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Introduction and Background

Considering that cars have been developed and sold commercially since the end of the 19th century, high-speed sensors and displays are a comparably recent event. At the end of the 20th century, more than 100 years after the start of commercial car sales, high-speed sensors and displays were, if at all, presented in concept cars or sold with selected luxury models. However, since the turn of the 21st century, the number of sensors and displays has grown, with the market really just gaining momentum at the time of writing in 2021. While the exact number for the expected market growth differ, market research agrees on the trend: it is significant. In [1], for example, the number of cameras per car is expected to grow between 2020 and 2030 from five to 20 and the number of displays from three to 15.

Displays and cameras are thereby not only growing in numbers, they are also growing in resolutions. Furthermore, thanks to the increasing adoption of Advanced Driver ASsist (ADAS) functions, the number of sensors other than cameras is also growing, as is the number of types of sensors. The race for being the first to successfully achieve the ultimate ADAS function where driver intervention is no longer required – level 4 or 5 Autonomous Driving (AD) [2] – is accelerating the trend in two different ways. First of all, more sensors are deployed in order to reduce the number of tasks drivers have to perform. Then, the drivers can use that freed capacity in order to focus more on information and entertainment (infotainment) on the displays provided.

All these innovations are spurred by key technological inventions and developments. Next to the continuing empowerment and shrinking of digital processing technologies that are responsible for many amenities of modern life in general, more specific inventions are: high-resolution digital image sensor technologies, empowering (new types of) sensors for automotive use like Light Detection And Ranging (Lidar) sensors, digital video (compression) formats, digital display technologies that are small, robust, and cost efficient enough to be commonly used inside cars, and modern user interaction methodologies proliferated by the use of smartphones (plus the mobile communication telecom infrastructure enabling it).

One of the resulting key challenges for deploying all the sensors and displays inside cars is how to integrate them into the Electric and Electronic (EE-)architectures and, especially, how to realize their communication. When the adoption of (digital) cameras and displays in cars started at the beginning of the 21st century, the actual communication was analogue. However, analogue video transmission has severe limits with respect to resolution and quality, which prohibits the subsequent processing necessary to realize modern ADAS and infotainment functions. So nowadays, digital video data transmission drives the demand for data rates in the In-Vehicle Communication (IVC) systems, while the availability of suitable high-speed communication technologies opens the door for innovations with respect to video-related customer functions and EE-architecture choices.

Unfortunately, it is thereby generally not possible to simply reuse the communication technologies from the consumer and IT industries, which already support the required high video data rates in a mass market. It is one goal of this book to explain the additional constraints IVC technologies have to master with respect to robustness and costs, why automotive suitable physical layer developments are important, and why Automotive SerDes and Automotive Ethernet technologies are the available choices in this context. In order to support a profound understanding of the interrelations between the automotive environment, the high-speed sensor and display use cases, and the communication technologies, and to motivate the choices, this book is structured as follows:

- In the continuation of this introductory Chapter 1, Section 1.1 motivates the focus on sensor and display applications. It explains the differences between sensor and display applications and between them and other use cases inside cars. Section 1.2 introduces the terminology used in the context of SerDes communication and the background of Automotive SerDes. Section 1.3 provides information on the origin of Ethernet as such and on Ethernet used as an IVC technology.
- Innovations and their underlying technologies are rarely introduced for the sake of “using a new technology”. Normally, they serve a purpose. The three main reasons for innovations in the industrial Business-to-Business (B2B) environment are: first, to allow for new functionalities (and business), second, to save costs, and/or third, to fulfill new regulatory requirements. In order to provide the context, this book introduces first, in Chapter 2, the high-speed sensor and display use cases with respect to their history in the car industry as well as the underlying technical and architectural choices in more detail.
- Chapter 3 introduces the automotive environment, in which the use cases have to function reliably and safely. Cars are particularly complex products, because they have to provide a vast variety of functions under extremely different conditions, while needing to be attractive to customers in a very competitive market. The automotive environment impacts all technical choices made for cars and is therefore covered early in this book.
- One reason consumer and IT communication technologies are often not usable in cars, is their incapability to meet the automotive ElectroMagnetic Compatibility (EMC) requirements (at least not at reasonable costs). EMC is especially important for all electronics inside cars, and thus detailed in a separate Chapter 4.
- The cable harness is the third heaviest and third most expensive component inside cars [3]. Communication cables need to be robust, cost efficient, and light at the same time. One more reason why consumer grade products are generally unsuitable for in-vehicle use. Chapter 5 introduces general choices for the communication channel that have to be made for all IVC technologies. This includes options for cables and connectors.
- Power supply and power saving is another extremely important aspect in cars, independent of the actual technologies used. Aspects relevant for sensor and display use cases that impact the IVC technology in general are discussed in Chapter 6.
- Chapter 7 introduces the choices for Automotive SerDes technologies.

