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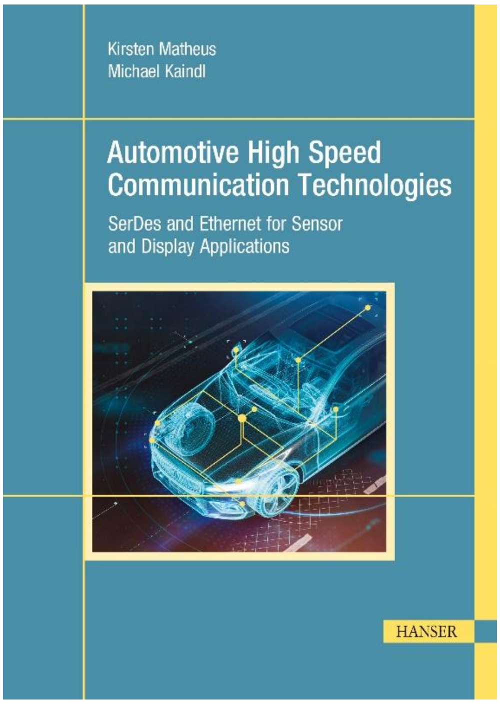

Leseprobe

zu

Automotive High Speed Communication Technologies

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Preface

It is common knowledge that the amount of electronics and software in cars is continuously increasing. Not only are more and more mechanical functions replaced by electronics, but also more driving related functions typically performed by the drivers are substituted or supported by electronic systems, making room for more elaborate and connected infotainment offerings at the same time.

From our perspective, one of the most important enabling infrastructure elements for all of this is the right set of powerful and robust, automotive suitable communication technologies, for which we are at the source. We, the authors of this book, both work at the central department within BMW that is responsible for the in-vehicle communication technologies.

The responsibilities of our department thereby entail it all: the early anticipation and identification of communication requirements, the development and standardization of suitable technologies, the validation and qualification of respective semiconductor products, the writing of requirement specifications on how to deploy the technologies in Electronic Control Units (ECUs) and within the Electric and Electronic (EE) architecture of the cars, ensuring that there are tools and test specifications available, problem solving in case of unexpected errors in the field, and more.

All major car manufacturers have similar departments with a similar set of tasks. Some car manufacturers, like BMW, get involved early. Others might get involved later. What they all have in common is the responsibility for the networking technologies that are used for the communication between many different ECUs, such as LIN, CAN, FlexRay (if used), and lately Automotive Ethernet (especially 100 Mbps). The result is a broad, public knowledge base for all these technologies in the industry and various standardization groups maintaining and advancing the knowhow.

For very application specific technologies, for communication links that are not part of the network (often called "private" communication links), or for communication functions bought in closed systems from Tier 1 suppliers, the situation is not quite as straight forward. These technologies are often not handled in the central departments but within the groups responsible for the application. For these technologies there is little (and practically no public) information available in form of technical descriptions and enabling specifications (EMC, channel, system functions, tests, …). Industry consortia, driving the technologies forward with consolidated interests, are rare.

The high-speed communication technologies for connecting cameras and displays used to be such application specific technologies. Often seen as private Point-to-Point (P2P) links with limited numbers per car that are/were supplied in closed systems using proprietary (if not analogue) communication technologies, there has been little incentive for communal efforts in the industry; up to now.

We see various reasons, why it is high time to take responsibility and to broaden the knowledge base in the industry.

1. The number of cameras and displays inside cars is increasing, as is the number of communication links connecting them.
2. The importance and safety criticality of the camera and display applications is increasing. Reliability requirements are higher for a camera image used for an autonomous driving function than for one used during a low-speed parking maneuver. Digital instrument cluster or wing mirror replacement displays are more safety critical than a display showing comparably slow changing map data.
3. The increasing data rates for camera and display links mean increased technical challenges in form of lower Signal-to-Noise-Ratio (SNR) margins and higher sensitivity to link impairments. This requires more specific knowledge on how to make it work. Additionally, not only cameras and displays are aiming for higher resolutions. Higher data rates are also in discussion for various types of sensors.
4. Responsibilities are shifting. Car manufacturers are starting to buy cameras and displays from different Tier 1 suppliers. With that, the systems are no longer closed and the responsibility for the communication technology moves from the Tier 1s to the car manufacturers.
5. EE-architectures are changing. Car manufacturers are exploring zonal architectures, which of now, exclude camera and display data transmission for the lack of sufficient data rates supported by suitable communication technologies. New technical developments for Automotive SerDes and Ethernet allow for architecture options with fewer restrictions.
6. The boundaries between Automotive SerDes and Automotive Ethernet are blurring. For future architectures, both technologies support enough data rate. With the right IC product designs, future SerDes can integrate into an Ethernet network and Ethernet can address camera and display applications. How to efficiently explore this, when both technologies are handled in different departments?
7. Automotive SerDes is being standardized and now actually provides an official framework for the respective work in the industry.

These are good reasons, why some car manufacturers have already moved the responsibility for the camera and display links to the central in-vehicle communication technologies departments. In our case, for example, some of the responsibility for SerDes was moved to us, the authors of this book, as early as 2015. Since then, we have investigated, learned, driven, collected, and are now eager to share. This book is the result. It keeps it technical. We intend this book to support beginners as well as experts at all stages of the value chain in gaining a comprehensive overview on the High-Speed (HS) sensor and display communication technologies Automotive SerDes and HS Automotive Ethernet. We believe in sound technical reasoning and would like to support all interested parties in drawing their own conclusions.

This is the first edition of a new book with lots of new content. It would not have been possible to complete it in the same quality without the many colleagues who answered all the smaller or larger questions we had. We would like to thank (in alphabetical order) Heather Babcock (TI), Kristian Baumann (BMW), Bert Bergner (TE), Andreas Brösse (BMW), Vijay Ceekala (TI), Jim Conder (Socionext), Kamal Dalmia (Aviva Links), Mario Heid (Omnivision), Stefan Holzknecht (BMW), Kilian Jacob (BMW), Ariel Lasry (Qualcomm), Balagopal Mayampurath (ADI), Andy McLean (ADI), Chanakya Metha (TI), Thorsten Meyer (Valeo), Roland Neumann (Inova), Takashi Nishimura (SONY), Jochen Schyma (NXP), Anton Sifferlinger (BMW), Luisma Torres (KDPOF), Dirk Waldhauser (BMW), Rick Wietfeldt (Qualcomm), Conrad Zerna (Aviva Links), and George Zimmerman (CME Consulting).

A very special thanks goes to Daniel Hopf (Continental) who reviewed and annotated the complete book and who made it more consistent and precise with his effort.

We would also like to thank BMW for giving us the opportunity to make a difference.

