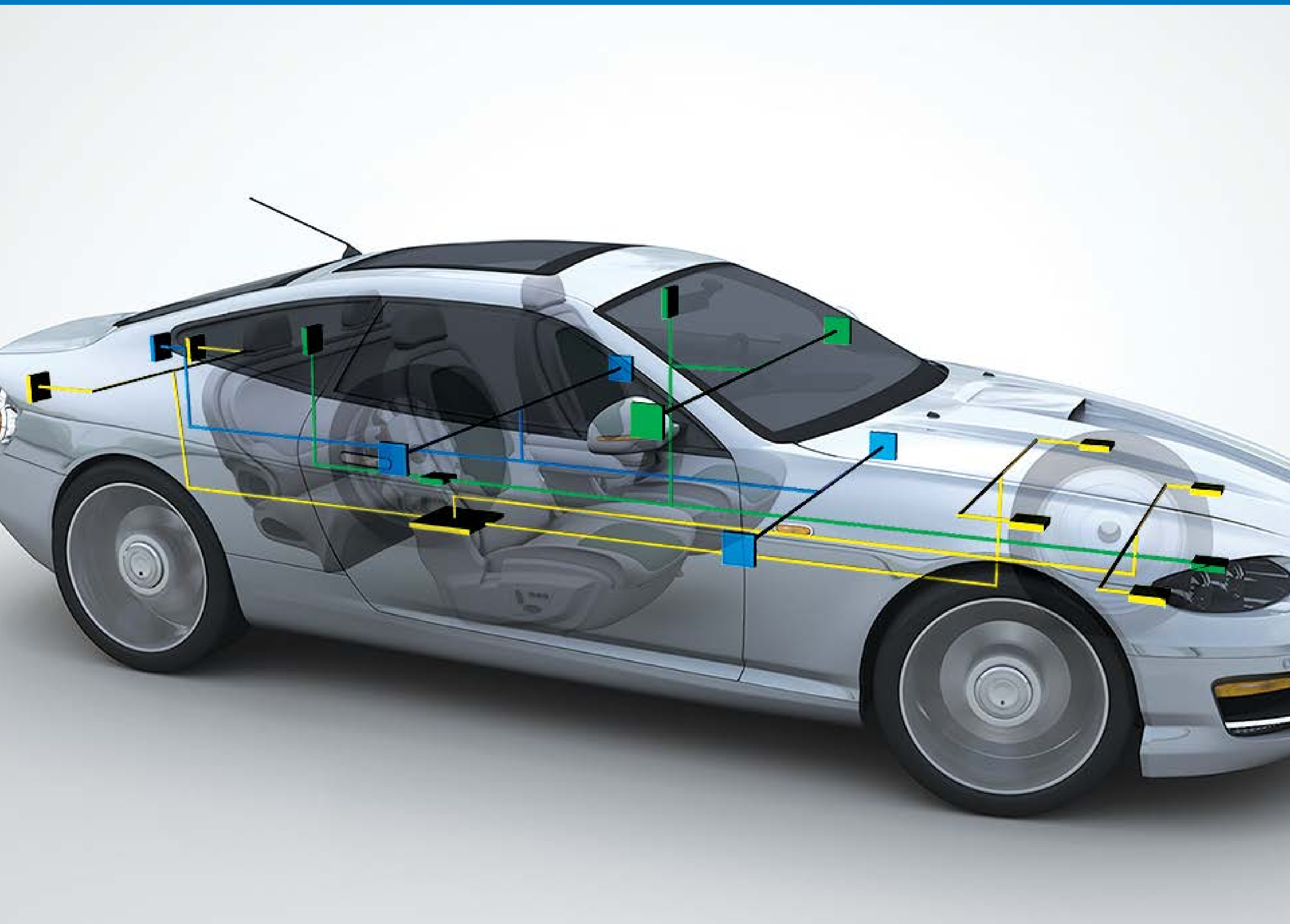

CAN-FD and Ethernet Create Fast Reliable Automotive Data Buses for the Next Decade

Y.B. Pradeep

The automotive industry has seen explosive growth of electronic control units (ECUs) in vehicles. These ECUs evolved from stand-alone units to intelligent nodes in networks using both proprietary protocols and industry-wide standards. Automotive networks have brought down cost and increased reliability and performance. The last decade saw the establishment of data buses as in-vehicle network standards. The next decade will see expansion of existing vehicle network protocols and adaptation of standard networking into cars. This article analyzes two of the new automotive networking protocols, CAN-FD and Ethernet.