- Chapter 8 introduces the High-Speed (HS) Automotive Ethernet technologies and provides a general comparison between HS Automotive Ethernet and SerDes standards.
- Both, Automotive SerDes and Automotive Ethernet are first of all use case independent physical and data link layer technologies. To deploy them for high-speed sensor and display use cases, quite a number of related higher layer standards and protocols are added, which might also affect or become part of specific SerDes or Ethernet products. Chapter 9 provides and overview and introduction to many related standards and protocols. These comprise color codes, control interfaces, video compression formats, content protection, as well as camera and display specific protocols.
- Last but not least, Chapter 10 looks at test, qualification, and tools. That they can be tested and serviced is an extremely important aspect for all use cases and technical solutions in cars. So, while this topic is addressed at the end of this books, to ensure testability for all system designs and new technologies is actually an important starting requirement.

Note that, while the order of content and chapters is intended to be as logical and sequential as possible, a perfect order does not exist for a subject as complex as the one addressed in this book. There are many interrelations between chapters, so that the book contains many forward and backward references.

1.1 The Distinctive Properties of High-Speed Sensor and Display Use Cases

Displays and sensors in cars – including cameras as a special type of sensor – actually address quite distinct use cases. Displays have the sole purpose of relaying technical, entertainment, or other information to the car users. Especially when backed by touch functionality, voice recognition, or related dials and knobs, they serve as an important element of the Human Machine Interface (HMI), with which the customers can control various functions inside their cars.

Sensors on the other hand, provide sensor specific, technical data that is, in its raw format, generally unusable to car occupants. Either the sensor data serves directly to control driving functions without the users ever being aware of their existence or it needs to be processed before it can be used for driver or passenger information or user interaction in ADAS functions. Camera images are the exception, as they might be used for machine vision/processing as well as for human vision, for example in back-up camera systems.

Table 1.1 lists additional properties that differ for display, camera, and other sensor use cases and that have some relevance for the architecture and other technical choices of the use cases discussed in the following chapters of this book, especially in Chapter 2. Table 1.1 also motivates why it makes sense to address cameras separately from other sensors. While there are some similarities between cameras and other sensors, there are also important differences.

Table 1.1 Comparison of distinct sensor and display use case properties

	Displays	Cameras	Other sensors
Data recipient	Human vision only	Human vision or machine processing	Machine preprocessing required
Quality of Service (QoS) requirements	Human vision allows for some latency and losses	Machine processing requires low latencies and is sensitive to losses, compression or other	
Size of housing	Generally large	Typically very small	
Power requirement	Power hungry because of the display (depends on size)	Small housings easily accumulate heat, which can impede the sensing quality. Power dissipation should therefore be low	
Location in car	Inside the cabin with stringent location requirements with respect to the occupants' positions	Facing outside or to the driver or other occupants	ADAS sensors are typically on the body shell facing outside, other sensors might be anywhere including under the hood
Possible add-on functions	Might comprise microphones, Consumer Electronics (CE) connectivity (including auxiliary sockets), or even cameras, typically no speakers though	Might comprise InfraRed (IR) Light Emitting Diodes (LEDs) for interior cameras and night vision, exterior cameras might comprise heating	Generally singular, collects one type of data only

There are, however, also aspects that unite the use cases. These are their requirement for highly asymmetric (high-speed) data communication and the related architectural choices. Both, sensor and display units, are generally located at the edge of a network as end nodes. Even if they are forwarding data in a type of display or sensor daisy chain – which happens seldom in any case – they can be designed such that they require no software-based processing, which might require frequent updates otherwise. These aspects not only unite the high-speed sensor and display use cases, it distinguishes them from (many) other Electronic Control Units (ECUs) inside the car.

