngineSpeed:

```
Message  Signal       Value  Unit
EEC1     EngineSpeed  621    rpm
```

To understand how DBC decoding works, we will explain the DBC syntax and provide step-by-step decoding examples.

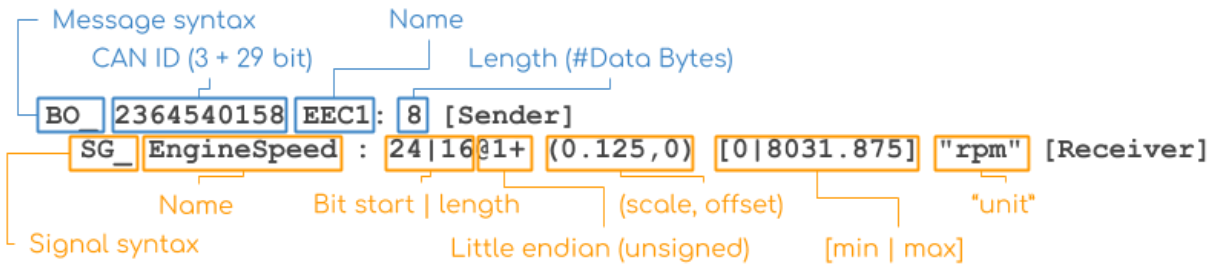
## DBC message & signal syntax

Let us start with a real CAN DBC file example. Below is a demo J1939 DBC file that contains decoding rules for speed (km/h) and engine speed (rpm). You can copy this into a text file, rename it as e.g. j1939.dbc and use it to extract speed/RPM from trucks, tractors or other heavy-duty vehicles.

### J1939 DBC demo example

```
VERSION ""


NS_ :
    CM_
    BA_DEF_
    BA_
    BA_DEF_DEF_

BS_:

BU_:


BO_ 2364540158 EEC1: 8 Vector_XXX
 SG_ EngineSpeed : 24|16@1+ (0.125,0) [0|8031.875] "rpm" Vector_XXX

BO_ 2566844926 CCVS1: 8 Vector_XXX
 SG_ WheelBasedVehicleSpeed : 8|16@1+ (0.00390625,0) [0|250.996] "km/h" Vector_XXX


CM_ BO_ 2364540158 "Electronic Engine Controller 1";
CM_ SG_ 2364540158 EngineSpeed "Actual engine speed which is calculated over a minimum crankshaft angle
of 720 degrees divided by the number of cylinders....";
CM_ BO_ 2566844926 "Cruise Control/Vehicle Speed 1";
CM_ SG_ 2566844926 WheelBasedVehicleSpeed "Wheel-Based Vehicle Speed: Speed of the vehicle as calculated
from wheel or tailshaft speed.";
BA_DEF_ SG_  "SPN" INT 0 524287;
BA_DEF_ BO_  "VFrameFormat" ENUM  "StandardCAN","ExtendedCAN","reserved","J1939PG";
BA_DEF_  "BusType" STRING ;
BA_DEF_  "ProtocolType" STRING ;
BA_DEF_DEF_  "SPN" 0;
BA_DEF_DEF_  "VFrameFormat" "J1939PG";
BA_DEF_DEF_  "BusType" "";
BA_DEF_DEF_  "ProtocolType" "";
BA_ "ProtocolType" "J1939";
BA_ "BusType" "CAN";
BA_ "VFrameFormat" BO_ 2364540158 3;
BA_ "VFrameFormat" BO_ 2566844926 3;
BA_ "SPN" SG_ 2364540158 EngineSpeed 190;
BA_ "SPN" SG_ 2566844926 WheelBasedVehicleSpeed 84;
```

At the heart of a DBC file are the rules that describe how to decode CAN messages and signals:




### DBC message syntax explained

- A message starts with BO_ and the ID must be unique and in decimal (not hexadecimal)
- The DBC ID adds adds 3 extra bits for 29 bit CAN IDs to serve as an 'extended ID' flag
- The name must be unique, 1-32 characters and may contain [A-z], digits and underscores
- The length (DLC) must be an integer between 0 and 1785
- The sender is the name of the transmitting node, or Vector__XXX if no name is available

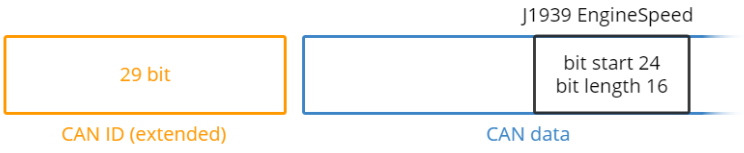
### DBC signal syntax explained

- Each message contains 1+ signals that start with SG_
- The name must be unique, 1-32 characters and may contain [A-z], digits and underscores
- The bit start counts from 0 and marks the start of the signal in the data payload
- The bit length is the signal length
- The @1 specifies that the byte order is little-endian/Intel (vs @0 for big-endian/Motorola)
- The + informs that the value type is unsigned (vs - for signed signals)
- The (scale,offset) values are used in the physical value linear equation (more below)
- The [min|max] and unit are optional meta information (they can e.g. be set to [0|0] and "")
- The receiver is the name of the receiving node (again, Vector__XXX is used as default)

# Example: Extract physical value of EngineSpeed signal

To understand how DBC decoding works, we'll show how to extract the signal EngineSpeed from the CAN frame in the intro:

```
CAN ID    Data bytes
0CF00400  FF FF FF 68 13 FF FF FF
```




### 1# Match the CAN ID vs DBC ID

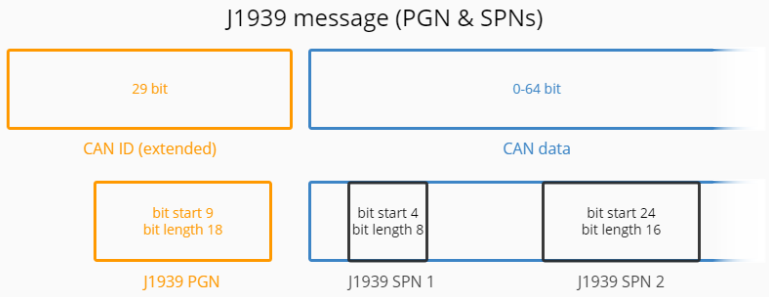
In practice, most raw CAN data log files contain 20-80 unique CAN IDs. As such, the first step is to map each CAN ID to the relevant conversion rules in the DBC. For regular 11-bit CAN IDs, this can simply be done by mapping the decimal value of the CAN ID to the DBC CAN IDs. For extended 29-bit CAN IDs, a mask (0x1FFFFFFF) needs to be applied to the 32-bit DBC ID to get the 29-bit CAN ID - which can then be mapped against the log file.

To easily convert between the IDs, see the 'DBC ID vs CAN ID' sheet in our DBC editor playground.

**Regarding J1939 PGN conversion**

In this example we directly map the 29-bit CAN ID to the 'masked' DBC ID. In practice, J1939 conversion is often done by extracting the 18-bit J1939 PGN from the CAN ID and the DBC ID and then comparing the PGNs.

The method depends on your software. In the CANedge tools like asammdf and our Python API tools, loading a J1939 DBC will automatically make the tools use J1939 PGN matching.




## 2# Extract the signal bits

Next, use the DBC bit start, length and endianness to extract the relevant bits from the CAN frame data payload. In this example, the start bit is 24 (meaning byte 3 when counting from 0) and the bit length is 16 (2 bytes):

```
FF FF FF 68 13 FF FF FF
```

**Big endian vs. little-endian (advanced)**

In the example, we use little-endian, meaning that the 'bit start' in the DBC file reflects the position of least-significant bit (LSB). If you add a DBC signal in a DBC file viewer (e.g. Vector CANDB++), the LSB is also used as the bit start in the DBC editor.

If you instead add a big-endian signal in a DBC editor GUI, you'll still see the LSB as the bit start - but when you save the DBC, the bit start is set to the most significant bit (MSB) in the signal. This approach makes GUI editing more intuitive, but can be a confusing if you switch between a GUI and text editor. To understand this fully, check out our CAN DBC editor playground.

| Bit indices | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 |
| 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 |
| 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 |
| 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 |
| 55 | 54 | 53 | 52 | 51 | 50 | 49 | 48 |
| 63 | 62 | 61 | 60 | 59 | 58 | 57 | 56 |

## 3# Scale the extracted bits

The EngineSpeed signal is little-endian (@1) and we therefore need to reorder the byte sequence from 6813 to 1368. Next, we convert the HEX string to decimal and apply the linear conversion:

```
physical_value = offset + scale * raw_value_decimal
       621 rpm = 0 + 0.125 * 4968
```

In short, the EngineSpeed physical value (aka scaled engineering value) is 621 rpm.