Why New Data Buses?

New automotive features such as advanced driver assistance systems, parking aids, lane departure systems, blind-spot detection, and infotainment systems have triggered the need for new data buses. These new buses must provide faster speed, bandwidth scalability, and a seamless upgrade path, while helping to reduce power consumption, weight, wire count, and deployment costs.

CAN with Flexible Data Rates (CAN-FD)

CAN-FD improves the bandwidth utilization of the dominant bus system in the automotive industry, the CAN protocol (figures 1, 2, 3). The increase in bandwidth utilization is achieved by:

1. Dual Bit Rate: CAN-FD frames support dual-bit-time capability
   a. Normal Bit Time
      - The bit time is identical to the existing CAN protocol. This includes those fields where multiple devices can transmit simultaneously – at the arbitration start and acknowledgement end.
      - The fields are as below:
        - Start-of-frame bit (SOF), arbitration field (12 bits), and 2 control bits
        - Acknowledge bit, acknowledge delimiter bit, end-of-frame (EOF) bits (7 bits) and inter-frame gap (3 bits)
   b. Reduced Bit Time
      - To achieve higher data rates CAN-FD allows bit times for certain fields that are shorter than the current CAN bit time.
      - Timing requirement for these fields are less stringent as it is guaranteed that the devices only transmit one after another. Bit-wise arbitration is not needed.
      - These fields are: 2 control bits, payload length (4 bits), payload data, and CRC (17 or 21 bits).

2. Pay Load Increase:
   a. The message length is 64 bytes compared to previously 8 bytes, improving the efficiency of the CAN protocol.
   b. To take advantage of this improvement in CAN-FD, you also need to update the system software.

Figure 1. Standard CAN Message

Figure 2. CAN-FD with Reduced Bit Time

Figure 3. CAN-FD with Reduced Bit Time and Increased Payload

CAN Frame Formats

CAN-FD is an evolution of the current CAN protocol and supports all existing CAN frame formats.
See figure 4 for a general CAN frame format.

Figure 4. General CAN Frame Format

CAN 2.0 – Standard Frame(s)

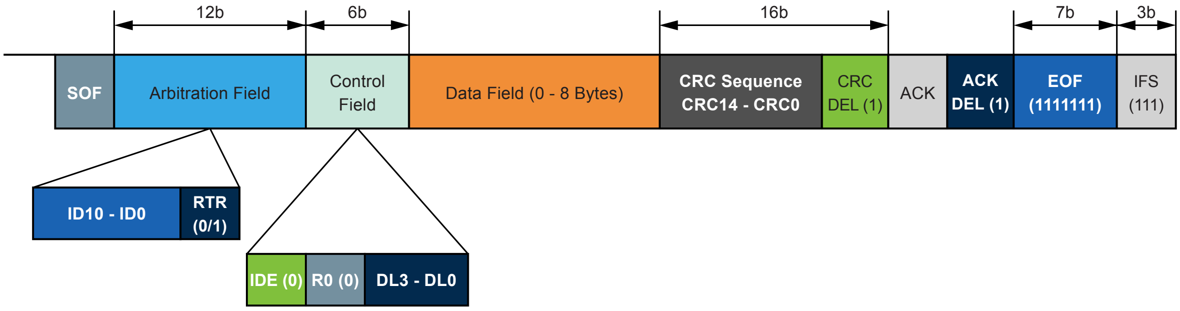

Figure 5. CAN 2.0 Standard Frame

The two bits as described below identify a standard frame (11-bit identifier):

- 13th bit – identifier extension (IDE) bit – dominant (0)
- 14th bit – reserved bit (R0) – dominant (0)

Another important bit is bit 12, the remote transmission request (RTR) bit.

- Dominant (0) – a data frame
- Recessive (1) – a remote frame

CAN 2.0 – Extended Frame(s)

The CAN 2.0 protocol also supports extended frames (figure 6).