Figure 1.1 shows two, fundamentally different architecture options. In order to directly compare the sensor and display use cases, the examples depicted assume that the sensor data is – after having been processed accordingly – displayed on a screen to the user. In a real car, such direct link between one sensor and display is seldom. A display might also be used to present pre-stored entertainment data, or they show aggregated results from the evaluation of various sensors. Sensors outputs, on the other hand, might result in vehicle control without user interaction or with audible feedback only.

The upper part of Figure 1.1 depicts the case in which sensor and display contain no video or sensor data processing themselves. The sensor data is transferred as collected (more or less) to the ECU, which processes the data, makes use of the result in its application, and then renders this into a video stream that is transferred to the display where it is presented on a screen. This could be the setup for a back-up camera. Colloquially, this scenario is often referred to as having "dumb" sensors and displays. The sensors and displays have no processing and thus "no intelligence". While some might object to the exact wording, key is that the sensors and displays in this scenario do not run any software that might require regular updates or upgrades.

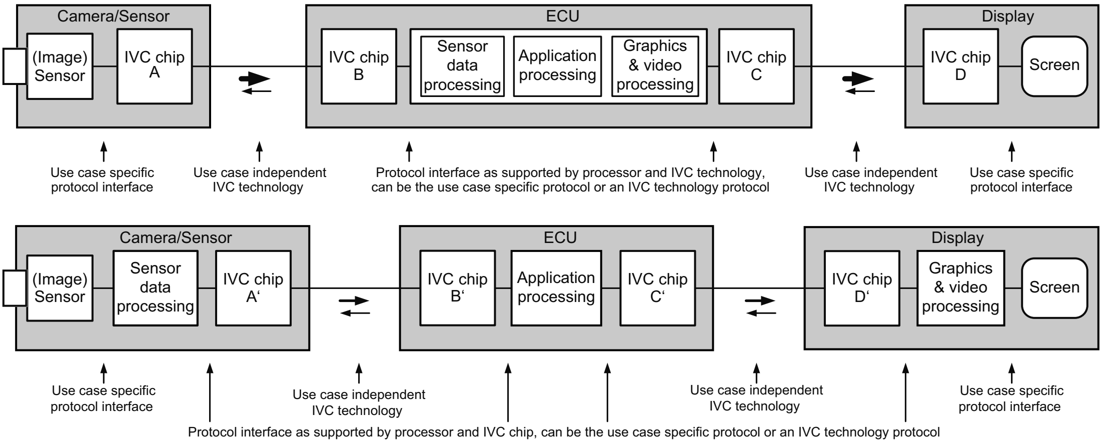

Figure 1.1 Principle architecture options for sensor and display use cases

In the lower part of Figure 1.1 the sensor as well as the display perform the major processing themselves. A typical example would be traffic sign recognition. The camera records the image, identifies the particular traffic sign in its processor, and then transfers only an identifier number to the ECU. The ECU would then perform a plausibility check in its application processing by comparing the identified traffic sign with its map data, before sending itself an identifier number to the display. The display then renders a picture of the sign that is displayed to the customer. Naturally, such a scenario makes the sensors and displays more complex. However, at the same time the amount of data that needs to be communicated is significantly smaller than in the case of sensors and displays without processing. The additional costs for the processing is potentially compensated for with a less expensive communication system that does no longer need to be “high-speed”.

Note that in some cases the only processing that is being performed in the sensors and displays is data compression or decompression. This somewhat intermediate case is not depicted in Figure 1.1. The extra processing needed in the sensors and displays can often be realized in hardware. In general, hardware compression is faster and less power consuming than compression in software. With compression the data rate is decreased, but not as much as when just identifiers are transmitted, which would be the case after full processing. So, a scenario with compression would result in intermediate processing and intermediate data rate. At the same time, the compression might have other impacts, such as compression losses or added processing latencies, which might not be acceptable (see also Table 1.1). For more details on the use cases, see Chapter 2.