June 2022, *Michael Kaindl* and *Kirsten Matheus*

Timeline

1886	Carl Benz is granted a patent on “Fahrzeug mit Gasmotorenbetrieb (engl.: gas powered vehicle)” [1] and starts building identical copies of cars. While several motor vehicles have been built prior to this and successful commercial exploitation still needs some years to come [2], 1886 can be seen as the starting year for commercial automobile production. Tachometers had been invented in 1817 and were first used in trains in 1840. It is unclear when they were first used in cars [3].
1892	First ever law on ElectroMagnetic Compatibility (EMC) is passed in Germany in the context of the upcoming telegraph and telephone business [4].
1902	German engineer Otto Schulze patents a technology using a magnet created eddy-current that translates the speed of rotation of the wheels to a dial. Until well into the 1980s, almost all speedometers in cars were based on this technology. Speedometers are standard equipment in cars by 1910 [5].
1904	First patent on radar technology is filed at the German patent office for “a method to notify of the presence of metallic objects with help of electromagnetic waves” which can determine the objects distance [6].
1908	The first car produced in a moving assembly line is the Ford Model T [7].
1917	Invention of the fuel gauge [8].
1927	Germany passes the first law on the use and installation of high frequency radio transmitters, which, with adaptations, is in place until 1995 [4].
1930	Sale start of first commercially successful in-car radio [9].
1931	The Commission Internationale de l’Éclairage (CIE) defines with the Red Green Blue (RGB) color space the first quantitative relationship between the distribution of wavelengths in the visible spectrum and perceived colors [10].
1933	Founding of the Comité International Spécial des Perturbations Radioélectriques (CISPR) in order to develop guidelines on EMC in Europe [4].
1952	First sale of commercial Frequency Modulation (FM) in-car radios. Amplitude Modulation (AM) is dominantly used in the market at the time [9].

1956	Advent of the first fully automated mobile telephone system, allowing making and receiving calls in cars using the public telephone network [11].
1956 Jan.	First showcase of a backup camera is presented at the General Motors Motorama in a Buick Centurion concept car [12].
1958 Dec.	Publication on laser marks its invention [13].
1973	Year of the invention of Ethernet. Ethernet is demonstrated for the first time at Xerox PARC in order to enable the transmission of data between Xerox's personal computer workstations and laser printers [14] [15].
1973	The International Electrotechnical Commission (IEC) creates a special technical committee to specify EMC for different fields of use [4].
1974	First Charge-Coupled Device (CCD) image sensor goes into production [16].
1974 Dec.	First release of the "Specification of Internet Transmission Control Protocol (TCP)" [17].
1976 Sep. 9	The president of JVC presents the Video Home System (VHS) [18]. Other markets outside Japan receive the first products from 1977 on [19].
1979	Aston Martin presents its Lagonda with an elaborate array of LED screens [20].
1979 Jun.	The 7-layer Open Systems Interconnection (OSI) model is published at the International Organization for Standardization (ISO) [21]. The respective committee was formed in 1977 [22].
1980 Dec.	The Institute of Electrical and Electronics Engineers (IEEE) starts the 802.3 working group dedicated to CSMA/CD (Ethernet) [23].
1981	Release of the first commercially available in-car navigation system by Honda called "Electro Gyro-Cator" that provided guidance by tracking the distance and direction travelled from the start point [24].
1982	Philips Semiconductors (now NXP Semiconductors) develops the Inter-IC bus (I2C) [25].
1982 Jan. 26	As the first car manufacturer, Toyota offers a sonar-based backup parking system in a series production car [26].
1982 Oct.	First commercial CD-player is sold in Japan (by Sony) [27].
1983	Introduction of the analogue content protection technology from Macrovision for VHS video cassettes [28].
1985	First factory-installed in-car CD player [9].
1986	Kodak develops the first digital camera to record 1.4 MPixels. It uses a CCD imager [29].
1986	The Buick Riviera is likely the first series production car with a touch screen [20].
1986 Feb.	First release of the Philips Semiconductors' (now NXP Semiconductors') I2S audio bus interface specification [30].

1987	Toyota sells its Royal Crown model with a color display for its CD-based navigation system [20].
1988	Establishment of the Moving Picture Experts Group (MPEG) for the development of standards for the coded representation of media data such as audio and video [31].
1988 Nov.	The Video Electronics Standards Association (today only using its abbreviation "VESA") is founded on the initiative of NEC in order to standardize video display interfaces [32]. The organization is incorporated in July 1989 [33].
1989 Oct.	The TCP/IP Internet Protocol Suite is being published as "Requirements for Internet Hosts – Communication Layers", RFC 1122 [34] and "Requirements for Internet Hosts – Application and Support", RFC 1123 [35].
1989/90	The World Wide Web (www) is invented at CERN [36].
1990	Development of the CMOS active pixel sensor [37].
1990	Mazda introduces its Eunos Cosmo with an in-dashboard color display as the first GPS-based navigation system [20].
1990 Sep.	IEEE 802.3 ratifies the Ethernet specification 10BASE-T [15], with which Ethernet allegedly won the battle over competing technologies [14].
1992	The first "smart" mobile phone with a touch screen, the IBM Simon, is commercially sold [38].
1992 Sep. 18	The International Telecommunication Union (ITU) releases the Recommendation T.81 for the Joint Photographic Expert Group (JPEG) compression format [39].
1994 Jun.	First release of the AEC-Q100 specification on automotive quality for integrated circuits at the Automotive Electronic Council (AEC) [40].
1994	National Semiconductor (now TI) introduces the Low Voltage Differential Signaling (LVDS) technology [41], which is subsequently published as ANSI/TIA/EIA-644-1995 [42] and as IEEE 1596.3 in July 1996 [43]. The data rate the standard originally supports is 655 Mbps.
1995	The ISO/IEC publishes a backwards compatible MPEG-2 Audio specification (MPEG-2 Part 3) – commonly referred to as MP3 – with additional bit and sample rates [44].
1995 Dec. 8	Toshiba, Matsushita, Sony, Philips, Time Warner, Pioneer, JVC, Hitachi, and Mitsubishi Electric announce their agreement on a unified DVD format [45].
1996	The ISO/IEC publishes the MPEG-2 video (MPEG-2 Part 2) specification, which is used among other, for the DVD standard. The ITU publishes it as H.262 [46].
1996	National Semiconductor (now TI) develops the first FPD-link specification, which it publishes in order to achieve a large market acceptance [47].