#### 4# DBC decode your full dataset

Steps 1-3 take outset in a single CAN frame. In practice, you'll decode raw data from e.g. vehicles, machines or boats with millions of CAN frames, timestamps, several unique CAN IDs and sometimes hundreds of signals.

To handle this complexity, specialized software is used to decode raw CAN data into human-readable form by loading the data log files and related DBC file(s). To illustrate what the output may look like, we've added a snippet of DBC decoded J1939 data logged with a CANedge. The data has been converted via asammdf, filtered to include a set of relevant signals and exported as CSV:

```
timestamps,ActualEnginePercentTorque,EngineSpeed,EngineCoolantTemperature,EngineOilTemperature1,EngineFu
elRate,EngineTotalIdleHours,FuelLevel1,Latitude,Longitude,WheelBasedVehicleSpeed
2020-01-13 16:00:13.259449959+01:00,0,1520.13,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.268850088+01:00,0,1522.88,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.270649910+01:00,0,1523.34,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.271549940+01:00,0,1523.58,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.278949976+01:00,0,1525.5,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.289050102+01:00,0,1527.88,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.299000025+01:00,0,1528.13,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.308300018+01:00,0,1526.86,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.309099913+01:00,0,1526.75,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.317199945+01:00,0,1526.45,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.319149971+01:00,0,1526.38,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.320349932+01:00,0,1526.15,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.23
2020-01-13 16:00:13.326800108+01:00,0,1524.93,92,106,3.8,1868.3,52,40.6440124,-76.1223603,86.25
…
```

# CAN DBC editor playground

Adding or editing signals in your DBC file can be confusing. To help you better understand how this works, we've created a very basic online 'CAN DBC editor playground'. You can open it and edit the yellow cells - or make a copy for personal use. Feel free to bookmark the editor and share it!

# J1939/OBD2 data & DBC samples

The best way to learn more about DBC conversion of raw CAN bus data is to try it out. Below you can download raw J1939/OBD2 data from the CANedge2. The zip also includes an OBD2 DBC and a demo J1939 DBC.

Via the link, you can also download the free asammdf GUI to open the data & DBC files. Try plotting EngineSpeed as an example. Download the sample data & dbc files.

# Advanced: Meta info, attributes & multiplexing

In this section we briefly outline some of the more advanced topics of CAN DBC files, incl. meta info, attributes, value tables and multiplexing. If you're new to DBC files you can optionally skip this section.

#### Comments (message/signal names, ...)

The DBC file can contain various extra information and below we outline the most common types. This information is stored in the DBC file after all the messages. The comment attribute lets you map a 1-255 character comment to a message ID or signal name, e.g. to provide more information. Example for EEC1 message:

```
CM_ BO_ 2364540158 "Electronic Engine Controller 1"
```

Example for EngineSpeed signal:

```
CM_ SG_ 2364540158 EngineSpeed "Actual engine speed which is calculated over
a minimum crankshaft angle of 720 degrees divided by the number of cylinders....";
```

### Attributes: Frame format, SPN IDs, ...

Custom attributes can be added to messages and signals in a similar way as the comment syntax. A typical attribute is the VFrameFormat, which can be used to describe the message frame type. It is initialized as below:
BA_DEF_ BO_ "VFrameFormat" ENUM "StandardCAN","ExtendedCAN","reserved","J1939PG";

Once initialized, a message can be mapped as follows (indexing from 0):

```
BA_ "VFrameFormat" BO_ 2364540158 3;
```

In this case, we inform that the message EEC1 is of the J1939 PGN type, which may result in specific display or handling in various DBC editor GUI tools, as well as data processing tools.

Similarly, you can add J1939 SPN IDs as an attribute as below:

```
BA_DEF_ SG_  "SPN" INT 0 524287;
BA_ "SPN" SG_ 2364540158 EngineSpeed 190;
```

Here, EngineSpeed is assigned the SPN 190. You might find it more natural to do this in the opposite way - i.e. use the SPN IDs in the message/signal section, then map the SPN names via attributes. While you can definitely do this, it is not the most common convention. Further, the first character in a CAN DBC signal name cannot be a number - so you'd need to write e.g. _190 or SPN_190.

### Value tables

Some CAN DBC signals are 'state variables', such as gear-shift, diagnostic trouble codes, status codes etc. These take discrete values and will require a mapping table to enable interpretation.

The CAN DBC format enables this via value tables, which let you assign a state description to the physical decimal value of each state of a signal. The states should be in descending order.

Example:

```
VAL_ 2297441534 MaterialDropActiveStatus 3 "NotAvailable" 2 "Error" 1 "On" 0 "Off" ;
```

### Multiplexed signals (OBD2 DBC example)

Multiplexing is sometimes used in CAN bus communication, with perhaps the most known example being within OBD2 communication. Consider for example the below OBD2 response frames:

```
7E8   03 41 11 30 FF FF FF FF
7E8   03 41 0D 37 FF FF FF FF
```

Here, both response frames carry 1 byte of data in byte 3, yet despite the CAN ID being identical, the interpretation of the data differs between the two frames. This is because byte 2 serves as a multiplexer, specifying which OBD2 PID the data is coming from. To handle this in a DBC file context, the below syntax can be applied:

```
BO_ 2024 OBD2: 8 Vector__XXX
 SG_ S1_PID_0D_VehicleSpeed m13 : 31|8@0+ (1,0) [0|255] "km/h" Vector__XXX
 SG_ S1_PID_11_ThrottlePosition m17 : 31|8@0+ (0.39216,0) [0|100] "%" Vector__XXX
 SG_ S1 m1M : 23|8@0+ (1,0) [0|255] "" Vector__XXX
 SG_ Service M : 11|4@0+ (1,0) [0|15] "" Vector__XXX
...
SG_MUL_VAL_ 2024 S1_PID_0D_VehicleSpeed S1 13-13;
SG_MUL_VAL_ 2024 S1_PID_11_ThrottlePosition S1 17-17;
SG_MUL_VAL_ 2024 S1 Service 1-1;
```

Here, the M in the Service signal serves as the 'multiplexor signal'. In this case, it toggles which OBD2 service mode is used (mode 01, 02, ...). The signal S1 is multiplexed by Service, which is evident from the SG_MUL_VAL_ field where the two are grouped. As evident, the signal S1 has the value m1 after the signal name, which means that if the Service signal takes the value 1, the data reflects the OBD2 service mode 01.

The above is referred to as simple multiplexing. But CAN DBC files also support extended multiplexing, where a multiplexed signal (in this case S1) can also be a multiplexor and thus control the interpretation of other parts of the data payload. To see this, note that S1 takes the same role as Service in the syntax, adding an M after m1 and being grouped with the two OBD2 PIDs, speed and throttle position.

Extended multiplexing works as before: If S1 takes the value 13 (HEX 0D), it means that only signals that are A) part of the S1 group and B) have a multiplexer switch value of 13 should be taken into account. In this example, it means that byte 4 reflects data for vehicle speed. If byte 3 equals 17 (HEX 11), byte 4 reflects data for the throttle position instead.

DBC multiplexing and extended multiplexing is an advanced topic and not supported by all data processing tools. However, you can use e.g. the CANDB++ DBC editor to more easily view and understand DBC files with multiplexing, like the OBD2 DBC: obd2 dbc file

The OBD2 DBC file can be used together with our CANedge CAN loggers for the purpose of decoding OBD2 frames in e.g. asammdf or our Python API modules. For more on this topic, see Vector's guide to extended multiplexing in DBC files here.

# DBC software tools (editing & processing)

Software that uses CAN DBC files can be split in two groups: Editing & data processing.