What is important in the context of this book: In both scenarios depicted in Figure 1.1, it is necessary to distinguish between the protocol interfaces that are used within the sensors or displays and the IVC technology. The protocol interfaces used for connecting the sensor and display chips are application specific, meaning that the imager interface technology inside a camera cannot be used for putting data onto the screen of a display and vice versa. At the same time, both camera and display might be connected to the ECU using the same IVC technology. Furthermore, the IVC chips used in both cases are not necessarily the same. This is why Figure 1.1, distinguishes between IVC chips with and without “ ’ ”. In the upper part of Figure 1.1, it is likely necessary to use an “IVC bridge” that bridges between the use case agnostic IVC technology and the use case specific protocol. In the lower part of Figure 1.1, the interface combination used, it depends on the availability of interfaces in the processing and IVC.

■ 1.2 Background to Automotive SerDes

The term “SerDes” is used for a number of different technologies in different use cases and scenarios. This section aims to clarify the ambiguity of the term at least for the use within this book. In order to do so, Section 1.2.1 starts with explaining the origin of the term “SerDes”. Section 1.2.2 introduces the SerDes terminology common in the automotive industry and Section 1.2.3 outlines the status of Automotive SerDes in the car industry. The technical choices and properties of the Automotive SerDes technologies as such are discussed in Chapter 7.

1.2.1 The Origin of “SerDes”

“SerDes” first of all describes a very basic physical principle. When two chips had to communicate in the early days, each output pin of one chip was simply directly connected to the input pins of the other chip and vice versa. When more than one information had to be exchanged, other sets of parallel pins and connections were added. For reasons explained in more detail further below, having more parallel data lines became impractical, and formerly parallel data was serialized before being transferred to other chips. There, it would be deserialized before being processed internally. Figure 1.2 shows this in a very simple example. To have this serializer-deserializer conversion of data at both ends of the communication then condensed into the term “SerDes”.

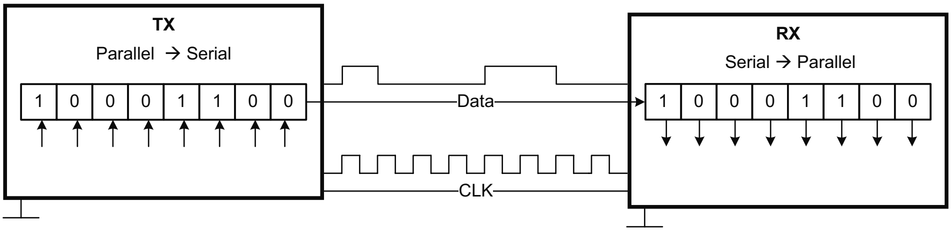

Figure 1.2 The basic principle of SERializer-DESerializer (SerDes) technologies

There are three main reasons to favor serial data transfer over parallel transmission [4] [5]:

1. lower number of pins at the Integrated Circuits (ICs)
2. better synchronization and supported data rates
3. less interference, especially less crosstalk

Ad 1. Lower number of pins at the Integrated Circuits (ICs)

Since their invention, the processing capabilities of IC's made huge progress. Moore's law observed that the transistor density has about doubled every two years [6]. At the same time, the packaging and pin density of ICs has not developed at the same pace, meaning that continued parallel data transmission would have resulted in prohibitively large ICs. This simply mandated using the existing pins more efficiently.

Ad 2. Better synchronization and supported data rates

Figure 1.3 shows a simple parallel transmission system consisting of one transmitter (TX), one receiver (RX), eight parallel data lines (D0 to D7), and one clock line (CLK). The clock line is important, because for the receiving unit it is essential that all eight lines are synchronized in order to be able to process the received data correctly. To the right of the TX – RX system shown in Figure 1.3, an example bit pattern is depicted as seen by the receiver. The upper part of Figure 1.3 shows the ideal situation. Here, the data of each data line is received in perfect synchronization. This might well be the case for low frequencies and short distances on well-designed Printed Circuit Board (PCB) layouts. The lower part of Figure 1.3 depicts – in a strongly simplified way – what can happen if the parallel data paths are not perfectly aligned. In this case, the receiver might not sample all bits in the same transmit slot.