1996 Nov. 5	Hewlett-Packard and Microsoft propose the standard RGB (sRGB) color space for monitors, printers, and the www [48]. In 1999, the IEC published it as IEC 61966-2-1:1999 [49].
1997	Publication of IEEE 802.3x, which supports full-duplex operation for Ethernet [50].
1998	First Publication of IEEE 802.1Q, which adds – among other functions – the option of eight priority queues and Virtual LANs (VLANs) to Ethernet communication [51].
1998	Daimler introduces the first radar based adaptive speed driver assist system into the market [52].
1998 Oct. 28	U.S. president Bill Clinton signs the Digital Millennium Copyright Act (DMCA), which provides the basis for the prosecution of copyright infringements on the Internet. It is subsequently adopted similarly in other countries and regions [53].
1999 May	Napster launches its “share it with all for free” platform. This is possible because of the combination of Internet and audio compression standards. It irreversibly changed the media industry and media consumption. It lasted until February 2001 [54].
1999 May	The first phone with an integrated camera, the Kyocera VP-210, is commercially sold to the general public [55].
1999 Apr. 2	Release of the Digital Visual Interface (DVI) by the Digital Display Working Group (DDWG), which focusses on providing a standardized connection between a computer and a displaying device [56].
1999 May 13	National Semiconductor (now TI) releases the Open LVDS Display Interface (OpenLDI) Specification v. 0.95 as an open standard to complete the digital connection between video sources and displaying devices [57] as initiated with the LVDS technology.
2000	The Nissan Infinity Q45 is offering a series production rear view/backup camera. This is said to have initiated the backup camera market [12].
2000 Feb. 17	Intel releases version 1.0 of the High-bandwidth Digital Content Protection (HDCP) specification, which targets at preventing the recording and distribution of HD video content [58]. In the coming years, its support is mandated by many content providers.
2001 Nov.	Start of Production (SOP) of the BMW 7 series using a central, dashboard-mounted display for user information and interaction (plus “iDrive”) [59]. Often, credit is given to BMW for initiating that such a screen as a central hub for car interaction has become a standard feature [60]. The same car is also the first with a digital video link to connect a display: The FPD-link is used for connecting the Rear Seat Entertainment (RSE) display.
2002 Dec. 9	Announcement of the HDMI 1.0 connectivity standard by the seven founding members Hitachi, Matsushita, Philips, Silicon Image, Sony, Thomson, and Toshiba [61] (now Lattice, Maxell, Panasonic, Philips, Sony, Technicolor, and Toshiba [62]).

2003	First publication of ISO/IEC 14496-10, also known as MPEG-4 Advanced Video Codec (AVC) or ITU H.264 [63].
2003 Jul.	ARM, Nokia, STMicroelectronics, and Texas Instruments (TI) found the Mobile Industry Processor Interface (today only using its abbreviation “MIPI”) Alliance to define standards for cell phones that at the same time reduce complexity and costs while allowing flexibility [64].
2003 Aug. 4	As the first region in Germany, Berlin ends its analogue terrestrial TV broadcast in favor of digital broadcast with Digital Video Broadcasting Terrestrial (DVB-T) [65]. This is an exemplary date for a worldwide transition. By 2017, worldwide digital terrestrial TV broadcast was split over four major technologies: DVB-T2, Integrated Services Digital Broadcasting (ISDB), Advanced Television Systems Committee (ATSC), or Digital Terrestrial Media Broadcast (DTMB) [66].
2004 Jul.	IEEE kicks off the development of standards that allow adding Quality of Service (QoS) functions to Ethernet [67]. This is first called Audio Video Bridging (AVB), shifted to IEEE 802.1 in 2005 [68], and, in 2012, renamed Time Sensitive Networking (TSN) [69].
2005	First release of the MIPI CSI-2 and DSI-2 specifications [70] [71].
2006 May	Publication of the first VESA DisplayPort specification v1.0 [72] [73]. The first embedded Display Port (eDP) specification is published in December 2008 [74].
2007	Nissan introduces the first surround view camera system with its Infiniti EX35 [75].
2008 Oct.	SOP of the first series production car deploying Ethernet as a communication technology. The BMW 7 series uses 100BASE-TX Ethernet as a diagnostic interface with Unshielded Twisted Pair (UTP) cabling and for the communication between HeadUnit (HU) and Rear Seat Entertainment (RSE) with Shielded Twisted Pair (STP) cabling [76].
2010	IEEE 802.3 releases the 802.3az specification on Energy Efficient Ethernet (EEE) [50]. This is an important step to saving energy in a switched Ethernet system. Much later, applied separately to each communication direction, it is especially useful in case of highly asymmetric communication.
2011 Oct.	The HDMI founders create the HDMI Forum in order to allow all interested companies to be an integral part of the development process [77].
2013 Sep.	SOP of the first series production car deploying “Automotive Ethernet”. The BMW X5 uses BroadR-Reach with single UTP for connecting the cameras to the surround view system [76]. The technology is ratified by the IEEE as IEEE 802.3bw/100BASE-T1 Ethernet on October 26, 2015 [78].
2014 Sep. 30	Publication date of the ISO 17215 specification series “Road Vehicles – Video Communication Interface for Cameras (VCIC)” defining Ethernet as the communication interface [79].

2015 Dec. 12	The so-called Paris Agreement is adopted by the United Nations Framework Convention on Climate Change (UNFCCC). Its goal to limit the global warming to below 2 °C (ideally to 1.5 °C) above preindustrial level [80] leads to stringent CO_2 targets for the car industry.
2016 Nov. 10	Call For Interest (CFI) is presented and approved that initiates the efforts to standardize what later becomes MultiGBASE-T1 Ethernet for 2.5, 5, and 10 Gbps data rate in automotive environments at IEEE 802.3 [81].
2016 Dec.	IEEE 802.3 releases the IEEE 802.3bu specification on Power over Data Line (PoDL) [50]. While this specification targets the single pair 100 Mbps and 1 Gbps Automotive Ethernet technologies, it set an important starting point for higher data rates.
2017 Jan.	The MIPI Alliance concludes its I3C specification v1.0. A public version is released in December of the same year [82].
2018	The Audi A8 is the first series production car with a Lidar [83]. However, after having subsequently removed it [84], the XPeng P5 might have rightly claimed to be once more the first in December 2021 [85].
2018 Aug. 2	The MIPI Alliance announces the standardization of their A-PHY [86].
2019 May	Founding of the Automotive SerDes Alliance (ASA) [87].
2019 July	CFI for an automotive suitable multi-Gbps optical Ethernet PHY technology is presented and accepted at IEEE 802.3 [88].
2020 Jun	IEEE 802.3 releases the IEEE 802.3ch/MultiGBASE-T1 specification for 2.5, 5, and 10 Gbps transmission over a single twisted pair in an automotive environment [50]. While the specification allows for symmetric data rates only, the EEE function may be activated individually per direction.
2020 Jun. 24	The “Greater than 10 Gb/s Electrical Automotive Ethernet PHYs Task Force (TF)” holds its first meeting at IEEE 802.3 [89]. Being able to use the technology asymmetrically is one of the properties discussed but adhered to only by applying EEE asymmetrically.
2020 Jul. 14	The Multi-Gigabit Optical Automotive Ethernet TF holds its first TF meeting at IEEE 802.3 [90].
2020 Sep. 15	MIPI announces the release of their MIPI A-PHY specification 1.0 [91].
2020 Oct. 13	The Automotive SerDes Alliance announces the finalization of their ASA Motion Link specification 1.01 [87].