## DBC editor tools

- **Vector CANDB++:** The free demo version of Vector's CANalyzer includes a useful version of CANDB++, the Vector DBC editor. It offers the most extensive functionality available, including quick "consistency checks" of DBC files
- **Kvaser Database Editor:** Kvaser provides a free and easy-to-use CAN DBC editor, which includes the ability to append DBC files and visualize the signal construction
- **canmatrix:** This open source Python DBC module lets you load DBC files, edit them and export them to other formats. It is used in e.g. asammdf and our Python API

## CAN data processing tools

Most CAN data processing tools support DBC files - including below:

- **asammdf GUI**: The asammdf GUI lets you load raw MDF4 data and DBC convert it to human-readable form - as well as create quick plots, analyses and exports
- **Python API**: Our Python API lets you automate the DBC conversion of your data e.g. for large-scale data analysis or as part of telematics dashboard integrations
- **Other tools**: Our MDF4 converters let you quickly convert your CANedge MF4 data to e.g. Vector ASC, PEAK TRC and more

## How to create a DBC file?

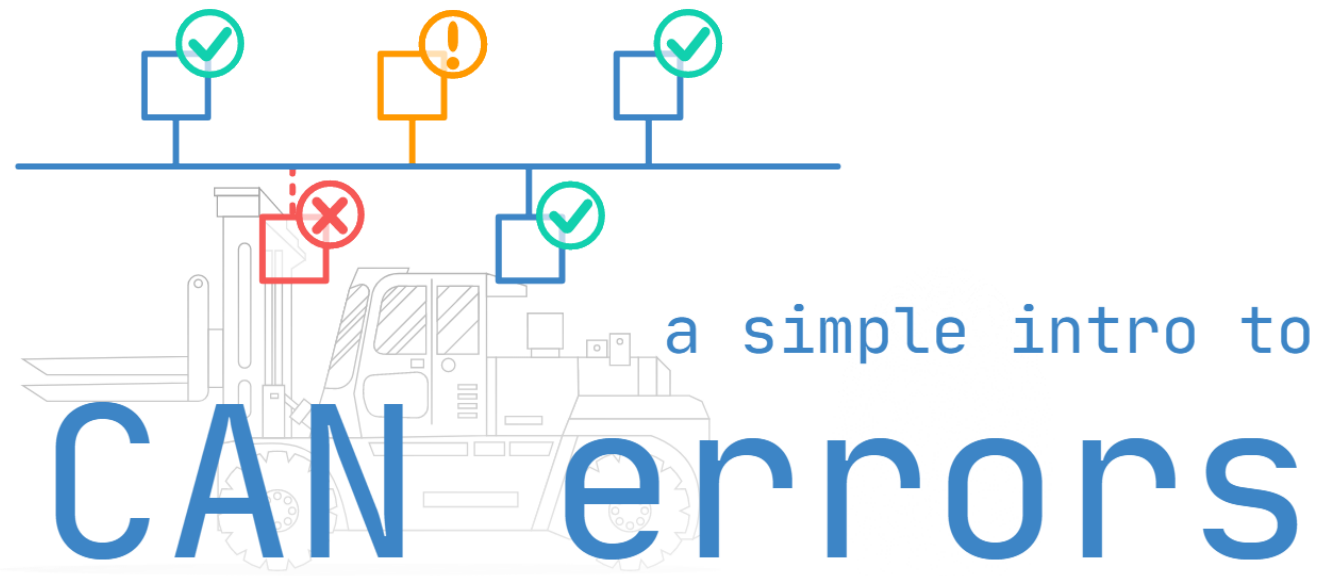
Getting started: If you need to construct a new DBC file, we recommend using one of the DBC editors above. For beginners, we recommend the Kvaser DBC editor. When creating a new DBC file, you can typically select a DBC template (e.g. a CAN FD DBC, J1939 DBC, NMEA 2000 DBC etc). Next, start by adding a single message and a single signal to the DBC and save it.

To ensure your DBC looks OK, we recommend to open the DBC in a text editor. This way you can verify that the basic DBC syntax looks as you'd expect - and you can use this version as a benchmark for comparison. It's a good idea to maintain git revisioning on any changes to the DBC from here.

Test your DBC: As a second step, we recommend to test the DBC file using a CAN bus decoder software tool. For example, if you're using a CANedge CAN bus data logger to record raw CAN data from your application, you can use the free CAN decoder software, asammdf, to load your raw data and your DBC file. This way you can quickly extract the signal you added in the DBC - and verify via a visual plot that the construction looks OK.

Expand your DBC: Next, you can add any remaining CAN messages and signals, as well as comments/descriptions, value tables etc. We recommend to do regular checks as before to ensure the construction is OK.

Check consistency: Finally, we recommend doing a full consistency check both in Vector's DBC editor, CANDB++, and Kvaser's DBC editor. In CANDB++ select 'File/Consistency Check' and keep an eye out for critical errors (though note that your DBC may be sufficiently valid for most tools, even if some issues are reported). In the Kvaser database editor, you can select each message to quickly spot signals with invalid fields (they'll be highlighted in yellow). Once you are done, we always recommend doing a visual analysis of your scaled CAN data to ensure that you do not have e.g. endianness, scale factor or offset errors.



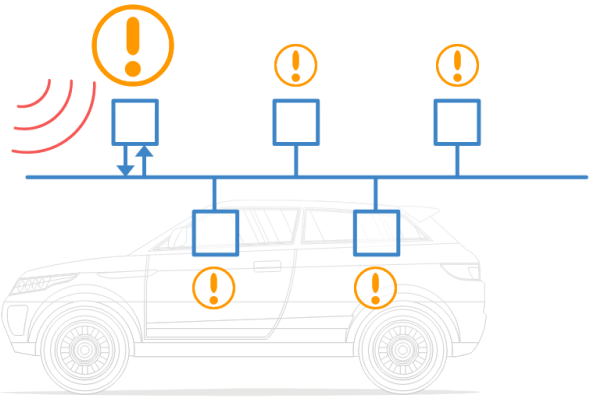

# CAN Bus Errors Explained - A Simple Intro

Need a practical intro to CAN bus errors?

In this tutorial you'll learn about the basics of CAN error handling, the 5 CAN bus error types, the CAN error frame and CAN node error states.

To get practical, we'll also generate & record CAN errors in 6 experiments.

## What are CAN bus errors?



As explained in our simple intro to CAN bus, the Controller Area Network is today the de facto standard across automotives and industrial automation systems.

A core benefit is the robustness of CAN, making it ideal for safety critical applications. Here, it is worth noting:

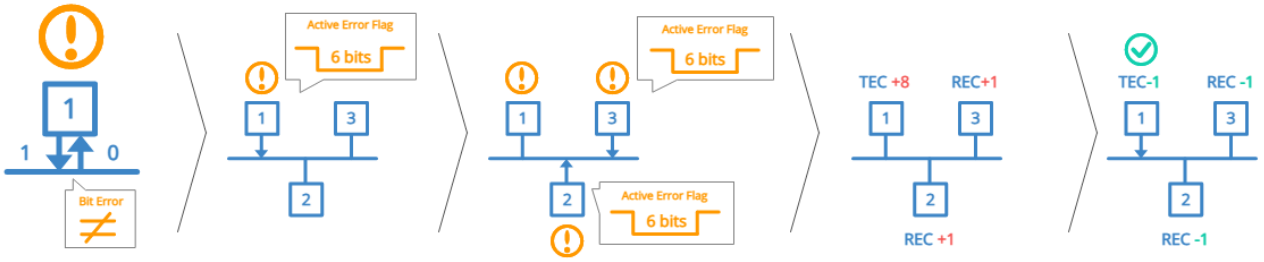
**Error handling is vital to the robustness of CAN.**

CAN bus errors can occur for several reasons - faulty cables, noise, incorrect termination, malfunctioning CAN nodes etc. Identifying, classifying and resolving such CAN errors is key to ensuring the continued performance of the overall CAN system.

In particular, error handling identifies and rejects erroneous messages, enabling a sender to re-transmit the message. Further, the process helps identify and disconnect CAN nodes that consistently transmit erroneous messages.