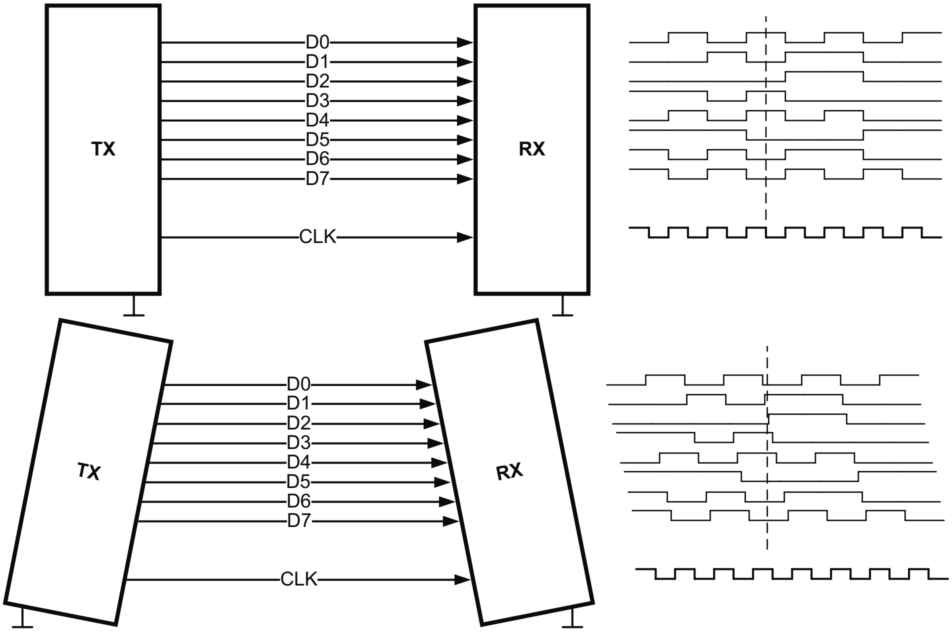

Figure 1.3 Synchronization issue in case of parallel data transmission

In this simplified figure, the data paths have unequal lengths. In real life such variations also depend on the chip process, voltage, and/or temperature. The higher the frequency, the more sensitive the system is to such delay variations, with the result that from a certain frequency on, it is not possible to reliably receive data transmitted on parallel lanes.

Naturally, transmitting over long cables increases the difficulties when compared with the transmission on a PCB.

A serial system does not have such synchronization problems, even if it needs to transmit with an n-times higher data rate in order to achieve the same throughput, when compared with a transmission over n parallel lanes.

Ad 3. Less interference, especially less crosstalk

Another important aspect in parallel data communication is the reference potential of the signals, the signal ground. The parallel data transmission as depicted in Figure 1.3 is single-ended and not differential. Single-ended means that one lane or wire carries the varying voltage levels that represents the signal while the other lane or wire needed for the communication is, usually, the ground.

Such a communication concept is quite susceptible to interference and would require a perfect signal ground to mitigate the effects of, for example, crosstalk. Crosstalk is the interference between adjacent data lines. The longer and closer the lines or cables and the higher the transmit frequency, the more severe the impact of crosstalk. In case of parallel data transmission, there are many adjacent lines per definition and the risk of crosstalk impairments is therefore high. To mitigate the impact of crosstalk, ground lines could be put between all parallel data lines on a PCB, meaning that at least the same number of signal ground lines are connected between the transmitter and the receiver.

Serialized data allows easily for differential transmission. In case of differential transmission the same signal is transmitted over two wires with opposite voltage levels. At the receiver of a differentially transmitted signal, the two signals are combined. This cancels out various noise sources. Serialized data with differential transmission thus has better interference robustness and avoids the impact of the signal ground on the signal integrity.

High-speed SerDes has thus become the dominant form of input and output for (most) high-integration chips [4] and almost all modern communication technologies are based on the serialization/deserialization principle shown in Figure 1.2. The simple example of Figure 1.2 is single ended, it uses a dedicated clock line, and a dedicated voltage level for a single signal. Modern SerDes technologies are differential and do not need a dedicated clock line. The enhanced circuit technology can recover a stable and precise clock signal from the bit stream received. This further improves the robustness of the SerDes technologies as differences in transmission time between the clock and the data signal (“clock skew”) are eliminated. Furthermore, the available circuit technologies allow modulating and encoding the transmitted data prior to sending it. This means that with a single, physical voltage level, more than one bit can be transferred, and the data rate can be increased (see also Chapter 7 for more details on actual solutions).

