TOSHIBA

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Introduction

As vehicles move toward becoming self-driving, their passengers will be looking for modern entertainment solutions to fill their time while travelling. This will involve some central media system distributing content to various screens around the vehicle and will require a networking solution that provides enough bandwidth while also fulfilling the strict quality and reliability demands of the automotive industry. However, with drivetrains moving from internal combustion to electric, such solutions will also need to contribute to both power-saving and weight reduction targets. Today's cable looms are in the top three for both weight and cost contributors in the vehicle, so any solutions need to help reduce both of these factors.

Advanced driver assistance systems (ADAS) and, in future, autonomous driving solutions, will also require huge quantities of real-time data from sensors, such as LiDAR and cameras, in order to process the environment around the vehicle. Not only is such data time critical, it could be safety critical too. In the past decade there have been a range of solutions introduced to handle the transport of large quantities of data, or to provide reliable data transport, to meet these needs. However, price, topology, bandwidth, and other limitations hinder the ability for any one of these networking technologies to grow to meet these demands, meaning that none of the existing automotive networks can provide a one-size-fits-all solution.

Ethernet has been in consideration as an alternative for a long time, but was never designed with the needs of a vehicle in mind. However, over the past years, the industry and standards organisations have worked together to develop features that support time-sensitive networking, traffic shaping, and time synchronisation across the network.

Putting cable harnesses on a diet

The cable harness in today's vehicles lies somewhere between 20 kg and 30 kg in weight, a significant contributor to both the weight and cost of the vehicle[1]. Features such as reverse parking cameras require dedicated cabling from the camera to the responsible electronics control unit (ECU) as there is no suitable alternative bus over which to share such data. As a result, the onus currently lies with cable manufacturers to find innovative ways to reduce cable harness weight, such as by moving from copper to high-strength aluminium alloy. This, however, only kicks the issue further down the road. The harsh reality is that technology is available that allows a lot of the information currently shared across multiple cables to be passed down a single high-speed twisted-pair connection.

The concept of networking within the vehicle is nothing new and today there are a range different networks integrated in vehicles. These include:

- LIN – a single wire serial bus capable of transferring data at 19,200 baud. All connected nodes share the available bandwidth, with the bus operating in single master, multiple slave topology. This low-cost solution makes it ideal for interfacing with body electronics such as wing-mirrors, powered seats, and ambient lighting.

- CAN and CAN-FD – this two-wire network was introduced in the mid 1980s, having been developed by Bosch. It has been officially standardised by the International Organization for Standardization (ISO) and, with the introduction of CAN-FD, has improved the data transfer rate by about 30 times, while reducing latency and improving error detection. Data transfer rates still lie under 4Mbps.

- FlexRay – this deterministic and failure tolerant bus was introduced in around 2005 and provides data rates of around 10 Mbit/s. It targets safety-critical, high-performance powertrain applications including drive-by-wire, active suspension, and adaptive cruise control. It can be implemented using a single twisted pair, while a dual twisted pair implementation can provide extra bandwidth and/or fault tolerance. Topologies include star, multi-drop and hybrids thereof.

- MOST (Media Oriented Systems Transport) – as the name implies, this network was designed with the transport of audio and video in mind. Utilising fibre-optic or electrical conductors it is usually implemented in a ring or daisy-chain topology and operates at up to 150 Mbits/s. This bandwidth is, however, distributed across the attached devices.

- LVDS (Low Voltage Differential Signalling) – there are a range of proprietary LVDS protocols supporting the transport of video information from cameras, such as in reverse parking applications, or audio. These are often point-to-point or multi-drop solutions that do not have the flexibility to grow outside their application sweet-spot.

Automotive Ethernet is designed to tackle all the applications of the higher-bandwidth bus systems, while ensuring their unique features, such as guaranteed latency and/or bandwidth, are also covered.

