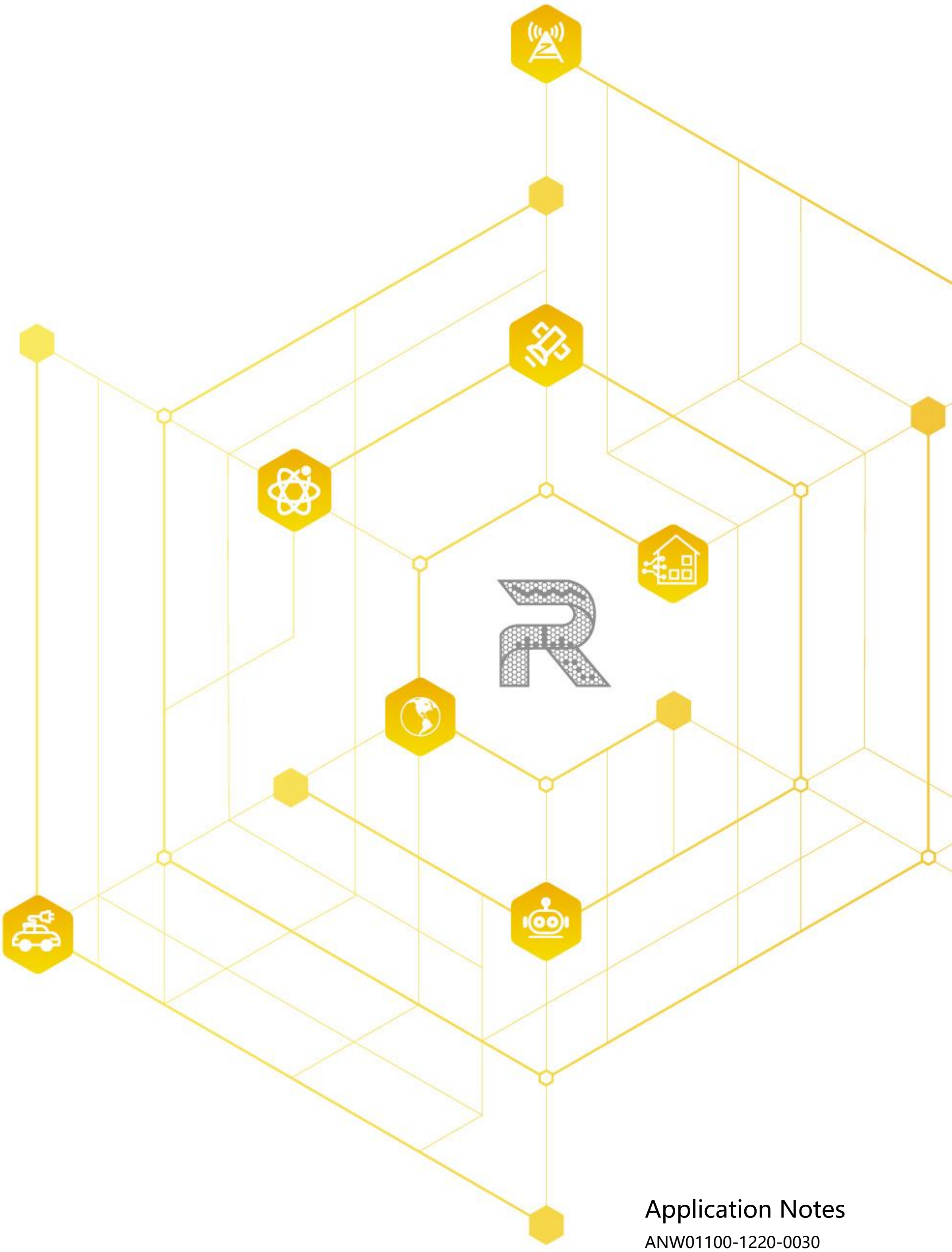
Technical Analysis of Automotive CAN-FD Bus



Application Notes

ANW01100-1220-0030

Introduction

In 1986, the German electrical company Bosch developed the Controller Area Network (CAN) communication protocol for automobiles. Since then, CAN has been standardized through ISO11898 and ISO11519. Today, the high performance and reliability of CAN have been widely recognized and adopted in industrial production.