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Abbreviations and Glossary

	Abbreviation	Explanation
1PPODL	One Pair Power Over Data Line	Study group name for IEEE 802.3bu
2D	2-Dimensional	
3D	3-Dimensional	
4PPoE	Four Pair Power over Ethernet	IEEE 802.3bt 2018, for cables consisting of four twisted pairs
8P8C	8 Positions 8 Contacts	Modular connector specified in IEC 60603-7
µ	micro	
µC	MicroController	
A	Ampere	
A2B	Automotive Audio Bus	Communication interface from ADI
AC	Alternating Current	
ACC	Adaptive Cruise Control	
ACK	ACKnowledge	
ACMD	A-PHY Control and Management Database	
ACMP	A-PHY Control and Management Protocol	
AD	Autonomous Driving	
ADAS	Advanced Driver ASsist or Advanced Driver Assistance System	
ADC	Analogue to Digital Converter or Conversion	
ADI	Analog Devices	
AEB	Automated Emergency Braking	
AEC	Automotive Electronic Council	Standardization organization focusing on electronic part qualification for the automotive industry
AFDX	Avionics Full-Duplex Switched Ethernet	Ethernet protocol used in the aerospace industry

	Abbreviation	Explanation
AGC	Adaptive Gain Control	
AIAG	Automotive Industry Action Group	
ALEI	Adaptation Layer Extended Information	Part of the IEEE 2977 DLL packet
ALSE	Absorber-Lined Shielded Enclosure	Described in ISO 11452-2
AM	Amplitude Modulation	Used for the reception of analogue radio in the short, medium and long wave bands
AMEC	Automatable Module Ethernet Connector	
AML	ASA Motion Link	Also ASAML
AMP	Amplifier	
ANSI	American National Standards Institute	US SSO based in Washington D.C.
AOSC	Always-On Sentinel Conduit	Part of CSI-2 v4.0
APD	Avalanche Photo Diode	
API	Application Programming Interface	
APIX	Automotive PIXel link	Inova's name for their proprietary SerDes technology
APPI	A-PHY Protocol Interface	
ARQ	Automatic Retransmission/Repeat reQuest	
ASA	Automotive SerDes Alliance	Alliance for Automotive SerDes connectivity, home of the ASA Motion Link
ASAML	ASA Motion Link	Also AML
ASE	Application Stream Encapsulator	Part of the ASAML
ASEP	Application Stream Encapsulation Protocol	Protocol adaptation for the ASA Motion Link
A-shell	Automotive shell	Unified communication interface for the side-channel of APIX
ASIC	Application-Specific Integrated Circuit	
ASIL	Automotive Safety Integrity Level	Classification methodology for functional safety
ASP	Abstract Service Primitive	
ATCA	Advanced TeleComputing Architecture	I2C derivate
ATS	Asynchronous Traffic Shaping	Defined in IEEE 802.1Qcr-2020
ATSC	Advanced Television Systems Committee	US American set of digital television standards
AUTOSAR	AUTomotive Open System ARchitecture	
AUTOSAR SecOC	AUTOSAR SECure Onboard Communication	
AV	Audio/Video	

	Abbreviation	Explanation
AVB	Audio Video Bridging	
AVC	Advanced Video Coding	
AVP	Autonomous Valet Parking	
AWG	Arbitrary Waveform Generator or American Wire Gauge	
AWGN	Additive White Gaussian Noise	
B2B	Business-to-Business	
BCI	Bulk Current Injection	
BER	Bit Error Rate	
B-frame	Bi-directional predictive coded picture or frame	Part of MPEG encoding
BGA	Ball Grid Array	Package type for semiconductors
BIST	Built-In Self-Test	
BK	Binding Key	Part of the ASA security concept
BMCA	Best Master Clock Algorithm	Part of IEEE 802.1AS-2011
BNC	Bayonet Neill Concelman	Connector used also for CBVS video, named after their inventors
BOM	Bill of Material	
bpp	bits per pixel	
bps	bits per second	
BSD	Blind Spot Detection	
BTA	Bus TurnAround	Part of MIPI C- and D-PHY
B/W	Black & White	
CAD	Command-Address-Data	Part of the ASAML OAM
CAN	Controller Area Network	
CAN FD	CAN Flexible Data rate	
CAT	CATegory	Used for data center cable standards
CBS	Credit Based Shaper	Used with IEEE 802.1Qav 2009
CCC	Capacitive Coupling Clamp method	For testing resistance to fast transient pulses
CCD	Charge-Coupled Device	Imager technology
CCS	Camera Command Set	Part of the MIPI CSI-2 interface building blocks
CD	Compact Disc or Collision/Contention Detection	
CDE	Cable Discharge Event	Type of ESD test
CDM	Charged Device Model	Type of ESD test
CE	Consumer Electronics	
CEC	Consumer Electronics Control	Part of HDMI supporting remote control of HDMI connected display devices

	Abbreviation	Explanation
CERN	Conseil Européen pour la Recherche Nucléaire (European Council for Nuclear Research)	
CFA	Color Filter Array	
CFI	Call For Interest	Project initiation item at IEEE 802.3
CFS	Clock Forwarding Service	Part of IEEE 2977
CiA	CAN in Automation	Organization that drives the CAN specification development for the automotive industry
CIA	Confidentiality, Integrity, and Availability	
CIE	Commission Internationale de l'Éclairage (engl. International Commission on Illumination)	International authority on light, illumination, color, and color spaces seated in Vienna
CIS	CMOS Image Sensor	
CISPR	Comité International Spécial des Perturbations Radioélectriques	Sets standards for EMC in cars, now part of IEC
CLK	CLocK	
CTL	ConTroL	
CTLE	Continuous-Time Linear Equalizer	
CMC	Common Mode Choke	
CMD	Command	
CML	Current Mode Logic or Channel Monitor Loop	
CMOS	Complementary Metal-Oxide Semiconductor	
CMYK	Cyan Magenta Yellow blacK	Subtractive color format used for printing
CO_2	Carbon DiOxide	
con.	connector	
CPU	Central Processing Unit	
CRC	Cyclic Redundancy Check	
CRT	Cathode-Ray Tube	
CS	Chip Select	
CSE	Camera Service Extensions	MIPI protocol
CSI	Camera Serial Interface	MIPI protocol
CSMA/CD	Carrier Sense Multiple Access with Collision Detection	
CTS	Conformance Test Specifications	General term but specifically used in MIPI
CuMg	Copper-Magnesium	
CuSn	Copper-Tin	