A first look at Automotive Ethernet

Ethernet as used in office buildings and our homes is not suitable for use within the vehicle without some significant modifications, mostly in the lowest three layers of the OSI model. A typical CAT5e cable consists of a shielded collection of 8 wires twisted into 4 pairs, of which two pairs are used for uni-directional data transfer in 100BASE-T. In order to meet the weight goals of automotive, this needs to be reduced to a single pair without shielding. In turn, the signalling needs to be adapted to ensure that electromagnetic interference (EMI) limits can also be met, while ensuring that induced noise does not negatively impact the integrity of the data transferred across the bus.

The 100 Mbits/s automotive version of Ethernet is named 100BASE-T1 and is covered by the IEEE 802.3bw standard. It makes use of a PAM-3, 3-level signal with a data rate of 66.67 Msymbols/s. Full-duplex data transfer over the single twisted pair can reach 15m, or 40m for a shielded twisted pair. 1000BASE-T1 is also supported, covered by the IEEE 802.3bp standard with the same cable length restrictions.

Several further standards define other aspects that ensure Ethernet within the vehicle provides the functionality required. They can be broadly grouped into Audio Video Bridging (AVB), Time Sensitive Networking (TSN), and other supporting standards. These include:

- AVB – these standards ensure that audio and video data arrive at their destination according to defined latencies and by reserving the necessary network resource. This is necessary for situations where there are multiple audio sinks, such as loudspeakers, and video sinks, such as LCD displays, that must output the same media synchronously, such as the playback of a film from a single source.

    - IEEE 802.1Qav – Queuing and Forwarding for Audio/Video (AV) Bridges – this essentially defines the rules that ensure AV streams pass through the network within the defined time constraint. It is responsible for shaping the traffic, ensuring that the network is not overwhelmed by bursts of traffic. This is implemented at layer 2 of the OSI model.

    - IEEE 802.1Qat – Stream Reservation – this provides a mechanism to reserve the end-to-end resource necessary to support the transfer of a data stream and guarantee Quality of Service (QoS). This is implemented at layer 2 of the OSI model.

- IEEE 802.1AS – Timing and Synchronisation for Time-Sensitive Applications – this mechanism shares synchronisation data between a grandmaster network node and all other nodes to ensure a common base reference clock. This is used to ensure a common time base for input sampling and playback. This standard is a subset of IEEE 1588.
- IEEE 1722 packets – this defines procedures that compensate for the worst-case transport delay to determine a presentation time. This is used in the case of an AVB talker (audio playback) whose data is to be output by several AVB listeners (multiple loudspeakers). The media stream data is distributed together with a presentation time for the data as defined in the 802.1AS layer.

- TSN – although latency and bandwidth reservation are core concepts within the AVB standards listed above, there are other use cases where even shorter latencies with high availability are required, such as closed loop control over Ethernet. The TSN Task Group took over and renamed the AVB Task Group to focus on these goals. The following standards belong to this effort:
    - IEEE 802.1 Qbv-2015 – this standard provides further enhancements to ensure end-to-end latencies for applications by blocking low priority traffic during defined time windows. This is to support applications such as closed loop control over Ethernet through the use of a time-aware scheduler.
    - IEEE 802.3Qbr-2016 – this specification focuses on Interspersing Express Traffic (IET) by reducing the latency of certain traffic in a mixed traffic environment, such as by intercepting long, low priority traffic.
    - IEEE 802.1Qbu-2016 – this standard defines the pre-emption methodologies in OSI model layer 2 that enables IET.
- IEEE 802.3az-2010 – Energy Efficient Ethernet (EEE) – during operation, or while the vehicle is parked, there may be little to no need to transfer data across the network. For such moments this standard provides a mechanism whereby the data link, and the associated hardware node, can be put into standby, leaving the receive circuitry active to receive a wake-up message.

Ethernet AVB applications within the vehicle

Perhaps the first application in the vehicle for Ethernet will for replacing the existing Infotainment networks. The initial efforts of the AVB Task Group were, after all, focused on supporting this type of application. The 100BASE-T1 implementation provides enough bandwidth to support surround-sound audio, multiple video streams and multiple microphone inputs for active noise reduction (Figure 1).