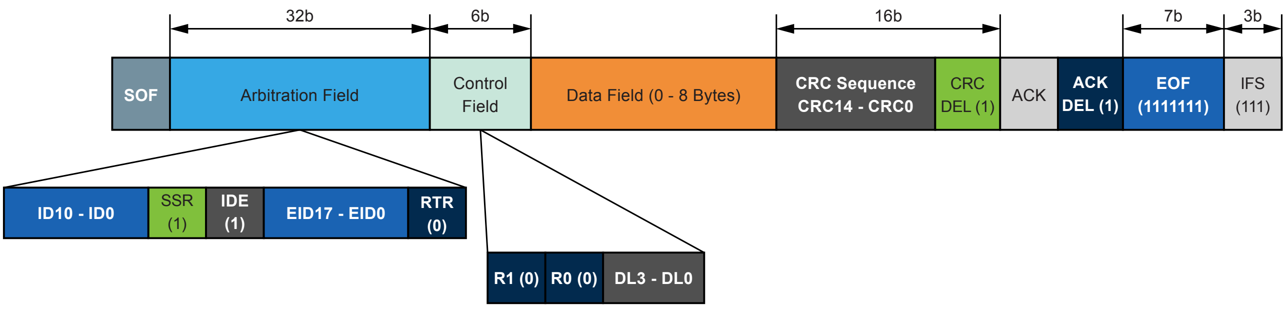

Figure 6. CAN 2.0 Extended Frame

The two bits as described below identify an extended frame (29-bit identifier):

- 13th bit – IDE field – recessive (1)
- 12th bit – SRR field – recessive (1)

The new position of the RTR bit is bit 32.

The extended frame includes two reserved bits (R0 & R1).

CAN-FD Standard Frame Format

You can see the larger data payload in the CAN-FD protocol (figure 7).

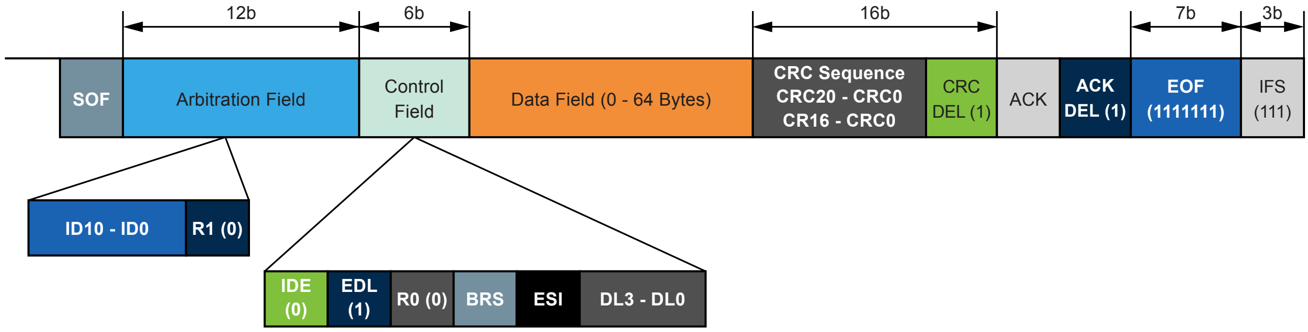

Figure 7. CAN-FD Standard Frame

The two bits as described below identify a CAN-FD frame:

- 13th bit – identifier extension (IDE) bit – dominant (0)
- 14th bit – R0 bit in standard frame is now extended data length (EDL) bit – recessive (1)

This implies that the CAN-FD specification should apply to the data length code (DLC) and the CRC sequence.

Bit 16 is a new bit - bit rate switch (BRS)

Note that there is no RTR bit.

New Features in CAN-FD

- Extended data length (EDL) bit, distinguishes CAN-FD frame from a standard CAN frame
  - Dominant – standard CAN frame format
  - Recessive – CAN-FD frame format
- Bit rate switch (BRS) bit: the CAN-FD rate immediately starts at the sampling point of BRS
  - Dominant – do not switch to new bit rate
  - Recessive – switch to new bit rate
- Error state indicator (ESI) bit
  - Dominant – error active transmitter
  - Recessive – error passive transmitter
- Two bits reserved for further protocol revisions – R0 (bit 15) & R1 (bit 12) – but the bit positions differ from earlier versions
- Modified CRC to maintain the same hamming distance for the longer frames as with standard CAN frames

CAN_FD Use Cases

Fast Software Downloads

CAN-FD serves to speed up end-of-line programming of vehicle ECUs. GM stated that with the use of CAN-FD, the ECU programming time is only one-third or even one-fifth of the current programming time [1]. Likewise diagnostics or software upgrades in repair garages are also faster.