## How does CAN error handling work?

Error handling is a built-in part of the CAN standard and every CAN controller. In other words, every CAN node handles fault identification and confinement identically. Below we've made a simple illustrative example:




**Example step-by-step**

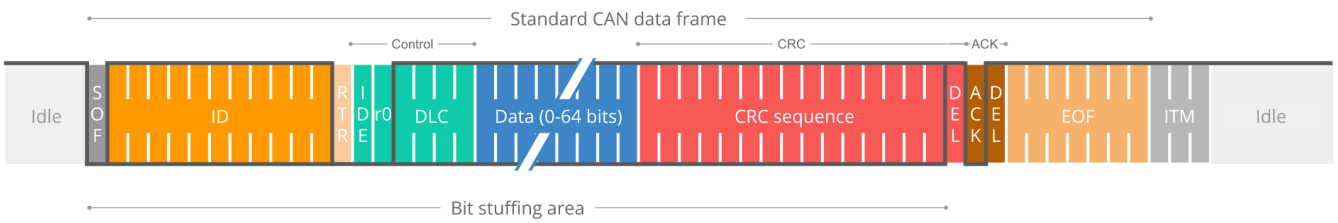
1. CAN node 1 transmits a message onto the CAN bus - and reads every bit it sends
2. In doing so, it discovers that one bit that was sent dominant was read recessive
3. This is a 'Bit Error' and node 1 raises an Active Error Flag to inform other nodes
4. In practice, this means that node 1 sends a sequence of 6 dominant bits onto the bus
5. In turn, the 6 dominant bits are seen as a 'Bit Stuffing Error' by other nodes
6. In response, nodes 2 and 3 simultaneously raise an Active Error Flag
7. This sequence of raised error flags comprise part of a 'CAN error frame'
8. CAN node 1, the transmitter, increases its 'Transmit Error Counter' (TEC) by 8
9. CAN nodes 2 and 3 increase their 'Receive Error Counter' (REC) by 1
10. CAN node 1 automatically re-transmits the message - and now succeeds
11. As a result, node 1 reduces its TEC by 1 and nodes 2 and 3 reduce their REC by 1

The example references a number of concepts that we will detail shortly: Error frames, error types, counters and states.

# The CAN bus error frame

In the illustrative example, the CAN nodes 'raise Active Error Flags', thus creating an 'error frame' in response to detecting a CAN error.

To understand how this works, let us first look at a "normal" CAN frame (without errors):



## CAN bus bit stuffing

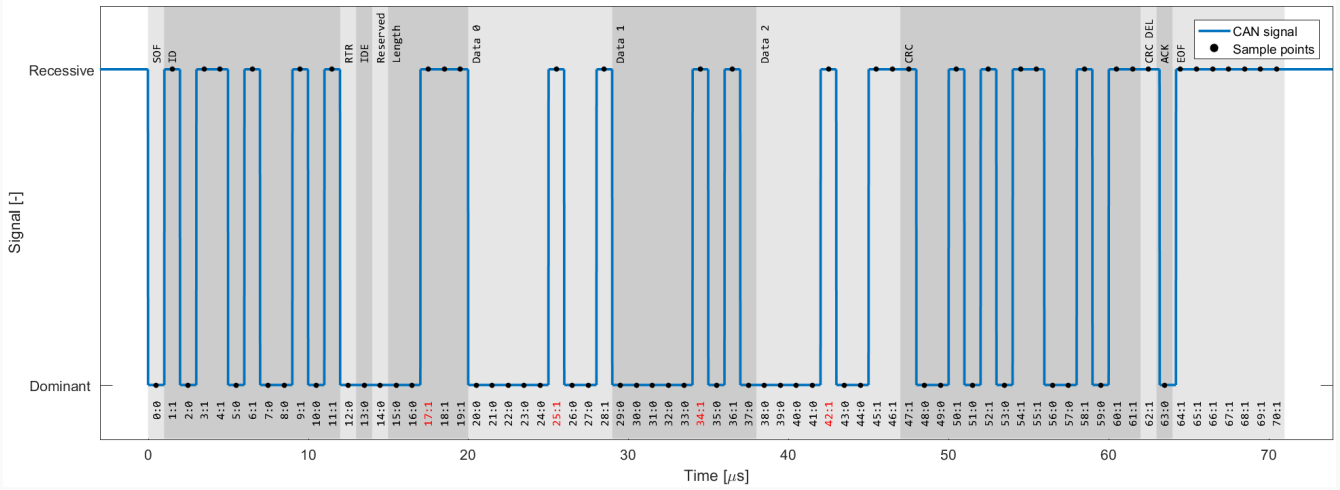
Notice that we highlighted 'bit stuffing' across the CAN frame.

Bit stuffing is a subtle, but vital part of the CAN standard. Basically it states that whenever a CAN node sends five bits of the same logic level (dominant or recessive), it must send one bit of the opposite level. This extra bit is automatically removed by the receiving CAN nodes. This process helps ensure continuous synchronisation of the network.

As per the previous example, when CAN node 1 detects an error during the transmission of a CAN message, it immediately transmits a sequence of 6 bits of the same logic level - also referred to as raising an Active Error Flag.


## Oscilloscope example

If we measure the transmission of a CAN frame via an oscilloscope and digitize the result, we can also see the stuff bits in practice (see the red timestamp marks):




# Active Error Flags

As we just learned, such a sequence is a violation of the bit stuffing rule - aka a 'Bit Stuffing Error'. Further, this error is visible to all CAN nodes on the network (in contrast to the 'Bit Error' that resulted in this error flag being raised). Thus, the raising of error flags can be seen as a way of "globalizing" the discovery of an error, ensuring that every CAN node is informed. Note that the other CAN nodes will see the Active Error Flag as a Bit Stuffing Error. In response they also raise an Active Error Flag.

As we'll explain shortly, it is important to distinguish between the error flags. In particular, the first error flag (from the 'discovering' node) is often referred to as a 'primary' Active Error Flag, while the error flags of subsequent 'reacting' nodes are referred to as the 'secondary' Active Error Flag(s).

# 3 CAN error frame examples

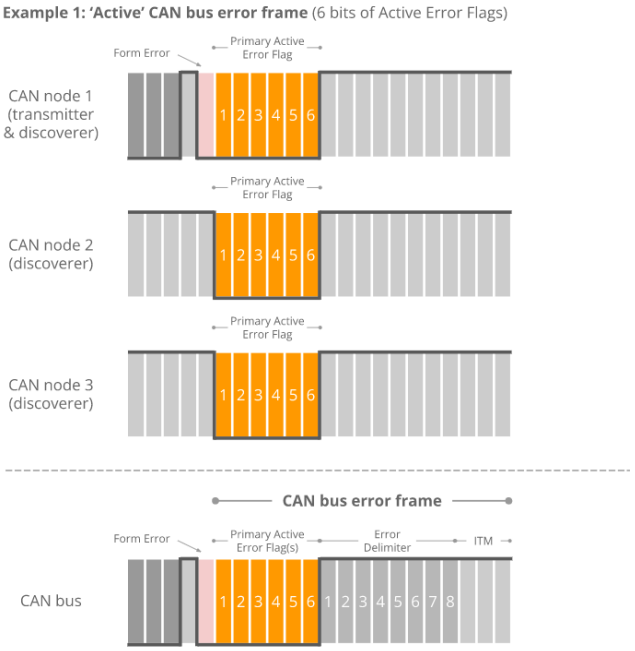
Let's look at three example scenarios:

## Example 1: 6 bits of error flags

Here, all CAN nodes simultaneously discover that an error exists in a CAN message and raise their error flags at the same time.

The result is that the error flags all overlap and the total sequence of dominant bits lasts for 6 bits in total. All CAN nodes will in this case consider themselves the 'discovering' CAN nodes.

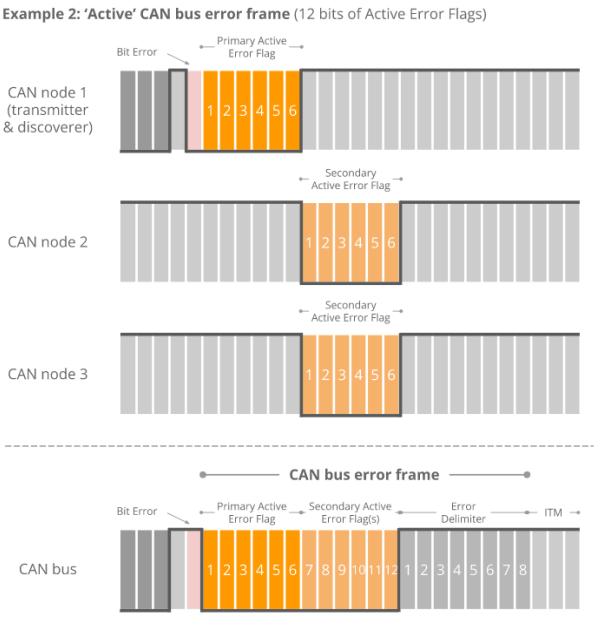
This type of simultaneous discovery is less common in practice. However, it could e.g. happen as a result of Form Errors (such as a CRC delimiter being dominant instead of recessive), or if a CAN transmitter experiences a bit error during the writing of a CRC field.




## Example 2: 12 bits of error flags

Here, CAN node 1 transmits a dominant bit, but reads it as recessive - meaning that it discovers a Bit Error. It immediately transmits a sequence of 6 dominant bits.