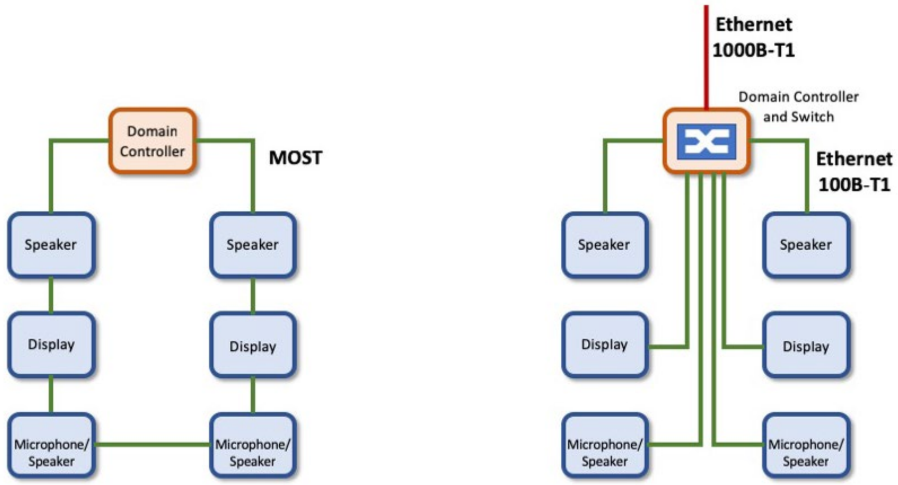

Figure 1 – Infotainment solutions could move away from a ring-based MOST network to switched network based upon Automotive Ethernet.

ADAS is another area that could quickly benefit too. Multiple cameras coupled with data from LiDAR and radar sensors linked to a domain ECU could utilise both the AVB and TSN features (Figure 2).

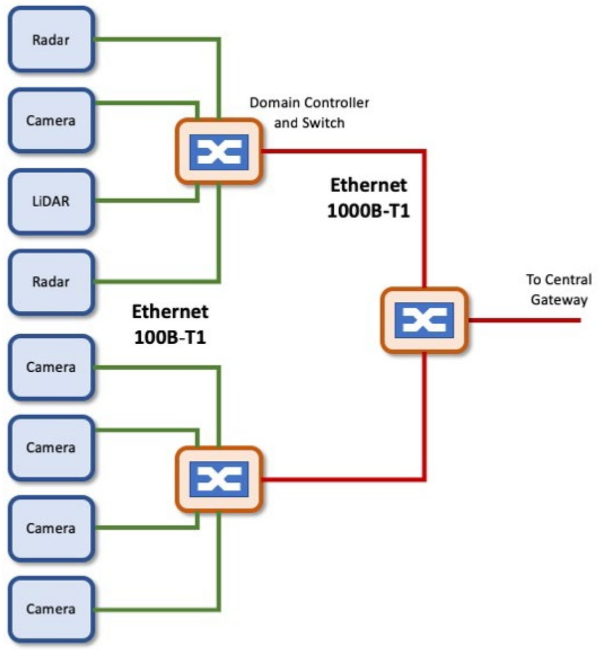

Figure 2 – Potential approach for ADAS and, in future, autonomous driving using Automotive Ethernet.

Over time, it is likely that all domain ECUs will feature an Ethernet port, making use of other automotive bus systems within their domain. For example, body electronics will likely still use LIN and the variants of CAN, although some aspects of the safety and powertrain domains may move to Ethernet. The backbone architecture linking these domain ECUs together will likely use 1000BASE-T1 due to the high bandwidth data requirements required between the domains, while various topologies, such as a daisy-chain or a meshed redundant approach, could be used to ensure redundancy (Figure 3).