With industrial development, the amount of data on industrial buses is increasing daily, especially in the automotive sector where CAN buses are widely used—the data volume is becoming enormous. For example, the presence of more auxiliary systems and human-machine interfaces inside automobiles makes the traditional CAN bus increasingly inadequate in terms of transmission speed and bandwidth, reaching the limit of its load capacity. According to the standard CAN frame structure defined by ISO11898-2, one single frame packet can transmit a maximum of 64 bits (8 bytes) of data, and even under optimal conditions, the bus load has reached about 70%.

To meet the current challenges of massive data volume, it is necessary to upgrade the bus to improve transmission rates. CAN-FD (CAN with Flexible Data-Rate) was created in this context.

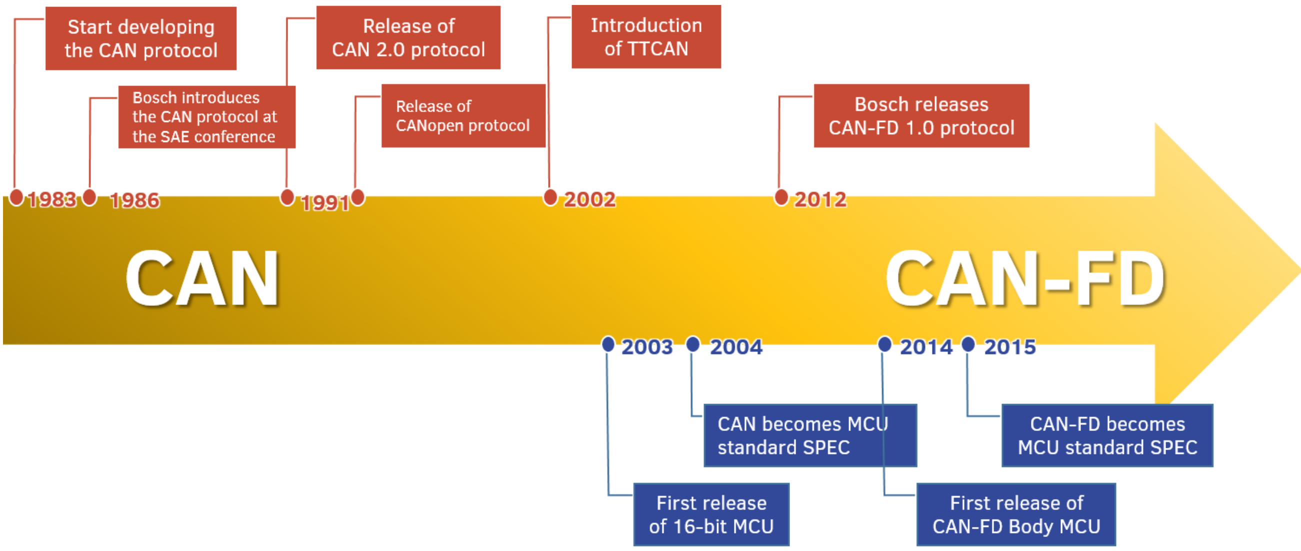


Figure 1 History of CAN bus development

Automotive CAN Network Topology Diagram

The diagram below exemplifies a CAN network topology in an automobile. As shown, a CAN network is composed of CAN nodes and multiple CAN buses. A CAN node mainly consists of a CPU, CAN controller, and CAN transceiver, while various Electronic Control Units (ECUs) with different functions are distributed across different CAN buses.