	Abbreviation	Explanation
CVBS	Color, Video, Blanking, and Synchronization	Analogue signal for color TV
CW	Continuous Wave	
D^2B	Domestic Digital Bus	
DAC	Digital to Analogue Converter/ Conversion	
DC	Direct Current	
DCC	Direct Capacitive Coupling method	For testing resistance to fast and slow transient pulses
DCP	Digital Content Protection LLC	Organization that licenses HDCP
DCS	Display Command Set	MIPI specification
DCT	Discrete Cosine Transformation	
DDC	Display Data Channel	VESA specification
DDWG	Digital Display Working Group	Organization responsible for DVI
DEC	Digital Equipment Corporation	
DES	DESerializer	
DFE	Decision Feedback Equalizer	
DFP	Digital Flat Panel	Early VESA specification
DIN	Deutsches Institut für Normung	German SSO based in Berlin
DK	Device Key	Part of the ASAML security concept
DL	DownLink	Transmission direction with the higher data rate in an asymmetric communication system. Often synonymously used with DS.
DLL	Data Link Layer	Layer 2 of the ISO/OSI layering model
DM	Dieselhorst-Martin	Type of cable stranding
DMA	Direct Memory Access	
DMCA	Digital Millennium Copyright Act	
DoS	Denial of Service	Security attack that floods a node's resources with so much data that it starts denying additional communication requests
DP	DisplayPort	Interface for display connectivity from VESA
DPCP	DisplayPort Content Protection	
DPI	Dots Per Inch or Direct Power Injection	Like PPI or type of EMC measurement
DS	DownStream	Transmission direction with the higher data rate in an asymmetric communication system. Often synonymously used with DL.
DSC	Display Stream Compression	Video compression format standardized by VESA

	Abbreviation	Explanation
DSE	Display Service Extensions	MIPI specification
DSI(-2)	Display Serial Interface	Protocol defined by the MIPI Alliance
DSI3	Distributed Systems Interface 3	Sensor interface of the DSI consortium
DSNU	Dark Signal Non-Uniformities	
DSP	Digital Signal Processor	
DTLS	Datagram TLS	UDP variant of TLS
DTMB	Digital Terrestrial Multimedia Broadcast	Standard for digital television transmission used in China
DUT	Device Under Test	
DVB(-T)	Digital Video Broadcasting (for Terrestrial)	Standard for digital television transmission, which originated in Europe
DVD	Digital Video/Versatile Disc	
DVI	Digital Visual Interface	
E	Electric (field)	
ECIA	Electronic Components Industry Association	US-based SSO
ECU	Electronic Control Unit	Name for physical units containing electronics inside cars
EDID	Extended Display Identification Data	Display mode information format of VESA used in the DDS
eDP	embedded DisplayPort	Interface for display connectivity from VESA
EE	Electrics and Electronics	
EEE	Energy Efficient Ethernet	Specified in IEEE 802.3az
EFM	Ethernet in the First Mile	Specified in IEEE 802.3ah
EIA	Electronics Industry Alliance	US- based SSO dissolved in 2011, now ECIA
ELFEXT	Equal Level Far End CrossTalk	
EMC	ElectroMagnetic Compatibility	
EME	ElectroMagnetic Emissions	
EMI	ElectroMagnetic Immunity	sometimes, not in this book though, also used for ElectroMagnetic Interference
ENIS	End-Node-Interconnect-Structure	MDI network in the A-PHY specification
EOP	End Of Production	
EPON	Ethernet Passive Optical Networks	
EPROM	Erasable Programmable Read-Only Memory	
ESD	ElectroStatic Discharge	
ESR	Equivalent Series Resistance	DC resistance of capacitors
ETSC	European Transport Safety Council	

	Abbreviation	Explanation
EU	European Union	
EuroNCAP	European New Car Assessment Program	
F	Farad	Unit for capacitances
FAKRA	FAchausschuss KRAftfahrzeuge	Subgroup in DIN, often synonymously used for a specific coaxial connector
FB	Ferrite Bead	
FBAS	Farb-Bild-Austast-Synchron-Signal	German for CVBS signal, colloquially “Farbfernsehsignal”
FCC	Federal Communications Commission	US government agency that regulates, among other, radio frequency use
FCS	Frame Check Sequence	
FCW	Forward Collision Warning	
FDD	Frequency Division Duplex	Method to separate two data streams (in the same or opposite directions) on one channel
FEC	Forward Error Correction	
FEXT	Far-End CrossTalk	
FFE	Feed Forward Equalizer	
FFT	Fast Fourier Transformation	
FHD	Full High Definition	
FM	Frequency Modulation	Used for the reception of analogue radio in the ultra short wave band
FMCW	Frequency Modulated Continuous Wave	
FMVSS	Federal Motor Vehicle Safety Standards	
FoFa	Forwarding Fabric	Part of the ASAML
FOT	Fiber Optical Transmitter	
FPD	Flat Panel Display	SerDes technology
fps	frames per second	
FR	Flame Retardant	PCB material type
FRC	Frame Rate Control	Method to emulate a high color resolution on a display than available
FRR	Front Range Radar	See LRR
FSED	Frame Service Extension Data	Part of MIPI CSE and DSE
G	Gear or Giga	Name of different data rate classes for the MIPI A-PHY or 10^9
Gbps	Gigabits per second	
GI-POF	Graded Index POF	
GMSL	Gigabit Multimedia Serial Link	Trade name for the proprietary SerDes technology of Maxim Integrated (now ADI)