1.2.2 Automotive SerDes Terminology

The previous Section 1.2.1 explained, why the term “SerDes” might be used in different contexts for quite different communication technologies. “SerDes” as a physical principle does not distinguish whether the communication is on a Printed Circuit Board (PCB), across a wire, or even wireless. Often, even Ethernet is called a SerDes technology, simply because it supports differential, serial transmission of data, while in this book Ethernet is treated as a different technology (see Section 1.3 or Chapter 8).

One way to lessen the ambiguity around the term is to give what is being discussed as SerDes in this book a clear definition and a different name. The following thus defines “Automotive SerDes” with listing the properties commonly associated with “SerDes” in the automotive industry. While it might not always be explicitly spelled out, apart from in the previous Section 1.2.1, “SerDes” or “Automotive SerDes” throughout this book has the characteristics as listed below.

a) It drives a wire.

b) It supports “asymmetric communication”, meaning high data rates in one communication direction (only).

c) It supports Point-to-Point (P2P) communication (only).

d) It supports the lowest two layers of the ISO/OSI communication model (only).

Ad a) Automotive SerDes drives a wire.

The electronics in cars are generally distributed. This is particularly true for sensors and displays, because they need to be at specific locations inside the car to fulfill their function. A lot of the sensing is done at the extremities of the body shell of a car, the displays need to be in alignment with the viewing positions from the seats. In contrast, processing units can be anywhere in the car where there is space and the right environment to put them. All units, however, need to communicate across copper or optical cables that can easily reach 10–15 m length. For installation in busses and trucks even 40 m are a typical requirement [7].

If a SerDes technology is used for sensors or displays, it thus has to be able to drive the respective cables, else it is not of interest for these use cases. Having cables and connectors available that support the high data rates in the challenging automotive environment, is therefore decisive for the success of the technology. See Chapter 5 for more details.

Ad b) Automotive SerDes supports high data rates in one communication direction (only).

SerDes communication is first of all unidirectional. The transmission direction goes from the serializing sender to the deserializing receiver. That SerDes allowed for unidirectional high data rates is how the technology was adopted in cars (see also Section 1.2.3); as it was usable for the one main transmit direction the sensor/video applications needed. For control, a separate, low data rate communication technology – for example the Local Interconnect Network (LIN) bus [8] – was used at the side to start with. It was then a matter of progress and cost reductions in semiconductor processing to optimize this set up. As a result, a bi-directional, low data rate control channel is now available with Automotive SerDes solutions. Naturally, the use cases would also work with symmetric high-speed communication. However, there is, generally, no need for the added complexity and costs, so Automotive SerDes solutions strived supporting high data rates in one transmit direction only.

“High” data rates are thereby relative and a matter of perspective. When the first cameras in cars used digital transmission technologies, the imagers might have had a Video Graphics Array (VGA) resolution of 640 × 480 (see Section 2.1.2 for details). With 30 frames per second (fps) and 16 bits color, this lead to about 150 Mbps data rate. At the time, this was considered a very high data rate for in-vehicle communication. When the Media Oriented Systems Transport (MOST) bus was introduced at about the same time, it supported 25 Mbps [9], which again was a huge leap from the Controller Area Network (CAN) bus [10] or LIN available before. In 2021 in the automotive industry (and therefore also in this book), data rates larger than 1 Gbps were considered high. Data rates larger than 10 Gbps were considered to be “very high”. In general, “very high” describes what is at the brink of feasibility at the time; also in this book.

Ad c) Automotive SerDes supports P2P communication (only).

At the physical layer, SerDes communication is P2P. This does not only mean that the SerDes link is not a bus, where more than two units would share the bandwidth, it also means that the complete SerDes communication starts at the one side of the communication and ends at the other, without extended networking capabilities. This suits especially camera and display use cases that only forward video data to or receive video data from the ECUs where the data is processed.