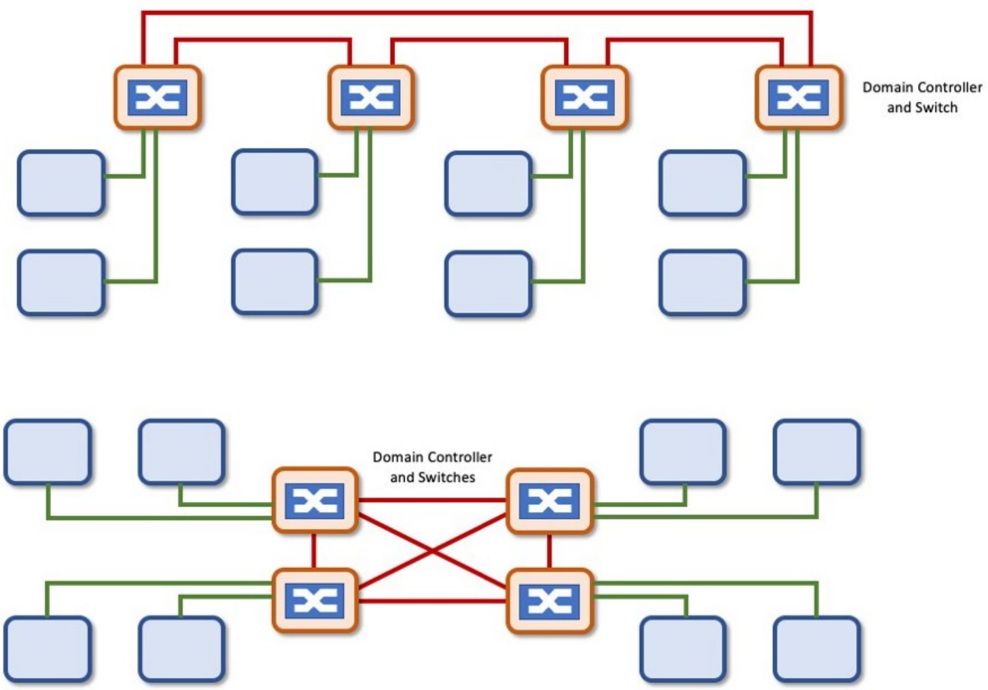

Figure 3 – **Implementing backbone redundancy using Automotive Ethernet; above, a daisy-chain implementation and, below, a fully meshed redundant backbone.**

Implementing Ethernet AVB in the vehicle

Many of the large system-on-a-chip (SoC) solutions used in automotive do not feature the Automotive Ethernet interface required to use this technology. Furthermore, when reviewing the target applications, there are many where a large SoC, or even a smaller proportioned microcontroller coupled with an Automotive Ethernet capable device, will result in a solution that is too large or expensive. With this in mind, Toshiba have released the second generation of their automotive Ethernet AVB/TSN bridge IC, the TC9562.

To support large SoCs, the device can be connected to a PCI express (PCIe) interface. This peripheral has its own voltage island to support L1 low-power mode when required. The Ethernet MAC supports all of the AVB and TSN standards described earlier, and includes inputs and outputs to support the generalised Precision Time Protocol (gPTP). In applications transferring large quantities of data, 6 channels of DMA are available for transferring data directly into the SRAM memory of the host SoC via PCIe. This can also be automatically filtered based upon the IP address of the data received, with the data from one IP address being transferred into one memory location, and data from a second source being transferred to another (Figure 4).