	Abbreviation	Explanation
GND	Ground	
GOF	Glass Optical Fiber	
GoP	Group of Pictures	Part of video compression
GPIO or GPI/O	General Purpose Input/Output	
Gpps	GigaPixels Per Second	
GPS	Global Positioning System	
gPTP	Generalized Precision Time Protocol	Protocol specified in IEEE 802.1AS-2011
GPU	Graphics Processing Unit	
GUI	Graphical User Interface	
GVIF	Gigabit Video InterFace	Trade name for the proprietary SerDes technology of SONY
H	Henry	Physical unit for magnetic (field) strength
HBM	Human Body Model	Type of ESD test
HBR	High Bit Rate	Data rate class for DP
HD	High Definition	
HDCP	High-bandwidth Digital Content Protection	
HDMI	High Definition Multimedia Interface	
HDR	High Dynamic Range or High(er) Data Rate	The latter is an I3C terminology
HDTV	High-Definition TeleVision	
HEIF	High Efficiency Image File format	New format for digital images
HEVC	High Efficiency Video Coding	Also known as H.265/MPEG-H Part 2
HF	High Frequency	
HFM	High-speed FAKRA Mini	Connector type for coaxial cables
HMI	Human Machine Interface	
H-MTD	High-speed Modular Twisted-pair Data	Connector type for STP cables
HQ	HeadQuarter	
Hres	Horizontal RESolution	
HS	High Speed	
HSB	Hue Saturation Brightness	Color format derived from RGB
HSD	High-Speed Data	Connector type for STQ cables
HSI	Hue Saturation Intensity	Color format derived from RGB
HSL	Hue Saturation Lightness	Color format derived from RGB
HSV	Hue Saturation Value	Color format derived from RGB
HSVL	High Speed Video Link	Early name for Automotive SerDes
Hsync	Horizontal SYNChronization	Related to horizontal blanking

	Abbreviation	Explanation
HU	Head Unit	Main ECU for infotainment functions inside cars
HW	HardWare	
I2C	Inter-IC, also I^2C or IIC	Serial communication bus invented by Philips in 1982
I2S	Inter-IC Sound, also I^2S	Audio bus invented by Philips in 1986
I3C	Improved Inter-IC bus	MIPI protocol
IATF	International Automotive Task Force	Defines an automotive quality management system
IBG	InterBurst Gap	Part of the ASAML TDD scheme
IC	Integrated Circuit	
ICC	Inductive Coupling Clamp method	For testing immunity against slow transients
ICMP	Internet Control Message Protocol	
ICT	In-Circuit Testing	
ICV	Integrity Check Value	Essential part of security mechanisms for authentication
IEC	International Electrotechnical Commission	SSO situated in Geneva, Switzerland
IEEE	Institute of Electrical and Electronics Engineers	"The world's largest technical professional organization for the advancement of technology (ieee.org)". Among other, standardizes Ethernet.
IET	Interspersing Express Traffic	IEEE 802.3br-2016
IETF	Internet Engineering Task Force	US-based SSO seated in Wilmington, DE
I-frame	Intra frame or picture	Still image representation of MPEG
IF	InterFace	
IL	Insertion Loss	
Infotainment	Information and Entertainment	
InGaAs	Indium Gallium Arsenide	Alloy used for IR image sensors
InSb	Indium Antimonide	Compound used for photovoltaic sensors reacting to IR light
INTB	Interrupt pin	As used for TI SerDes chips
I/O	Input/Output	
IoT	Internet of Things	
IP	Internet Protocol	
IP Code	Ingress Protection Code or International Protection Code	IEC (= EN) 60529 defines classes for mechanical protection for components in cars
IPMI	Intelligent Platform Management Interface	I2C derivate

	Abbreviation	Explanation
IPsec	Internet Protocol SECurity	
IR	InfraRed	Frequency spectrum just below the visible light
ISDB	Integrated Services Digital Broadcast-ing	Digital television standard that originated in Japan
ISI	Inter Symbol Interference	
ISM	Industrial, Science, Medical	Identification of “open” frequency bands that may be used for these purposes
ISO	International Organization for Standardization	SSO seated in Geneva, Switzerland
ISP	Image Signal Processor	
IT	Information Technology	
ITU	International Telecommunication Union	SSO seated in Geneva, Switzerland
IUT	Implementation Under Test	
IVC	In-Vehicle Communication	
IVI	In-Vehicle Infotainment	
IVN	In-Vehicle Network(ing)	Physical communication network in cars, typically comprising several IVC technologies
JAE	Japan Aviation Electronics industry Ltd.	
JEIDA	Japan Electronic Industry Development Association	Japanese SSO, now JEITA
JEITA	Japan Electronics and Information Technology industries Association	Japanese SSO
JITC	Just-In-Time-Canceller	Retrain possibility of the A-PHY 1.0
JPEG	Joint Photographic Experts Group	
JTAG	Joint Test Action Group	
JVC	Japan Victor Company	Originator of VHS
k	kilo	10^3
LAN	Local Area Network	
Laser	Light Amplification by Stimulated Emission of Radiation	
LCA	Lane Center Assist	
LCD	Liquid Crystal Display	
LCL	Longitudinal Conversion Loss	
LDF	LIN Description File	
LED	Light Emitting Diode	
LFLT	Line FauLT	Pin at GSML deserializer
Lidar	LIght Detection And Ranging	Sensor type
LIN	Local Interconnect Network	

	Abbreviation	Explanation
LISN	Line Impedance Stabilization Network	
LK	Link Key	Part of the ASA security concept
LLC	Limited Liability Company	
LNB	Low Noise Block (converter)	Part of satellite antenna systems to enable a low noise reception
LOMMF	Laser Optimized MMF	
LP	Low Power	
LPI	Low Power Idle	Part of EEE
LRR	Long Range Radar	
LSB	Least Significant Bit	
LSFR	Linear Shift Feedback Register	
LT	Lower Tester	
LTE	Long Term Evolution	4G mobile phone standard
LVCMOS	Low Voltage CMOS	
LVDS	Low Voltage Differential Signaling	Early principle behind serialization
m	mandatory	
M	Mega	10^6
M2M	Machine to Machine	
MAC	Medium or Media Access Control	Part of ISO/OSI DDL layer for Ethernet
MASS	MIPI Automotive SerDes Solutions	
MC	Message Counter, MultiCast, or Mode Conversion	
MCM	MultiChip Modules	
MCS	Manufacturer Command Set	Part of MIPI DSI
MDC	Management Data Clock	Used with Ethernet PHY management
MDI	Media Dependent Interface	Part of Ethernet physical layer definition
MDIO	Management Data Input/Output	
MEMS	Micro Electro-Mechanical System (module)	
(x)MII	Any type of Media Independent Interface	Interface used between Ethernet PHYs and MAC
MIMO	Multiple Input Multiple Output	
MIPI	Original meaning: Mobile Industry Processor Interface, however, this meaning is no longer used.	Alliance developing technical specifications in the mobile eco-system (and also the MIPI A-PHY)
MJPEG	Motion Joint Photographic Experts Group	Video and audio compression formats
MM	Machine Model	Type of ESD test
MMF	MultiMode Fiber	Type of GOF