Error Status

A transmit node error may result in a sudden stop of the message, thus affecting safety-critical systems. Every CAN-FD message includes the condition of the transmit node in the error status information (ESI) bit. This way, the receiver can monitor the transmit node and take fail-safe actions prior to any actual issues.

Increased Data Payload

CAN-FD enables message lengths of up to 64 bytes to avoid splitting long messages. This results in a very simplified transport layer of the CAN stack. Implementing complex flow control mechanisms involving multiple messages is not needed.

Faster Communication Between ECUs

The increasing amount of automotive features leads to a drastic augmentation of data exchanged between the automotive ECUs. CAN-FD can easily handle the higher amount of data due to its higher bandwidth, and it enables speeds similar to FlexRay.

Reduced Bus Loads

As a result of the higher communication speed, the ECUs can send and receive data more quickly using CAN-FD frames rather than the standard CAN frames. This directly reduces bus loading.

Example: An instrument cluster informs the driver of many vehicle parameters. It has to drive three to seven gauges, control 20 to 30 tell-tales, generate chimes, and display signal warnings to indicate status or system malfunction. This node receives and transmits information via many CAN messages from multiple ECUs. The CAN load on such a system can be as much as 75% - 80%. CAN-FD alleviates this problem by reducing the CAN bus load.

Transmission Line Length

In case of networks in trucks or articulated buses, the bus is as long as 9 to 20 meters. The arbitration field limits the speed of the entire network.

The J1939-14 standard defines a maximum bit rate of 500kbps. However, CAN-FD enables much higher speeds. The arbitration fields may remain at 500kbps whereas the data payloads can be exchanged at much higher data rates. This increases the throughput of the network.

Migration from CAN to CAN-FD

The introduction of CAN-FD will not affect today's vehicle networks such as LIN and MOST. Migration paths are necessary to include CAN-FD into existing CAN networks. This is because a CAN-FD compliant node can accept current CAN frames in addition to CAN-FD frames without any errors. A normal CAN node, however, will generate an error frame on the network in the presence of CAN-FD frames. OEMs can mitigate migration efforts to a true CAN-FD network by several measures.

A typical scenario:

- New ECUs deployed in the network must be CAN-FD compliant while still operating within the current CAN communication frame format.
  - The MCUs need to be CAN-FD compliant.
  - When upgrading the software, integrate new CAN drivers only with minimal or no impact on upper layers.
- Achieve higher data rates with a software update to incorporate CAN-FD frame format.
  - Limiting the payload to 8 bytes can restrict software change to CAN driver only.
  - Experiments at Bosch have shown that current transceivers help to achieve an average data rate of 2.5Mbps [2].
  - Use of "partial networking": during a CAN-FD operation. The transceivers of the existing CAN network remain passively disconnected or switched off.

You can realize a true CAN-FD-compliant network by software updates to support payload sizes of up to 64 bytes for high bandwidth utilization, or by using CAN-FD-qualified transceivers for much higher data rates.

Summary

- CAN-FD provides increased throughput at costs comparable to existing CAN networks.

- CAN-FD provides additional bandwidth and faster speeds. This helps to reduce the number of nodes within the network.
- CAN-FD maintains the reliability of the existing CAN due to changed CRC polynomials.

Automotive Ethernet

In 2008 BMW was the first OEM to start using Ethernet for on-board diagnostics (OBD) with the car's head unit [3].

There are many advantages of using Ethernet as an automotive network:
- Mass production of Ethernet-enabled devices drastically reduces cost
- Bandwidth scalability with no negative impact on safety, functionality, or performance
- Connectivity options both inside and outside the vehicle
- Galvanic isolation due to transformer coupling

BMW used Ethernet only in the garage service bays and not as a data bus within the car. Ethernet was never seen as a core automotive data bus. Two recent developments supported the rise of Ethernet:
- The recently released MOST150 standard also integrates an Ethernet channel
- The development of low-cost, high-speed PHY (physical interface ICs) capable of sending up to 100mbps over an unshielded twisted pair cable

Bosch predicts that Ethernet can become the de-facto electrical/electronic backbone in the near future [4].