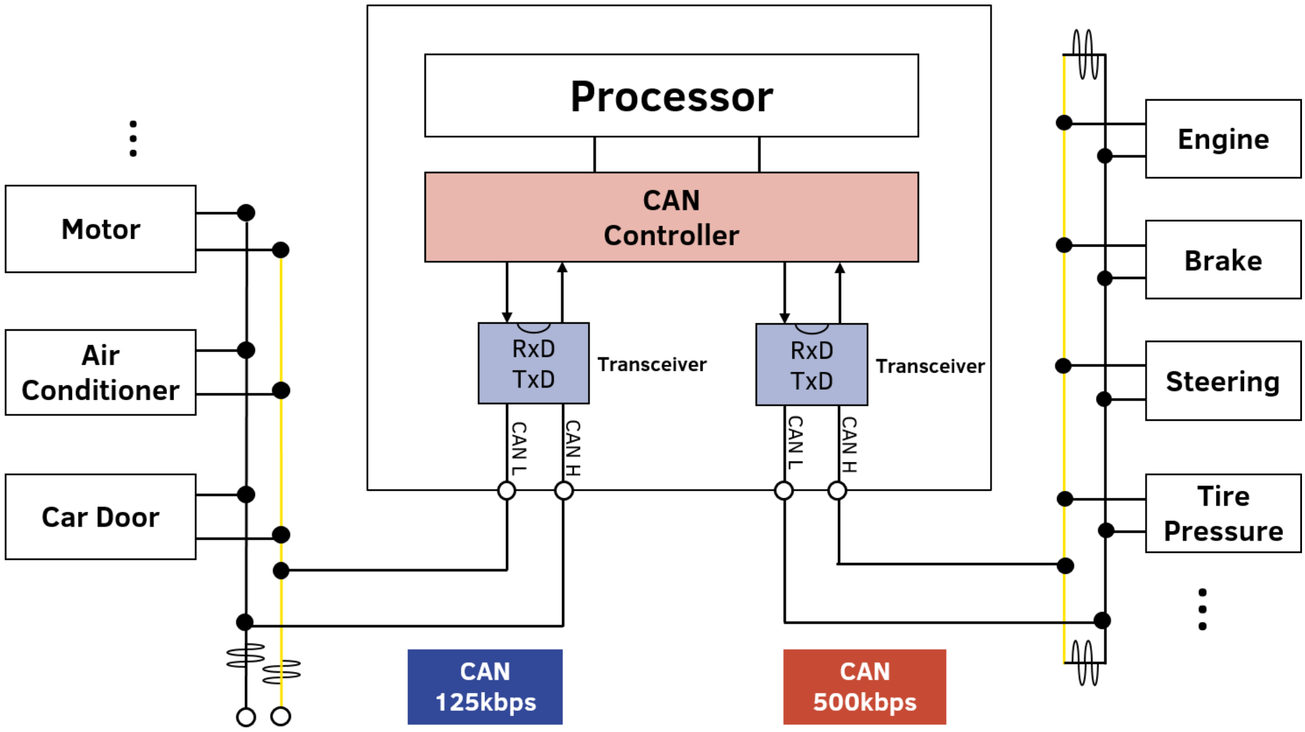


Figure 2 CAN network topology structure

Reference to OSI Protocol Stack Model

The CAN protocol covers the Transport Layer, Data Link Layer, and Physical Layer as specified in the ISO OSI reference model. Within the Data Link Layer of the ISO/OSI reference model, the CAN protocol divides it into the MAC sublayer and LLC sublayer, with the MAC sublayer being the core component of the CAN protocol.

The function of the Data Link Layer is to organize the signals received from the Physical Layer into meaningful messages and to provide transmission control processes such as error control. Specifically, this includes message framing, arbitration, acknowledgment, error detection or reporting. The functions of the data link layer are usually implemented in the hardware of the CAN controller. The physical layer, in turn, defines the actual methods of signal transmission, bit timing, bit encoding, and synchronization steps. Signal level, communication speed, sampling point, driver and bus electrical characteristics, and connector types are not defined and should be determined by users based on system requirements.