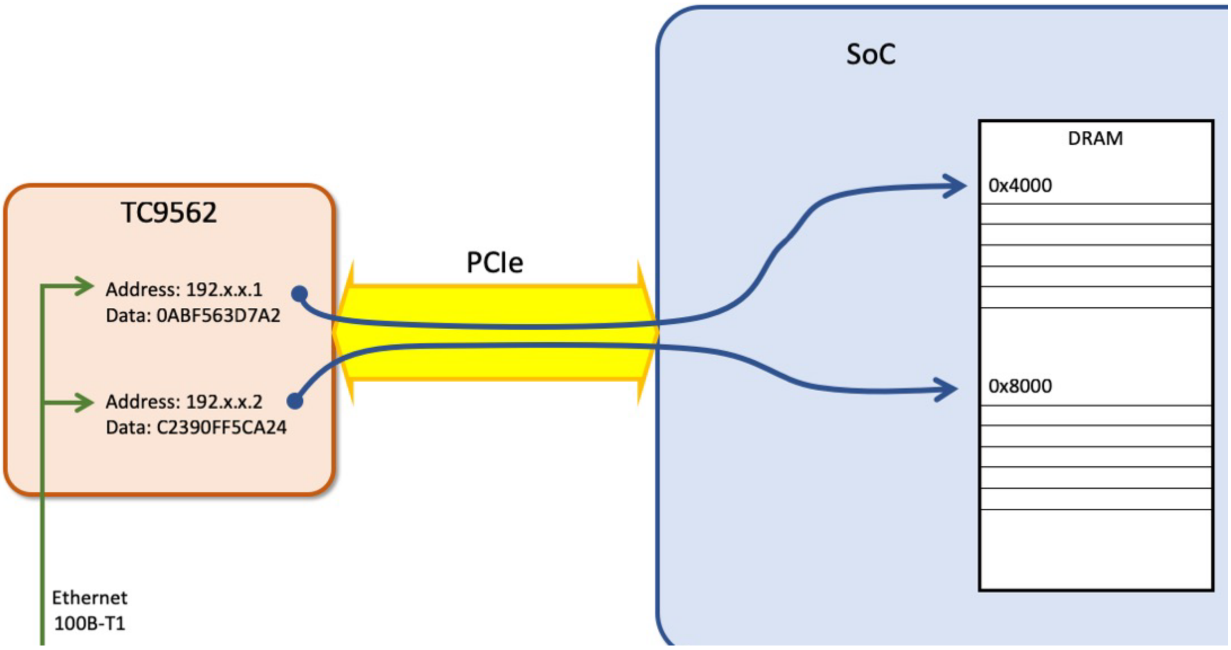

Figure 4 – The TC9562 can, via DMA, transfer the data from specific devices directly into the DRAM of the host SoC, without the SoC's processor needing to intervene.

The Ethernet MAC also supports all common media-independent interfaces (MII) including reduced gigabit (RGMII) and serial gigabit (SGMII). Additionally, the eMAC also has its own always-on voltage islands to support sleeps modes, with support for wake-detection on the detection of Magic packets, or the generation of wake-up packets based upon the specific pattern of incoming packets.

In addition to common serial interfaces, such as the two UARTs, I²C and SPI, a QSPI peripheral provides an interface for booting the device. The TDM/I2S interface provides a full-duplex TDM port with support for multi stream operating as a clock master (TDM/I2S) or clock slave (TDM only) supporting 24-bit audio at up to 192 kHz.

At the centre of the TC9562 is an integrated ARM® Cortex®-M3 core that provides developers with the flexibility to define how the system is controlled and managed. Operating at up to 187.5 MHz, and with access to up to 320 KB of memory, the TC9562 can even be used as a stand-alone Ethernet node in some applications, such as connected audio amplifiers, audio systems and interfaces to wireless modems (Figure 5).

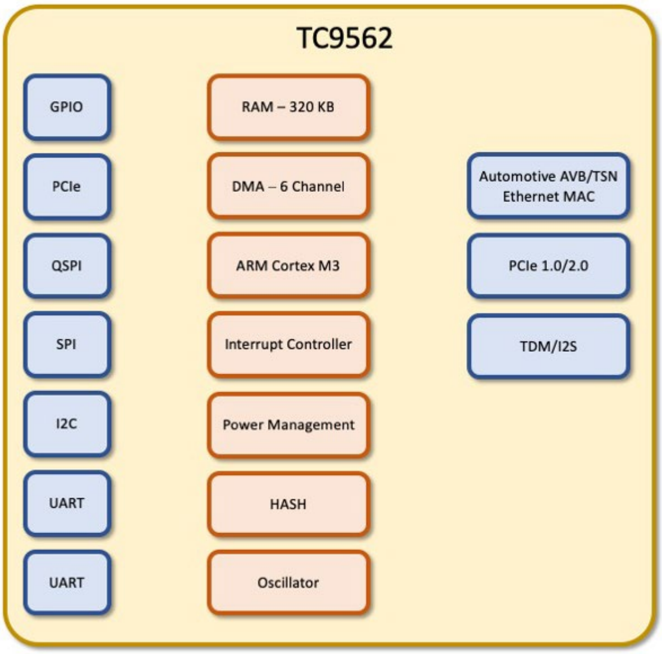

Figure 5 – Block diagram of the TC9562 showing the wide range of peripherals, Automotive Ethernet MAC, and ARM Cortex-M3 processing core.