	Abbreviation	Explanation
MMIC	Monolithic Microwave Integrated Circuits	ICs optimized for processes running between 300 MHz and 300 GHz
MOST	Media Oriented Systems Transport	Automotive communication system (being phased out)
MP3	MPEG-2 Part 3	Audio compression format
MPAA	Motion Picture Association of America	
MPEG	Moving Pictures Experts Group	Important group for video compression algorithms
MPEG-LA	MPEG Licensing Administration	
MQS	Micro Quadlock System	Connector type for UTP cables
MRR	Mid-Range Radar	
MSB	Most Significant Bit	
MSE	Mean Square Error	
MST	Multi-STream	DP terminology
MTD	Modular Twisted-pair Data	Connector type for UTP cables
MTP	Multi-stream Transport Packet	Part of MST/DP
NACK or nACK	Not ACKnowledged	
NBI	Narrow Band Interference	
NCAP	New Car Assessment Program	
NCF	Node Capability File	Part of LIN
NEXT	Near-End CrossTalk	
NFC	Near Field Communication	
NHTSA	National Highway Traffic Safety Administration	US administration body for safety of road vehicles
nMQS	Nano MQS	Connector type for UTP cables
NRZ	Non-Return to Zero	Modulation scheme with two voltage levels
nt	thermal noise	
NTSC	National Television System Committee	Analogue television standard used especially in North America and Japan
NVM	Non-Volatile Memory	
NZ	Neutral Zone	Area in which electromagnetic interference is neutralized
o	optional	
OAM	Operation, Administration, Management channel	Side channel available with, for example, the ASAML and IEEE 802.3ch 2020 Ethernet
OB	Odd Bytes	Part of MIPI A-PHY/IEEE 2977
OFDM	Orthogonal Frequency Division Multiplexing	

	Abbreviation	Explanation
OLED	Organic Light-Emitting Diode	
OPEN	One Pair EtherNet (Alliance)	Alliance developing the enabling specifications for Automotive Ethernet
OpenLDI	Open LVDS Display Interface	
OSI	Open System Interconnection	
OTA	Over The Air (Updates)	
OTP	One-Time Programmable memory	
P	Profile or Power	MIPI A-PHY terminology
P1/P2	Profile 1/Profile 2	Part of MIPI A-PHY
P2P	Point-to-Point	Communication that starts and ends within one physical link.
PA	Parking Assist	
PAEB	Pedestrian AEB	
PAL	Phase Alternation Line or Protocol Adaptation Layer	Analogue television standard used especially in Europe and China Connect between native protocols and the MIPI A-PHY
PAM	Pulse Amplitude Modulation	
PCB	Printed Circuit Board	
PCIe	Peripheral Component Interconnect express	High-speed serial computer expansion bus
PCLK	Pixel CLocK	Important in image sensors
PCM	Pulse Code Modulation	
PCO	Point of Control and Observation	Part of ISO 9646
PCS	Physical Coding Sublayer	Part of the physical layer
PD	Powered Device	Device that receives power over the communication line
P&D	Plug & Display	First VESA display connectivity standard
PDU	Protocol Data Unit	
PER	Packet Error Rate	
PE-X	PolyEthylene (also XPE)	
PFC	Priority-based Flow Control	Part of IEEE 802.1Qbb 2011
P-frame	Predictive coded Frame or picture	Part of MPEG encoding
PHD	PHY Header Data	Part of the IEEE 802.3cz PCS
PHY	PHYsical Layer	Lowest layer (layer 1) of the ISO/OSI layering model
PICS	Protocol Implementation Conformance Statements	
PIN	P-type – Intrinsic region – N-type	Diode type with larger intrinsic region

	Abbreviation	Explanation
PLC	Product Life Cycle or Power Line Communication	
PLL	Phase Lock Loop	
PLS	Physical Layer Signaling (service interface)	Communication between reconciliation and MAC layer in IEEE 802.3 specifica-tions
PMA	Physical Medium Attachment	Part of the physical layer
PMBus	Power Management Bus	I2C derivate
PMD	Physical Medium Dependent	Part of the physical layer (used in A-PHY or IEEE 802.3 optical Ethernet transmission technologies)
PoC	Power Over Coaxial	
PoD	Power Over Differential cables	
PoDL	Power Over Data Line	Specified in IEEE 802.3bu 2016 for single pair (T1) Ethernet
PoE	Power Over Ethernet	Specified in IEEE 802.3af 2003 for two pair Ethernet versions
POF	Polymer/Plastic Optical Fiber	
PP	PolyPropylene	
p-p	Peak-to-Peak	
PPI	Pixels Per Inch or PHY Protocol Interface	PHY Protocol Interface is part of the MIPI C-PHY
PPM	Parts Per Million	
pps	Pixels Per Second	
PRBS	Pseudo-Random Bit Sequence	
Prio	Priority	
Pro-AV	Professional Audio and Video	
Prot.	Protocol	
PS	PolyStyrene	Insulation material
PSAACRF	Power Sum Alien Attenuation to Crosstalk Ratio Far-end	
PSANEXT	Power Sum Alien Near-End crossTalk	
PSD	Power Spectral Density	
PSE	Power Supply/Sourcing Equipment	Part that supplies the power in case power is supplied over the data line
PSI5	Peripheral Sensor Interface Five	Low speed sensor bus
PSNR	Peak Signal-to-Noise-Ratio	
PSR	Panel Self Refresh	Part of DP/eDP
PTB	Precision Time Base	Part of the ASAML technology
PVC	PolyVinyl Chloride	

	Abbreviation	Explanation
PWM	Pulse-Width Modulation	Physical principle for simple data transmission
QAM	Quadrature Amplitude Modulation	
QFN	Quad Flat No leads	Type of semiconductor housing
QM	Quality Management	Lowest functional safety level in ISO 26262
QoS	Quality of Service	
R/W	Read/Write	
Radar	RAdio Detection And Ranging	
RAM	Random Access Memory	
RBP	Reverse Battery Protection	
RBR	Reduced Bit Rate	Data rate class for DP
RCA	Radio Corporation of America or Reverse Channel Audio	Connector used for CVBS video or part of the HDMI interface
RCCB	Red Clear Clear Blue	Alternative CFA for imagers
RCTA	Rear Cross Traffic Alert	
RCW	Rear Collision Warning	
RD	Running Disparity	Part of the 8B10B encoding scheme
RF	Radio Frequency	
RFC	Request For Comments	Name for standard documents created by the IETF
RFFE	Radio Frequency Front End	
RG	Radio Guide	Old nomenclature for cables
RGB	Red Green Blue	
RGGB	Red Green Green Blue	Name sometimes used for Bayer CFA
RJ	Registered Jack	
RL	Return Loss	
RMII	Reduced MII	
ROM	Read Only Memory	
RQ	ReQuest	
RS-FEC	Reed Solomon FEC	Type of FEC
RSE	Rear Seat Entertainment	
RTP	Real-time Transport Protocol	
RTS	ReTranSmission	
RX or Rx	Receiver/receive	
SA	Shield/Screening Attenuation	
SAE	Society of Automotive Engineers	US-based SSO
SATA	Serial Advanced Technology Attachment	Computer bus interface connecting computing with storage