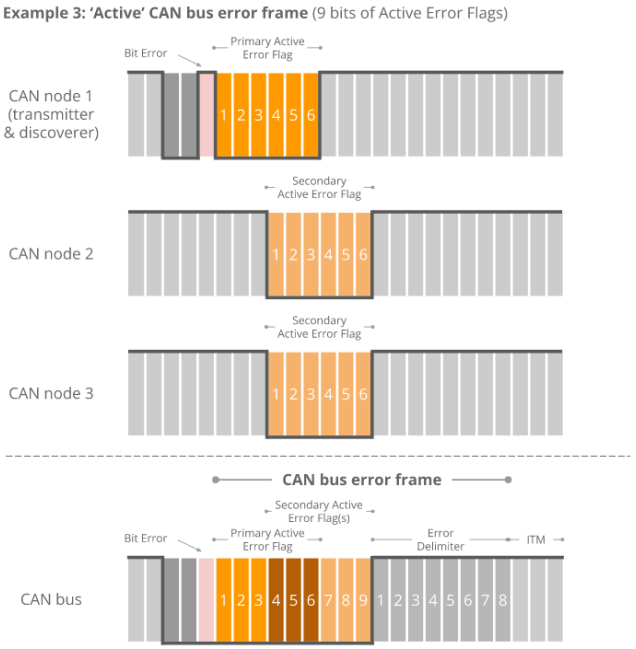
The other nodes only discover the Bit Stuffing Error after the full 6 bits have been read, after which they simultaneously raise their error flags, resulting in a subsequent sequence of 6 dominant bits - i.e. 12 in total.



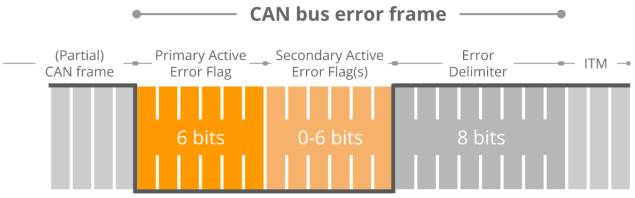
### Example 3: 9 bits of error flags

Here, CAN node 1 has already transmitted a sequence of 3 dominant bits when it discovers a Bit Error and begins sending 6 dominant bits.

Once halfway through the primary Active Error Flag, nodes 2 and 3 recognize the Bit Stuffing Error (due to the 3 initial dominant bits being followed by another 3 dominant bits) and they begin raising their error flags. The result is that the sequence of dominant bits from error flags becomes 9 bit long.




The above logic of raising error flags is reflected in what we call an 'active' CAN error frame.




Note in particular how the secondary error flags raised by various nodes overlap each other - and how the primary and secondary flags may overlap as well. The result is that the dominant bit sequence from raised error flags may be 6 to 12 bits long.

This sequence is always terminated by a sequence of 8 recessive bits, marking the end of the error frame.

In practice, the active error frame may "begin" at different places in the erroneous CAN frame, depending on when the error is discovered. The result, however, will be the same: All nodes discard the erroneous CAN frame and the transmitting node can attempt to re-transmit the failed message.

## Passive Error Flags

If a CAN node has moved from its default 'active' state to a 'passive' state (more on this shortly), it will only be able to raise so-called 'Passive Error Flags'. A Passive Error Flag is a sequence of 6 recessive bits as seen below.

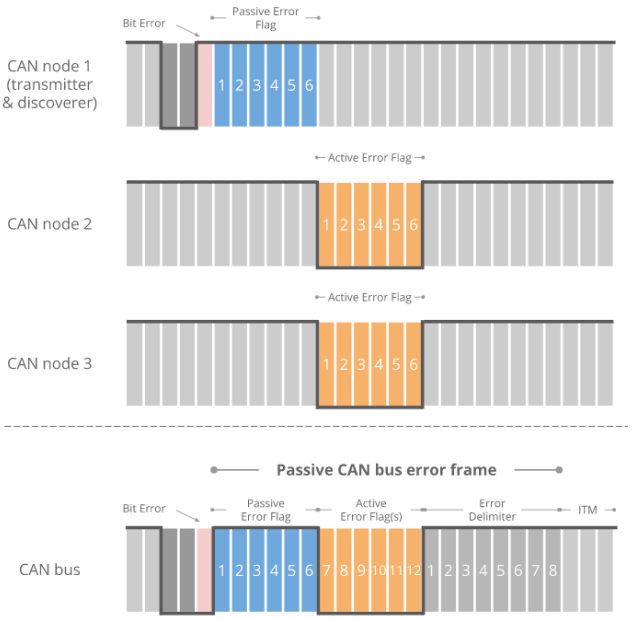
In this case it's relevant to distinguish between a Passive Error Flag raised by a transmitting node and a receiving node.

### Example 4: Transmitter is Error Passive

As shown in the illustration (Example 4), if a transmitter (such as CAN node 1 in our example) raises a Passive Error Flag (e.g. in response to a Bit Error), this will correspond to a consecutive sequence of 6 recessive bits.

This is in turn detected as a Bit Stuffing Error by all CAN nodes. Assuming the other CAN nodes are still in their Error Active state, they will raise Active Error Flags of 6 dominant bits. In other words, a passive transmitter can still "communicate" that a CAN frame is erroneous.

**Example 4: 'Passive' CAN bus error frame** (transmitter in Error Passive mode)

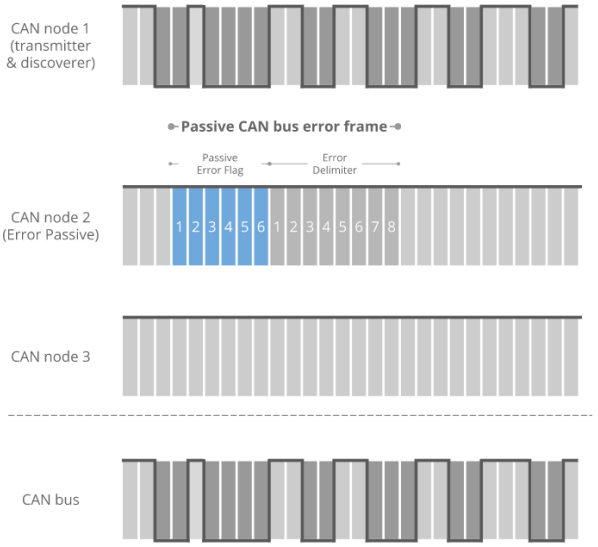



### Example 5: Receiver is Error Passive

In contrast, if a receiver raises a Passive Error Flag this is in practice "invisible" to all other CAN nodes on the bus (as any dominant bits win over the sequence of recessive bits) - see also Example 5.

Effectively, this means that an Error Passive receiver no longer has the ability to destroy frames transmitted by other CAN nodes.

**Example 5: 'Passive' CAN bus error frame** (receiver in Error Passive mode)




# CAN error types

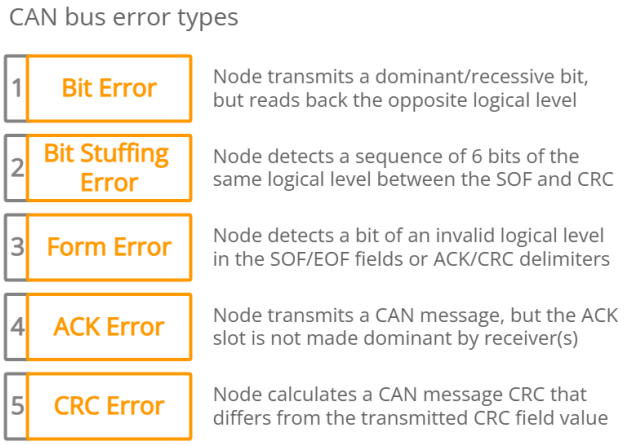
Next, let us look at what errors may cause CAN nodes to raise error flags.

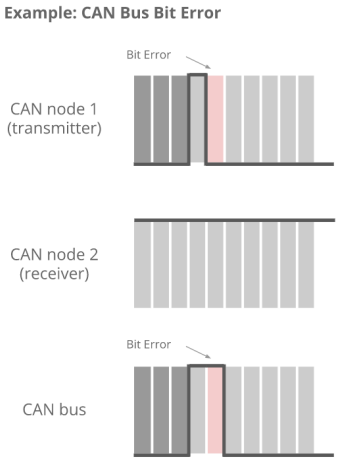
The CAN bus protocol specifies 5 CAN error types:

1. Bit Error [Transmitter]
2. Bit Stuffing Error [Receiver]
3. Form Error [Receiver]
4. ACK Error (Acknowledgement) [Transmitter]
5. CRC Error (Cyclic Redundancy Check) [Receiver]

We've already looked at Bit Errors and Bit Stuffing Errors briefly, both of which are evaluated at the bit level. The remaining three CAN error types are evaluated at the message level.