Occasionally, Automotive SerDes architectures are discussed that envision a daisy chain of cameras or displays (see also Section 2.1.3). This is generally done to save hardware in the processing ECU and/or to reduce the needed cable length. On the physical layer anyway, but also on the Data Link Layer (DLL) the communication still typically remains P2P between each display/camera and the processing ECU. The cameras/displays do not communicate among each other as would be possible if the communication was truly networked.

Ad d) Automotive SerDes supports the lowest two layers of the ISO/OSI communication model (only).

As the Automotive SerDes communication is P2P, the respective technologies generally comprise the PHYsical layer (PHY) and some DLL functions. This means that of the seven different communication functions defined in the ISO/OSI layering model [11], Automotive SerDes only covers layer one and two. This in return means that Automotive SerDes technologies do not need communication-specific software. Any particular requirements that might affect the software are related to the handling of the application specific protocols, which might be part of the Automotive SerDes products or the application data transported across the SerDes link, but not the Automotive SerDes technology itself (see Section 9.6 and Section 9.7 for more details on the protocols).

These are the general properties of “Automotive SerDes”. Yet another terminology with ambiguities refers to the actual chip products that are often just called “Serializer” and “Deserializer”. Figure 1.4 provides an overview. The term “Serializer (SER)” originally stands for the part that serializes and then transmits the data, the “Deserializer (DES)” for the part that receives and then deserializes the data. However, in modern Automotive SerDes technologies, the chip at the side of the communication that transmits the high data rate, also receives a smaller data rate for the control channel and the chip at the side that receives the high data rate also transmits a smaller data rate for control purposes. Both parts are, however, still called SER and DES. Furthermore, these now enhanced SERs and DESs can be integrated in a System on Chip (SoC) with the sensors, processing, or display control chips. They can also be part of stand-alone IVC bridge chips. In the automotive industry these bridge chips are also referred to as SER on the side that sends the high data rate and as DES on the side that receives the high data rate. This means, SER and DES might refer to three different sets of functionalities.

In order to reduce confusion, in this book, the bridge chip depicted in Figure 1.4 is called a “SerDes bridge”, a “SER-bridge”, or a “DES-bridge”, depending on the context. Just SER or DES, describes the function on one or the other side of the communication link discussed, including a potential control channel. When, in the following text, exceptionally the original meanings of SER and DES are relevant, it is explicitly mentioned. Note that SerDes bridge chips can come in a number of flavors. These depend on the application specific protocols they bridge into, and also on the number of SERs and/or DESs they incorporate. Among other possible combinations, dual and quad DES-bridges are particularly common.

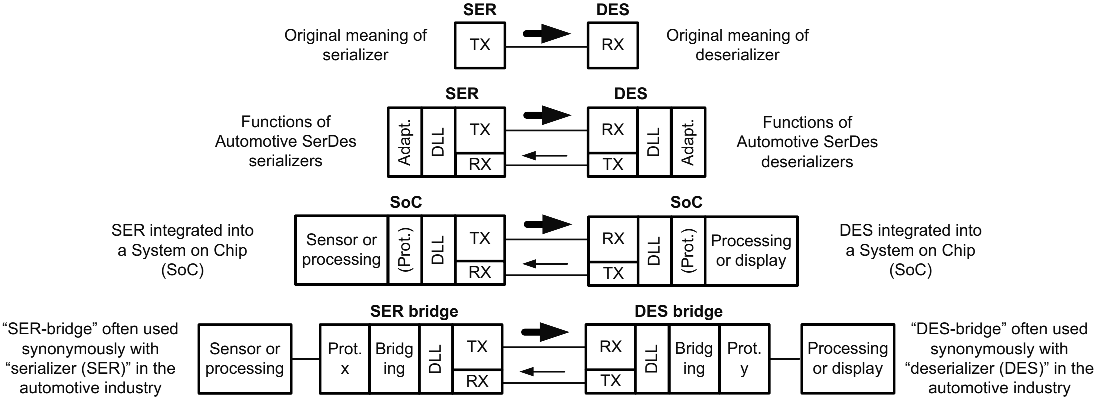

Figure 1.4 Different uses of the terms “SERializer (SER)” and “DESerializer (DES)”