Approaching automotive audio applications with Ethernet AVB

The implementation of an audio system as part of the vehicle's Infotainment is significantly simplified through the use of the TC9562. At the head-unit end, the device operates as a bridge to Automotive Ethernet for a PCIe-enabled SoC and the media stream talker. However, the TC9562 can also be used stand-alone device, together with a digital-to-analogue converter (DAC) and power amplifier for audio output, and analogue-to-digital converter (ADC) for microphone inputs (Figure 6).

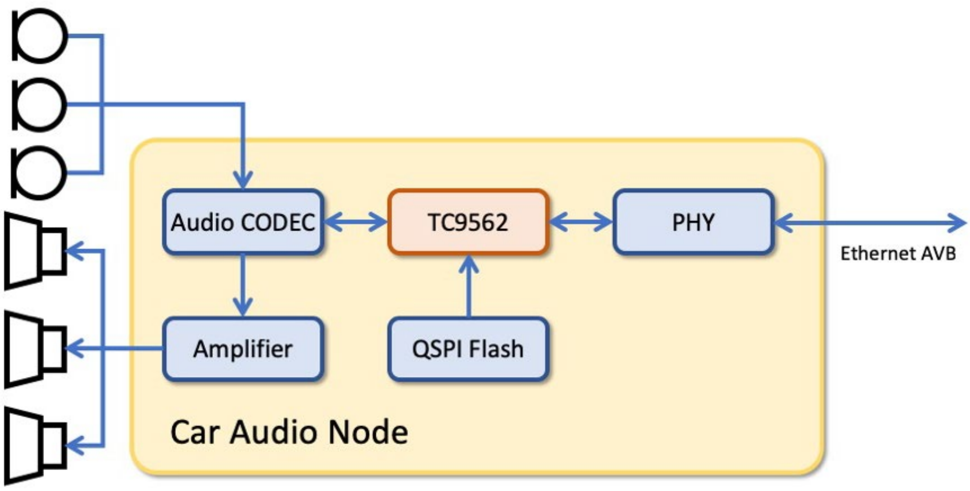

Figure 6 – The TC9562 can be used to implement a full audio node as part of an Infotainment system, including audio output, and a microphone input for the implementation of noise cancellation.

Further elements can be added to the network using a similar approach, such as telematics unit featuring an LTE/4G wireless connectivity module together with the TC9562.

Summary

With the introduction of ever more ADAS features into vehicles, and autonomous driving on the horizon, the automotive industry needs to coalesce around a flexible, high-speed bus that provides low-latency, high-reliability and supports bandwidth reservation. The existing in-vehicle networking technologies have all been designed to tackle a specific application space, and each fulfils their role admirably. However, none of them can scale up to the future needs of the automotive industry.

With its ubiquity and a wealth of knowledge, experience and software available, Ethernet, attuned to the needs of automotive applications, is the natural way forward. Its twisted pair wiring is both simple to accommodate in the wiring harness, while being lightweight, contributing to both weight reduction and a reduction in manufacturing complexity and cost. However, the uptake of the interface will struggle if the total price-point per node exceeds existing technologies, especially in relatively simple applications such as audio and telematics. The TC9562 tackles this challenge in two ways. By providing developers a programmable solution that can execute its own application using the integrated processing core, end nodes for audio functionality can be implemented without needing to resort to an additional processing unit. For more complex applications the device can either be used standalone as a PCIe peripheral, or the integrated processing core can be used to complement powerful SoCs, accelerating some data transfer activities, to provide optimal Automotive Ethernet AVB/TSN functionality.

Contact us to discuss incorporating our products and solutions into your design:
http://apps.toshiba.de/web/ContactUs/

toshiba.semicon-storage.com

References

1. https://www.sws.co.jp/en/product/wireharness.html

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