Below we detail each error type:

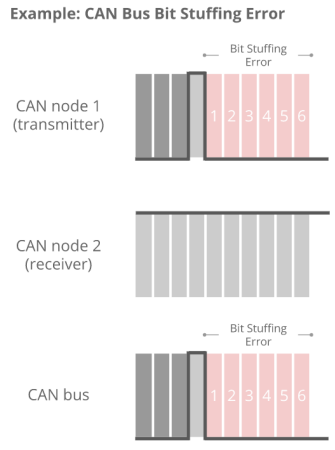



## #1 Bit Error

Every CAN node on the CAN bus will monitor the signal level at any given time - which means that a transmitting CAN node also "reads back" every bit it transmits. If the transmitter reads a different data bit level vs. what it transmitted, the transmitter detects this as a Bit Error.

If a bit mismatch occurs during the arbitration process (i.e. when sending the CAN ID), it is not interpreted as a Bit Error. Similarly, a mismatch in the acknowledgement slot (ACK field) does not cause a Bit Error as the ACK field specifically requires a recessive bit from the transmitter to be overwritten by a dominant bit from a receiver.

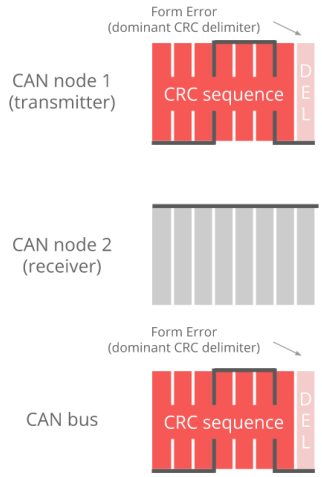



## #2 Bit Stuffing Error

As explained, bit stuffing is part of the CAN standard. It dictates that after every 5 consecutive bits of the same logical level, the 6th bit must be a complement. This is required to ensure the on-going synchronization of the network by providing rising edges. Further, it ensures that a stream of bits are not mis-interpreted as an error frame or as the interframe space (7 bit recessive sequence) that marks the end of a message. All CAN nodes automatically remove the extra bits.

If a sequence of 6 bits of the same logical level is observed on the bus within a CAN message (between the SOF and CRC field), the receiver detects this as a Bit Stuffing Error aka Stuff Error.

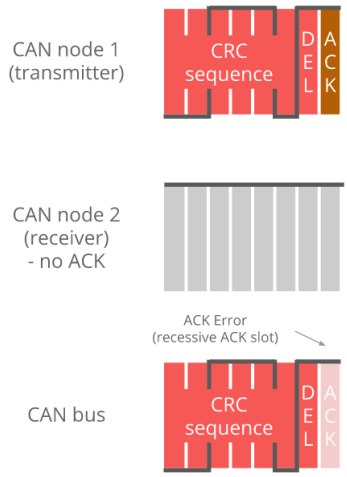
Example: CAN Bus Form Error




## #3 Form Error

This message-level check utilises the fact that certain fields/bits in the CAN message must always be of a certain logical level. Specifically the 1-bit SOF must be dominant, while the entire 8-bit EOF field must be recessive. Further, the ACK and CRC delimiters must be recessive. If a receiver finds that any of these are bits are of an invalid logical level, the receiver detects this as a Form Error.

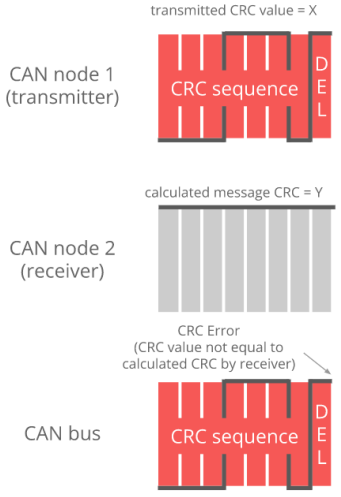
Example: CAN Bus ACK Error




## #4 ACK Error (Acknowledgement)

When a transmitter sends a CAN message, it will contain the ACK field (Acknowledgement), in which the transmitter will transmit a recessive bit. All listening CAN nodes are expected to send a dominant bit in this field to verify the reception of the message (regardless of whether the nodes are interested in the message or not). If the transmitter does not read a dominant bit in the ACK slot, the transmitter detects this as an ACK Error.

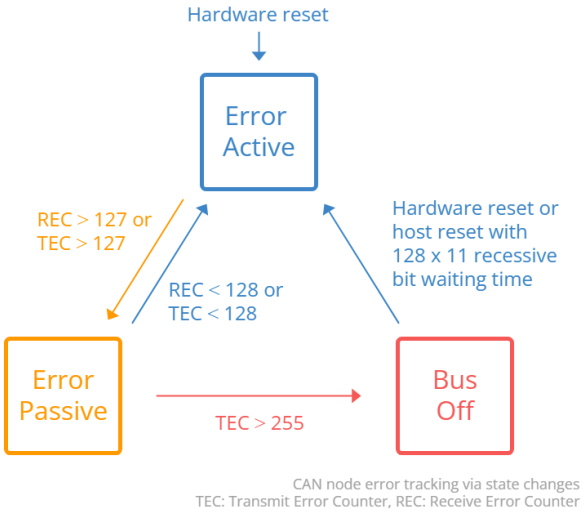
Example: CAN Bus CRC Error




## #5 CRC Error (Cyclic Redundancy Check)

Every CAN message contains a Cyclic Redundancy Checksum field of 15 bits. Here, the transmitter has calculated the CRC value and added it to the message. Every receiving node will also calculate the CRC on their own. If the receiver's CRC calculation does not match the transmitter's CRC, the receiver detects this as a CRC Error.

# CAN node states & error counters

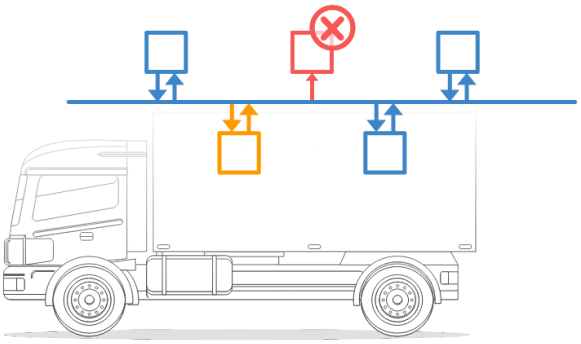



As evident, CAN error handling helps destroy erroneous messages - and enables CAN nodes to retry the transmission of erroneous messages.

This ensures that short-lived local disturbances (e.g. from noise) will not result in invalid/lost data. Instead, the transmitter attempts to re-send the message. If it wins arbitration (and there are no errors), the message is successfully sent.

However, what if errors are due to a systematic malfunction in a transmitting node? This could trigger an endless loop of sending/destroying the same message - jamming the CAN bus.

**This is where CAN node states and error counters come in.**



In short, the purpose of CAN error tracking is to confine errors by gracefully reducing the privileges of problematic CAN nodes.

Specifically, let's look at the three possible states:

1. **Error Active**: This is the default state of every CAN node, in which it is able to transmit data and raise 'Active Error Flags' when detecting errors
2. **Error Passive**: In this state, the CAN node is still able to transmit data, but it now raises 'Passive Error Flags' when detecting errors. Further, the CAN node now has to wait for an extra 8 bits (aka Suspend Transmission Time) in addition to the 3 bit intermission time before it can resume data transmission (to allow other CAN nodes to take control of the bus)
3. **Bus Off**: In this state, the CAN node disconnects itself from the CAN bus and can no longer transmit data or raise error flags

Every CAN controller keeps track of its own state and acts accordingly. CAN nodes shift state depending on the value of their error counters. Specifically, every CAN node keeps track on a Transmit Error Counter (TEC) and Receive Error Counter (REC):

- A CAN node enters the Error Passive state if the REC or TEC exceed 127
- A CAN node enters the Bus Off state if the TEC exceeds 255

### How do the error counters change?

Before we get into the logic of how error counters are increased/reduced, let us revisit the CAN error frame as well as the primary/secondary error flags.