Ethernet Use Cases

Infotainment Systems

Current infotainment systems are proprietary and non-scalable. Automotive Ethernet addresses this issue, and the very first demonstrated use case was the transfer of audio/video data.

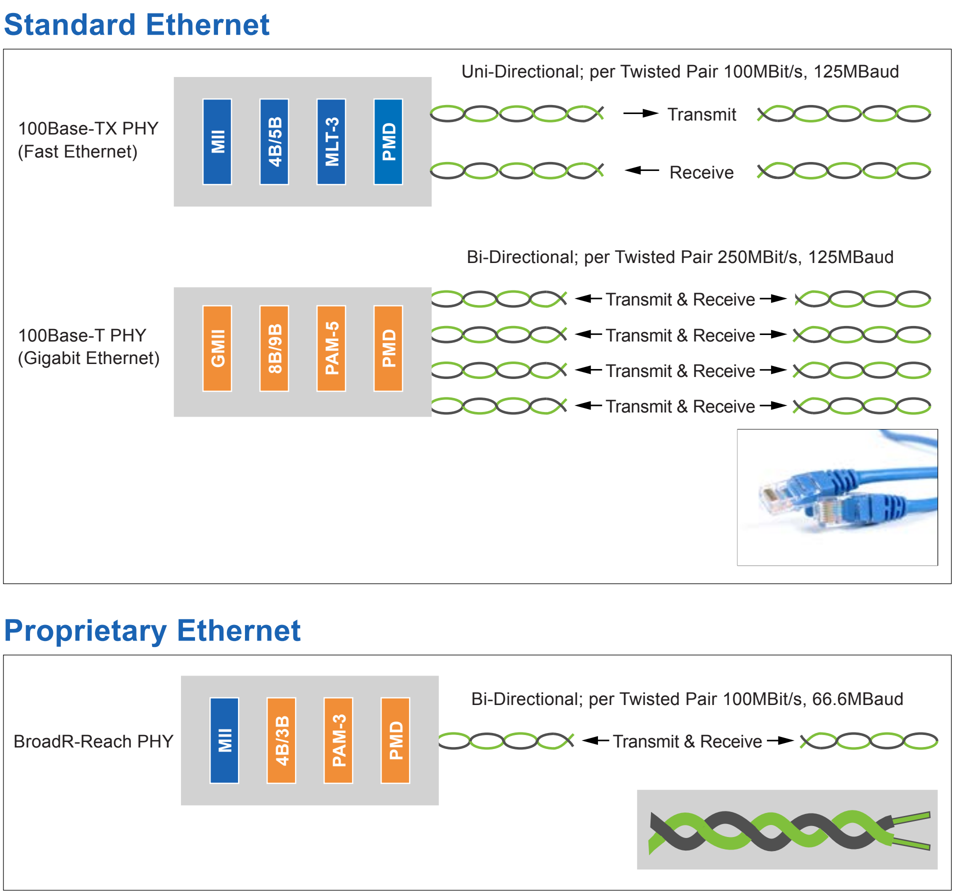

Figure 8. Standard Ethernet vs. Proprietary Ethernet

To improve the deterministic behavior of Ethernet's asynchronous data transfer, IEEE released the Ethernet AVB protocol (IEEE 802.1 AS, QAT, QAV, and BA). Ethernet AVB defines a mechanism for synchronized audio and video data transfer with guaranteed latency.

To implement AVB, the Ethernet MAC peripherals must contain dedicated features:

- Time stamping of Ethernet packets
    - Capability to differentiate the various IEEE1588 messages
    - Support hardware time stamping of specific IEEE1588 messages to achieve high accuracy
    - High-resolution timer to achieve nanoseconds accuracy
- Credit-based traffic shaper
    - Credit-based traffic shaping is mandatory for any transmission on an AVB network
    - Considering the high packet-transmission rate (once every 125µs in case of Class A networks), it would add a large burden on the CPU to shape each packet in software. A hardware-implemented traffic shaper can greatly reduce CPU load.