OSI Basic Reference Model

7-Application Layer
6-Presentation Layer
5-Session Layer
4-Transport Layer
3-Network Layer
2-Data Link Layer
1-Physical Layer

CAN-Defined Functions in Each Layer

Layers	Defined Functions	Functions
Layer 4	Retransmission Control	Persistent Retry
Layer 2 (LLC)	Message Filtering (Selective Reception of Messages)	Supports Point-to-Point, Broadcast, and Multicast Communication
	Overload Notification	Notifies When Reception Preparation is Incomplete
Layer 2 (MAC)	Error Recovery Function	Retransmission
	Message Framing	Four Frame Types: Data Frame, Remote Frame, Error Frame, Overload Frame
	Connection Control Method	Contention-Based Access (Supports Multicast)
	Arbitration During Bus Collisions	Priority-Based Arbitration (Higher-ID Messages Continue Transmission)
	Fault Confinement Mechanism	Automatic Distinction Between Temporary and Permanent Errors, Isolates Faulty Nodes
	Error Notification	CRC Error, Stuffing Error, Bit Error, ACK Error, Form Error
	Error Detection	All Nodes Can Detect Errors
	Acknowledgment Method	Two Acknowledgment Types: ACK and NACK
Layer 1	Communication Method	Half-Duplex Communication
	Bit Encoding Method	NRZ Encoding with 6-Bit Stuffing
	Bit Timing	Bit Timing & Number of Sampling Points (User-Configurable)
	Synchronization Method	Synchronization via Sync Segment (SS) (Includes Synchronization Capability)

Figure 3 Comparison reference of OSI models

Introduction to CAN-FD

CAN-FD Data Frame Structure

CAN-FD adopts two types of bit rates: from the BRS bit in the control field to ACK field (including CRC delimiter) is variable rate, while the remaining part uses the same rate as traditional CAN bus. The data frame structure for CAN-FD is shown below:

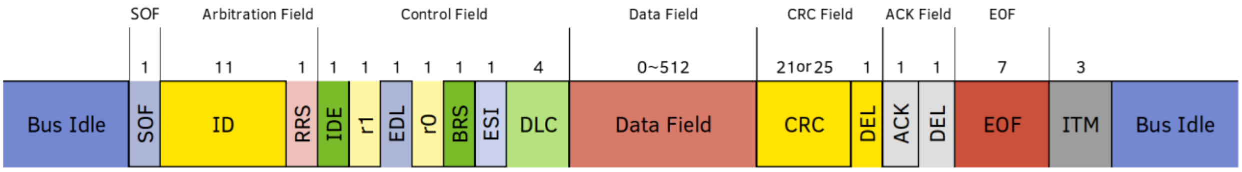


Figure 4 CAN-FD frame format

- IDE (Identifier Extension): 0 indicates 11-bit ID, 1 indicates 29-bit ID.
- r0, r1 (Reserved for future use): CAN-FD does not support remote frames.
- EDL (Extended Data Length): 0 indicates CAN-FD frame, 1 indicates CAN frame.
- BRS (Bit Rate Switch): 0 means no switching, 1 means switch rate.
- ESI (Error State Indicator): 0 means error active, 1 means error passive.
- DLC (Data Length Code): Linear part for CAN rate, non-linear for CAN-FD variable part.

CRC Field
For CRC, due to the bit stuffing rule in CAN, there is a possibility of frame misdetection, which hinders the intended design target. CAN-FD changes the CRC algorithm to compute the CRC bitstream with stuffed bits. To avoid more than six consecutive bits in the checksum part, a stuffing bit is added every four bits, starting from the first bit—the stuffing bit's value is the inverse of the previous bit. If it's not, an error is flagged.

The CRC field in CAN-FD is extended to 21 bits. Data field length varies greatly, so different CRC generating polynomials are applied depending on DLC size. For example, CRC_17 is used for frames shorter than 210 bits, while CRC_21 is for frames under 1023 bits.

DLC Encoding
CAN-FD uses a new DLC encoding scheme. When data field length is 0 to 8 bytes, linear coding is used; for 12 to 64 bytes, nonlinear encoding is used, as shown in Figure 5.