As evident from the CAN error frame illustration, a CAN node that observes a dominant bit after its own sequence of 6 dominant bits will know that it raised a primary error flag. In this case, we can call this CAN node the 'discoverer' of the error.

At first, it might sound positive to have a CAN node that repeatedly discovers errors and reacts promptly by raising an error flag before other nodes. However, in practice, the discoverer is typically also the culprit causing errors - and hence it is punished more severely as per the overview.

CAN bus error counter logic

| | |
|---|---|
| TEC +8 | Transmitter raises primary error flag |
| REC +8 | Receiver raises primary error flag |
| REC +1 | Receiver raises secondary error flag |
| REC -1 | Receiver successfully receives message |
| TEC -1 | Transmitter successfully sends message |

TEC: Transmit Error Counter, REC: Receive Error Counter

### Details on TEC/REC counters

There are some additions/exceptions to the above rules, see e.g. this overview.

Most are pretty straight-forward based on our previous illustrative example. For example, it seems clear that CAN node 1 would increase the TEC by 8 as it discovers the Bit Error and raises an error flag. The other nodes in this case increase their REC by 1.

This has the intuitive consequence that the transmitting node will quickly reach the Error Passive and eventually Bus Off states if it continuously produces faulty CAN messages - whereas the receiving nodes do not change state.

The case where a receiver raises the primary error flag may seem counter-intuitive. However, this could for example be the case if a receiver CAN node is malfunctioning in a way that causes it to incorrectly detect errors in valid CAN messages. In such a case, the receiver would raise the primary error flag, effectively causing an error. Alternatively, it can happen in cases where all CAN nodes simultaneously raise error flags.


### CAN/LIN data & error logger

The CANedge1 lets you easily record data from 2 x CAN/LIN buses to an 8-32 GB SD card - incl. support for logging CAN/LIN errors. Simply connect it to e.g. a car or truck to start logging - and decode the data via free software/APIs. Further, the CANedge2 adds WiFi, letting you auto-transfer data to your own server - and update devices over-the-air.

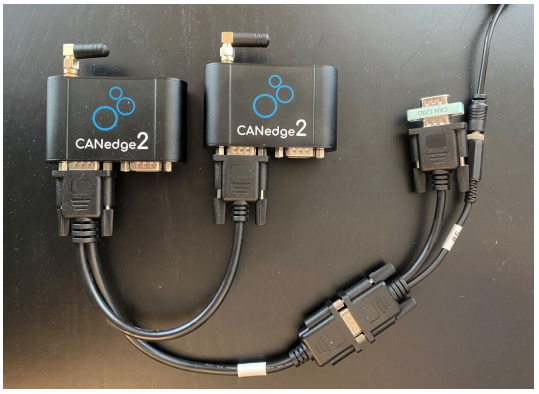
# Examples: Generating & logging error frames

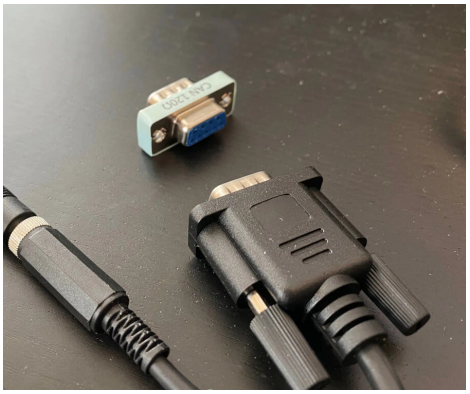
We have now covered the theoretical basics of CAN errors and CAN error handling. Next, let us look at generating and logging errors in practice. For this we will use a couple of CANedge devices - and for some tests a PCAN-USB device.

## Test #1: No CAN bus errors

As a benchmark, we start with a test involving no CAN bus errors. Here, a CANedge2 'transmitter' sends data to another CANedge2 'receiver' - and both log CAN bus errors.

By loading the MF4 log file in the asammdf GUI we verify that no CAN errors occurred during this test, which is to be expected.



## Test #2: Removing the CAN bus terminal resistor

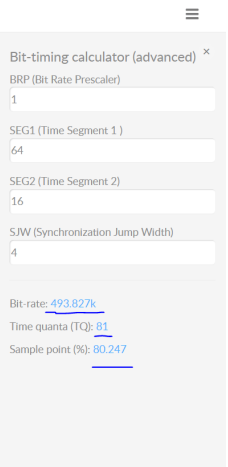
In this test, we remove the CAN termination in the middle of a log session. This effectively corresponds to immediately setting the bit level to dominant. As a result, the CANedge2 transmitter immediately starts logging **Bit Errors** (which occur when it attempts to transmit a recessive bit, but reads a dominant bit). The CANedge2 Receiver logs **Bit Stuffing Errors** as it detects 6 consecutive dominant bits. These errors are recorded until the termination is added again.

*[see the online article for screenshots of the errors in asammdf]*

### How relevant is this in practice?

Lack of termination is rarely a practical issue if you're recording data from a vehicle, machine etc. However, it's a common issue when working with 'test bench' setups. Here, the lack of termination may cause confusion as it can be difficult to distinguish from an inactive CAN bus. If in doubt, enabling error frame logging on the CANedge can be useful in troubleshooting.

## Test #3: Setting an incorrect baud rate




In this test we configure the CANedge receiver node to have a baud rate of 493.827K vs. the baud rate of the transmitter of 500K. This is a fairly extreme difference and results in **ACK Errors** for the transmitter and **Bit Stuffing Errors** for the receiver.

In more realistic scenarios, smaller differences in the baud rate configuration of various nodes may cause intermittent error frames and thus message loss.

*[see the online article for screenshots of the errors in asammdf]*

### How relevant is this in practice?

This example is rather extreme. However, in practice we have sometimes seen CAN buses that use standard bit rates (250K, 500K, ...), but with specific bit timing settings that differ from the ones that are typically recommended (and hence used by the CANedge). This will not lead to a complete shut-down of the communication, but rather periodic frame loss of a few percentages. To resolve this, you can construct an 'advanced bit rate' in the CANedge configuration, essentially setting up the bit-timing to better match the CAN bus you're logging from.

## Test #4: Removing the acknowledging CAN node


In this test, we use three CANedge units configured as follows:

- CANedge1: Configured to acknowledge data
- CANedge2 A: Configured in 'silent mode' (no acknowledgement)
- CANedge2 B: Configured to transmit a CAN frame every 500 ms

In the default setup, data is transmitted by the CANedge2 B onto the CAN bus and recorded with no errors. However, if we remove the CANedge1 from the bus there are no longer any CAN nodes to acknowledge the frames sent by the transmitter.

As a result, the transmitter detects **ACK Errors**. In response, it increases its Transmit Error Counter and raises Active Error Flags onto the CAN bus. These are in turn recorded by CANedge2 A (which silently monitors the bus) as **Form Errors**.

*[see the online article for screenshots of the errors in asammdf]*

The CANedge records Form Errors due to the fact that the transmitter raises them upon identifying the lack of a dominant bit in the ACK slot. As soon as a dominant bit is observed by the receiver in the subsequent EOF field (which should be recessive), a Form Error is detected.

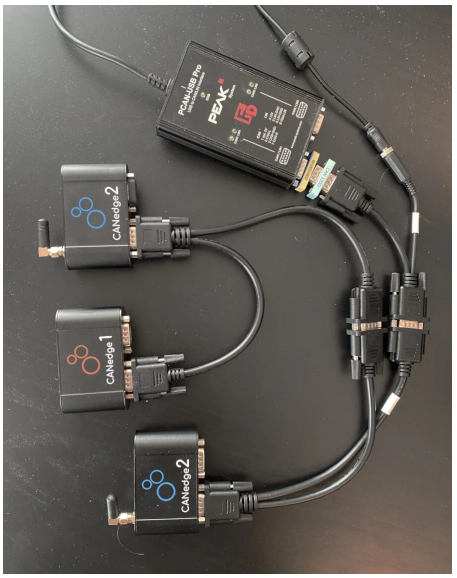
As evident, the transmitter broadcasts 16 Active Error Flags as its TEC is increased from 0 to 16 x 8 = 128. The transmitter has now exceeded the threshold of a TEC of 127 and enters Error Passive mode. As a result, the transmitter still experiences ACK Errors, but now only raises Passive Error

Flags (not visible to the receiver). At this point, the transmitter keeps attempting to transmit the same frame - and the receiver keeps recording this retransmission sequence.