The actual transfer of real-time audio/video data is handled via IEEE P1722 packets (figure 9).

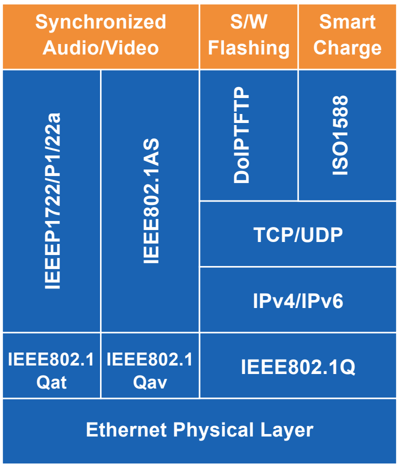

Figure 9. IEEE AVB Standard Stacks

Advanced Driver Assistance Systems

Ethernet is able to integrate infotainment, telematics, and advanced driver assistance system (ADAS) features such as surround view parking and lane departure warning. The current LVDS (low voltage differential signaling) single-camera system will develop into applications with multiple high-resolution cameras. Images from these cameras, radars, and mapping services will merge into a bird's-eye view of the vehicle surrounding. Scalable Ethernet is ideal to transfer such huge data from multiple sources.

The ISO17215 Ethernet standard is currently in development. It will standardize communication protocols for on-board camera systems with driver assistance functions.

Energy Efficient Ethernet (EEE)

IEEE802.3az is the energy-efficient Ethernet (EEE). It introduces low-power modes and wake-up functionality to save energy when the devices are not used. It also allows for less power consumption during periods of low data activity. The Ethernet MAC supports the EEE features.

Electric Refueling Station – Smart Charging

ISO15118 is the vehicle-to-grid communication standard. It describes the mechanism to establish connection to the charging station, authentication by certificates, metering data exchange, charging status/profiles, and payment modalities. The use of Ethernet eliminates the need for any gateway ECUs to communicate with the charging station.

Diagnostics

There are many standards in development to use Ethernet for diagnostic purposes. Ethernet is well-suited for diagnostics as it can be easily connected to any PC/tablet-based tool. The related standards are ISO/PAS 27145 and ISO13400.

Connected Car

The smart phone has brought connectivity into a car, and vehicles shall interact with the surrounding eco-system. Cars exchange real-time information on traffic conditions, terrain, climate conditions, as well as mapping systems. They combine all this information to propose routes, calculate driving time, estimate distances, display 3D city models, and stream audio/video data. Ethernet can be the simplest way to plug into the internet highway.

Ethernet as Network Backbone

A network backbone interconnects various sub-networks with different protocols and/or operating speeds. With a 1500-byte payload limit and speeds up to 100mbps, Ethernet is suitable to aggregate multiple messages in a single packet. You can use

IEEE1722 and P1722a to encapsulate the sub-net protocols. You can aggregate multiple CAN-FD messages from a subnet sent across gateways in a single Ethernet message. As an asynchronous protocol Ethernet's sheer speed overcomes the need for strict timing tolerances. Message buffers reduce timing jitters and increase latency tolerance.

Migration to Ethernet

The new PHY with MII or RMII interface has enabled semiconductor vendors to introduce automotive microcontrollers with Ethernet MAC peripheral. This provides OEMs with scalable bandwidth, faster speeds, and an effective alternative to the proprietary MOST network.

The automotive industry has also started working to standardize Ethernet platforms for use in diverse systems including driver assistance, infotainment, and safety. This will help to reduce costs, ease integration, and simplifies sourcing from multiple vendors.

Summary

When it comes to high-bandwidth data transmission, car manufacturers can chose between LVDS and MOST. LVDS is fast but expensive since it requires shielded cables. MOST is also fast and has excellent EMC characteristics, but its optical wiring is very expensive and difficult to handle during production. Today, Ethernet replaces the expensive LVDS systems, in particular for driver assistance cameras and infotainment systems. Current 100mbps links are sufficient to connect endpoints in a vehicle. The automotive industry, however, will soon face the need for gigabit links to ensure Ethernet becomes the backbone of the car electronic architecture.

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