One last note on the terminology. The terms “SerDes” and “Automotive SerDes” are a relatively new phenomena in the automotive industry. The industry tried other names, such as “High Speed Video Links (HSVL)” [12], “pixel links” [13], or, most commonly, “LVDS”. Low Voltage Differential Signaling (LVDS) is a Serialization/Deserialization standard published in 1995 that combines low level signaling and differential communication (see also Section 7.2). It is often seen as the birthplace of SerDes and the early SerDes technologies used in the automotive industry were LVDS based. However, many modern Automotive SerDes technologies have nothing in common with the original LVDS. It is therefore no longer correct to use the term LVDS synonymously with Automotive SerDes. When the term “LVDS” is used within this book, it is used only when exactly LVDS is meant.

1.2.3 The Status of Automotive SerDes

The first time a SerDes technology was used in a series production car was in 2001. In its new 7-series, BMW used SerDes to connect the center display to the main infotainment, where the graphic data to be displayed was being rendered. The sources of original video data, such as cameras or a TeleVision (TV) receiver, were designed to be transferrable over analogue transmission systems. The graphic data for navigation systems was a new type of data that did not automatically cater for analogue transmission but required a high resolution on top. The SerDes technology used was the first Flat Panel Display (FPD) SerDes technology from National Semiconductor (now Texas Instruments, TI). The overall transmission rate was about 500 Mbps using four wire pairs (three for data and one for the clock, see also Section 7.3.1) and a separate CAN connection for the control data.

Since then, the market has grown slowly but continuously. From 2005 on, Automotive SerDes solutions were even usable with dedicated, automotive suitable connectors; a fact not to be underestimated for the successful use of a communication technology (see Section 5.3.2 for more details). In 2021, the overall number of SerDes nodes in cars was expected to be about the same as the overall number of Ethernet nodes in cars [14]. The market growth had been accompanied by new features, such as higher data rates, integrated control channel, capabilities to transmit power with the data, support of coaxial cables and alike. Furthermore, more suppliers had entered the market, albeit offering their own non-interoperable, proprietary versions of Automotive SerDes solutions (see also Section 7.3 for technical details). And while the original FPD-Link technology was opened to be used by other semiconductor vendors, all follow up versions were also proprietary.

It is not so obvious, how the situation came about. After all, every technology used inside a car requires extra effort in terms of qualification (tools and test), logistics, and maintenance and that over many years (see also Section 3.1.2.2). If a car manufacturer decides to select just one supplier and technology to avoid multiplying the effort, the car manufacturer risks to be locked-in with a suboptimal technology down the road. This is because one vendor would need to supply the changing and growing portfolio alone, and it is unlikely that this one vendor will be the best choice for all chip variants needed. The monopolistic vendor might even lose the incentive to adapt and improve in the future. A living standard, for which a number of vendors is selling interoperable products, is the most desirable situation for a car manufacturer. It is likely optimized on various companies' core competences, entails an eco-system for tools, tests, cables, and alike, and is bound to be developed further for future versions.

So, why did this situation with various proprietary Automotive SerDes solution evolve? In the authors' opinion, it is a combination of the following two aspects: first, fast advancements of camera and display technologies that swept into the automotive industry from outside, and second, the connectivity was (is) P2P at the edge of the IVC network outside strategic decision making. Furthermore, camera and display applications have always had a large car user visibility. Up to know, only proprietary technologies were able to support the new features, as fast as the automotive industry wanted to use them. At the same time, it did not matter as much when proprietary technologies were used, especially, when the two units at each end of the communication link were provided by the same Tier 1 supplier in a closed system. The Tier 1 supplier offers exactly what the car manufacturer requires and looks for a cost optimized solution in order to win the contract. The car manufacturer also wants the best possible features available for its customers. As long as the costs work out, the incentive to push for a standard in such a scenario is limited.

While there might have been discussions on standardizing Automotive SerDes, until very recently though, they have not been followed through. There are a number of reasons, why the situation with respect to standardization has changed just now. First of all, it is a matter of sheer volume. The number of cameras and displays in cars is growing, while at the same time analogue connections for these applications are being phased out. Second, the car manufacturers are envisioning EE-architectures, in which cameras, high-speed sensors, and displays are bought from different Tier 1s than the ECU processing the data, potentially even with different time lines.

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