### How relevant is this in practice?

This type of error is one we often encounter in our support tickets. Specifically, users may be trying to use our CAN loggers to record data from a single CAN node (such as a sensor-to-CAN module like our CANmod). If they decide to enable 'silent mode' on the CANedge in such an installation, no CAN nodes will acknowledge the single CAN node broadcasting data - and the result will either be empty log files, or log files filled with retransmissions of the same CAN frame (typically at very high frequency).

## Test #5: CAN frame collisions (no retransmission)




When setting up a CAN bus, it is key to avoid overlapping CAN IDs. Failing to do so can result in frame collisions as two CAN nodes may both believe they've won the arbitration - and hence start transmitting their frames at the same time.

To simulate this, we use the same setup as in test #4. In addition, we connect a PCAN-USB device as a secondary transmitter.

The CANedge2 transmitter is now configured to output a single CAN frame every 10 ms with CAN ID 1 and a payload of eight 0xFF bytes. Further, we configure the CANedge2 to disable retransmission of frames that were disrupted by errors. The PCAN-USB outputs an identical CAN frame every 2 ms with the 1st byte of the payload changed to 0xFE. The PCAN device has retransmissions enabled.

This setup quickly creates a frame collision, resulting in the CANedge and PCAN transmitters detecting a **Bit Error**. In response to this, both raise an Active Error Flag, which is detected as a **Bit Stuffing Error** by the CANedge receiver. The PCAN device immediately attempts a retransmission and succeeds, while the CANedge waits with further transmission until the next message is to be sent.

*[see the online article for screenshots of the errors in asammdf]*

### How relevant is this in practice?

This type of error should of course never happen in e.g. a car, since the design and test processes will ensure that all CAN nodes communicate via globally unique CAN identifiers. However, this problem can easily occur if you install a 3rd party device (e.g. a sensor-to-CAN module) to inject data into an existing CAN bus. If you do not ensure the global uniqueness of the CAN IDs of external CAN nodes, you may cause frame collisions and hence errors on the CAN bus. This is particularly important if your external CAN node broadcasts data with high priority CAN IDs as you may then affect safety critical CAN nodes.

### Test #6: CAN frame collisions (incl. retransmission)

In this test, we use the same setup as before, but we now enable retransmissions on the CANedge2 transmitter.

In this case, the frame collision results in a sequence of subsequent frame collisions as both the CANedge2 and the PCAN-USB device attempt to re-transmit their disrupted messages.

Due to the resulting Bit Errors, both raise a total of 16 Active Error Flags, which are detected as Bit Stuffing Errors by the silent CANedge2 receiver. Both transmitters then enter Error Passive mode and stop raising Active Error Flags, meaning none of them can destroy CAN frames on the bus. As a result, one of the transmitters will succeed in transmitting a full message, thus ending the retransmission frenzy - and enabling both devices to resume transmission. However, this only lasts for a few seconds before another collision occurs.

#### How relevant is this in practice?

The collision handling is a good example of how effective the CAN error handling is at 'shutting down' potentially problematic sequences and enabling CAN nodes to resume communication. If a frame collision occurs, it is likely that both CAN nodes will be set up to attempt retransmission, which would cause a jam if not for the error handling and confinement.

## LIN bus errors

Similar to CAN bus errors, the LIN protocol also specifies a set of four error types, which we outline briefly below. The CANedge supports both CAN/LIN error frame logging.

### #1 LIN Checksum Error

As for the CAN CRC Error, this error type implies that a LIN node has calculated a different checksum vs. the one embedded in the LIN bus frame by the transmitter. If you're using the CANedge as a LIN Subscriber, this error may indicate that you've configured the device 'frame table' with incorrect identifiers for some of the LIN frames on the bus.

This can in turn be used to 'reverse engineer' the correct lengths and IDs of proprietary LIN frames via a step-by-step procedure. See the CANedge Docs for details.

### #2 LIN Receive Error

These occur if a specific part of the LIN message does not match the expected value, or if there is a mismatch between what is transmitted vs. read on the LIN bus.

### #3 LIN Synchronization Error

This error indicates an invalid synchronization field in the start of the LIN frame. It can also indicate a large deviation between the configured bit rate for a LIN node vs. the bit rate detected from the synchronization field.

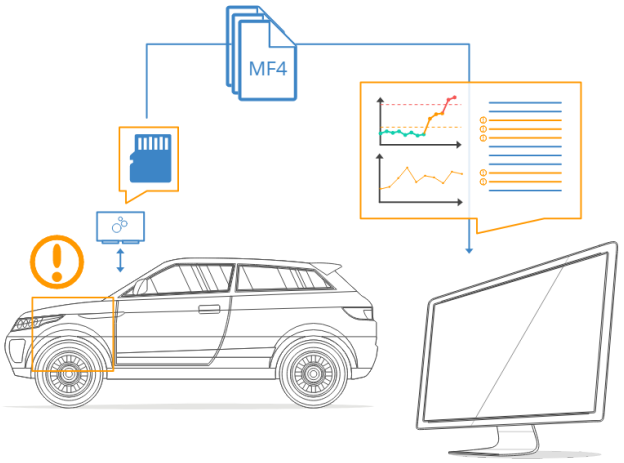
### #4 LIN Transmission Error

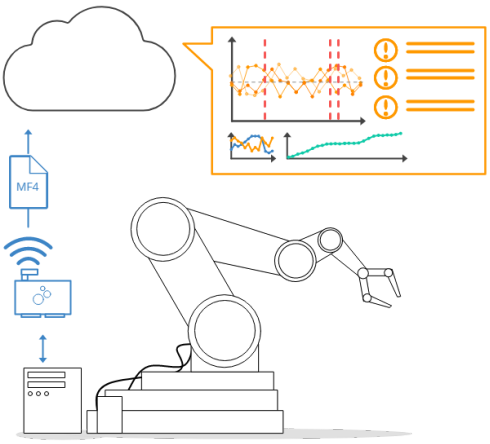
Transmission errors can occur for LIN identifiers registered as SUBSCRIBER messages. If there are no nodes responding to a SUBSCRIBER message, a transmission error is logged.

# Example use cases for CAN error frame logging

### CAN bus diagnostics in OEM vehicles

An automotive OEM may have the need to record CAN error frames in the field during late stage prototype testing. By deploying a CANedge, the OEM engineering team will both be able to troubleshoot issues based on the actual CAN signals (speed, RPM, temperatures) - as well as issues related with the lower layer CAN communication in their prototype systems. This is particularly vital if the issues of interest are intermittent and e.g. only happen once or twice per month. In such scenarios, CAN bus interfaces are not well suited - and it becomes increasingly relevant to have a cost-effective device to enable scalable deployments for faster troubleshooting.




### Remotely troubleshooting CAN errors in machinery

An OEM or aftermarket user may need to capture rare CAN error events in their machines. To do so, they deploy a CANedge2 to record the CAN data and related error frames - and automatically upload the data via WiFi to their own cloud server. Here, errors are automatically identified and an alert is sent to the engineering team to immediately allow for diagnosing and resolving the issue.

# FAQ

### Does the CANedge support all CAN/LIN error types?

Yes, the CANedge is able to record all CAN/LIN error types. It does, however, not currently record its own error counter status as this is deemed less relevant from a logging perspective.

### Will a CANedge raise error flags?

The CANedge is only able to raise error flags onto the CAN bus if it is configured in its 'normal' mode, in which it is also able to transmit messages. If in 'restricted' mode it can listen to CAN frames and acknowledge CAN frames - but not raise Active Error Flags onto the bus. In 'monitoring' mode (aka 'silent mode') it can listen to the CAN bus traffic, but not acknowledge messages nor raise Active Error Flags. The CANedge will always record internal CAN/LIN error frames.

### What information can be recorded regarding a CAN/LIN error?

If a CAN frame is erroneous, resulting in an error frame, the CANedge generally only records the error type - without any data related to the erroneous frame (beyond the timestamp). One exception to this rule is for acknowledgement errors, where the CANedge will still record unacknowledged CAN frames (incl. from retransmission attempts).

### Is error handling a cybersecurity risk?

Some researchers have pointed out the risk that 'bad actors' could utilize the CAN bus error handling functionality to enforce remote 'bus off' events for safety-critical ECUs. This is a good example of why CAN bus data loggers & interfaces like the CANedge2 with remote over-the-air data transfer and updates need to be highly secure (see also our intro to CAN cybersecurity). For a nice overview of a remote bus off attack, see this intro by Adrian Colyer.

**Thank you for reading our guide - we hope you found it useful!**

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