	Data Byte Count	Data Length Code			
		DLC3	DLC2	DLC1	DLC0
ISO11898-1	0	0	0	0	0
	1	0	0	0	1
	2	0	0	1	0
	3	0	0	1	1
	4	0	1	0	0
	5	0	1	0	1
	6	0	1	1	0
	7	0	1	1	1
	8	1	0	0	0
Proposal for Additional Codes in CAN-FD	12	1	0	0	1
	16	1	0	1	0
	20	1	0	1	1
	24	1	1	0	0
	32	1	1	0	1
	48	1	1	1	0
	64	1	1	1	1

Figure 5 DLC linear and nonlinear encoding

Characteristics of CAN-FD Bus
- Uses differential signals for transmission, offering excellent noise immunity.

- All nodes are peer-level; any node can send messages when the bus is idle.
- Non-destructive Bit-wise Arbitration: the identifier inside the message determines priority, ensuring data completeness and timeliness.
- CAN-FD inherits the address-less concept from CAN; adding nodes doesn't affect existing hardware and software.
- The communication speed can be set according to the scale of the network and the capabilities of the system. Nodes on buses with different speeds can interact through gateways.
- Fault tolerance: All nodes can detect errors and notify others. If a transmitting node detects an error, it stops and keeps resending the message until successful.
- Remote data requests can be made by sending a Remote Frame.

Bus Analysis by DS70000 Oscilloscope

DS70000 Bus Analysis Features

Serial bus communication is widely used in the automotive industry. From braking systems to navigation, buses are everywhere; proper functioning depends on reliable communication among ECUs, sensors, and actuators. Besides digital protocol verification, waveform quality, noise, and synchronization between sensor/actuator signals also need to be checked at the simulated physical layer.

The DS70000 oscilloscope, developed by RIGOL, boasts outstanding bus analysis features:

- With a high sampling rate, based on RIGOL's self-developed "Phoenix" core technology platform, it achieves a maximum Sampling Rate of 20 GSa/s and a Real-time Bandwidth of up to 5 GHz, enabling more accurate signal capture and reproduction.
- With the new-generation RIGOL UltraVision III platform, DS70000 featured a larger Memory Depth up to 2 Gpts, enabling longer waveform acquisition at high sampling rates and meeting the requirements for long-duration observations.
- Rich triggering functions and up to 1,000,000 waveforms per second refresh rate for capturing elusive signal glitches.
- Powerful bus analysis features, supporting mainstream serial buses such as RS232/UART, I2C, SPI, LIN, CAN, CAN-FD, FlexRay, I2S, MIL-STD-1553, MIPI-RFFE and USB2.0, etc.
- The decoded results are displayed in a list, showing information for each frame on the bus, including address, data, and identifier. All frame analysis results can be viewed in a list window on the screen and exported as a test report.

CAN-FD Bus Decoding and Analysis Steps

In real design scenarios, protocol analysis helps engineers quickly find errors, debug hardware, and accelerate development, ensuring fast and high-quality project completion.

Protocol analysis is based on protocol decoding; only accurate decoding leads to meaningful analysis and effective debugging.

The DS70000 oscilloscope supports CAN-FD decoding and analysis, allowing 4-channel bus analysis. Figure 6 shows the decoding configuration interface.

Figure 6 Oscilloscope Analysis Configurat

- This option allows you to select the protocol type, supporting CAN-FD as well as SPI, FlexRay, I2S, 1553B, etc., for analysis.
- This is where you toggle the bus decoding on or off.
- Here you can set the signal source’s threshold and type.
- This option sets the signal rate for CAN and CAN-FD, and allows precise sampling position adjustment.

The DS70000 series oscilloscope features an intuitive decoding interface, providing engineers with an efficient testing tool.

Summary

This article provides a comprehensive introduction to the development of the CAN bus, its topology, the OSI protocol stack, and a deeper look at CAN-FD—including data frame structure, CRC field, and DLC encoding. In addition, with RIGOL’s DS70000 series digital oscilloscope, you can perform protocol decoding and analysis for CAN-FD and many other protocols.

The DS70000 is built on the UltraVision III hardware platform, meticulously developed by RIGOL engineers over ten years, and features the self-developed "Phoenix" core technology platform. It achieves a real-time sampling rate of up to 20 GSa/s and incorporates a variety of user-friendly designs, delivering an outstanding testing and analysis experience.

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