	Abbreviation	Explanation
SCART	Syndicat desConstructeurs d'Appareils Radiorécepteurs et Téléviseurs	Connector type for CVBS television
SCCP	Serial Communication Classification Protocol	Optional control protocol for the PoDL standard IEEE802.3bu 2016
SCI	Sub Constellation Index or Scalable Coherent Interface	Header field of the A-PHY or part of the LVDS standard
SCL	Serial CLock	Used for the I2C clock
SDA	Serial DAta	Used for the I2C data
SDI	Serial Data In	SPI terminology
SDL	Specification and Description Language	
SDO	Serial Data Out	SPI terminology
SDP	Shielded Differential Pair	Comprises all shielded differential communication cables, STP and SPP
SDR	Standard Data Rate	I3C terminology
SecOC	Secure Onboard Communication	Part of AUTOSAR
SENT	Single Edge Nibble Transmission	Low speed sensor bus
SEooC	Safety Element out of Context	Part of ISO 26262
SEP	Service Extensions Packet	Part of the MIPI CSE protocol
SEPIC	Single-Ended Primary-Inductor Converter	Type of DC-DC converter
SER	SERializer	
SerDes	SERializer/DESerializer	
SFCW	Stepped Frequency Continuous Wave	
SG	Speed Grade	Name of different data rate classes in ASA
SI-POF	Step Index POF	
SMA	SubMiniature version A	Type of (none-automotive) coaxial connector
SMBus	System Management Bus	I2C derivate
SNR	Signal to Noise Ratio	
SoC	System On Chip	
SOME/IP	Scalable service-Oriented MiddlewarE over IP	Middleware used with Automotive Ethernet communication
Sonar	SOund Navigation And Ranging	Other name for ultrasonic sensors
SOP	Start Of Production	
SOVS	System Operational Vector Space	
SPAD	Single-Photon Avalanche Diode	
S-parameters	Scattering parameters	
SPI	Serial Peripheral Interface	
SPP	Shielded Parallel Pair cable	

	Abbreviation	Explanation
SQI	Signal Quality Indicator	
sRGB	Standard RGB	
SROI	Smart Region of Interest	Part of MIPI CSI-2 v3.0
SRP	Stream Reservation Protocol	
SRR	Short Range Radar	
SSL	Secure Sockets Layer	Predecessor of TLS
SSO	Standard Setting Organization	
STP	Shielded Twisted Pair (cables)	
STQ	STar-Quad/Shielded Twisted Quad (cables)	
StVZO	STraßenVerkehrs-Zulassungs-Ordnung	Name of road traffic licensing regulations in Germany
SUV	Service or Sports Utility Vehicle	
SVCD	Super Video Compact Disc	
SVS	Surround View System	
SW	SoftWare	
sync	SYNChronization	
TAS	Time Aware Shaper	IEEE 802.1Qbv 2015
TC	Technical Committee	
TCL	Transverse Conversion Loss	
TCP/IP	Transmission Control Protocol/Internet Protocol	Protocol suite often used in conjunction with Ethernet, comprises also UDP and many other protocols
TCON	Timing CONtroller	Used in displays
TDD	Time Division Duplex or Test-Driven Development	Method to separate two data streams (in the same or opposite directions) on one channel or a type of agile development methodology
TDR	Time Domain Reflectometry	
TEM	Transversal ElectroMagnetic	
TF	Task Force	Nomenclature of the IEEE 802.1 and IEEE 802.3 groups developing the specifications
TFT	Thin Film Transistor	Type of LCD technology
TI	Texas Instruments	
TIA	Telecommunications Industry Association	US-based SSO in Arlington, VA
TLIS	Transmission-Line-Interconnect-Structure	Link segment in A-PHY
TLP	Transmission-Line Pulse measurement	
TLS	Transport Layer Security	Security protocol for TCP

	Abbreviation	Explanation
TMDS	Transition-Minimized Differential Signaling	
ToF	Time Of Flight	Camera type useable to create a 3D image
TP	Test Point	
TRC	Three Repetition Code	
TSN	Time Sensitive Networking	Various IEEE 802.1 standards supporting QoS over Ethernet.
TTL	Transistor-Transistor Logic	
TV	TeleVision	
TVS	Transient Voltage Suppression	Type of ESD protection
TX or Tx	Transmitter/transmit	
UART	Universal Asynchronous Receiver – Transmitter	Serial interface
UDP	User Datagram Protocol	Transport protocol used in conjunction with Ethernet
UHBR	Ultra-High Bit Rate	Bit rate class for DP
UHD	Ultra-High Definition	
UL	UpLink	Transmission direction with the lower data rate in an asymmetric communication system. Often synonymously used with US.
UML	Unified Modelling Language	
UNECE	United Nations Economic Commission for Europe	
UNFCCC	United Nations Framework Convention on Climate Change	
URL	Uniform Resource Locator	
US	UpStream	Transmission direction with the lower data rate in an asymmetric communication system. Often synonymously used with UL.
USB	Universal Serial Bus	
USD	United States Dollars	
USGMII	Universal Serial Gigabit Media Independent Interface	
USL	Unified Serial Link	Part of CSI-2 v3.0
USRR	Ultra Short Range Radar	
USXGMII	Universal Serial 10 Gbps Ethernet Media Independent Interface	
UT	Upper Tester	
UTP	Unshielded Twisted Pair (cabling)	

	Abbreviation	Explanation
UUID	Universally Unique IDentifier	Used for the identity of an ASA Device
UWB	Ultra-Wide Band	
V	Voltage or Volts	
VCD	Video CD	
VCIC	Video Communication Interface for Cameras	Specified in ISO 17215 for Ethernet communication
VCR	Video Cassette Recorder	
VCSEL	Vertical Cavity Surface-Emitting Lasers	Light source for optical transmission systems
VDC-M	VESA Display Compression-M	Compression for mobile devices
VDE	Verband Deutscher Elektrotechniker	German SSO
VESA	Original meaning: Video Electronics Standards Association, however, it is no longer used	Alliance developing technical specifications in the realm of displays (including DCS and DP/eDP)
VGA	Video Graphics Array	Specific format for early video transmission
VHDL	Very high-speed integrated circuit Hardware Description Language	
VHS	Video Home System	
VLAN	Virtual Local Area Network	
VNA	Vector Network Analyzer	
Vres	Vertical RESolution	
Vsync	Vertical SYNChronization	Related to vertical blanking
WG	Working Group	
WOL	Wake-On LAN	
www	World Wide Web	
XAUI	10 Gbps Attachment Unit Interface	
XFI or XIFI	No specifics given	Extension of XAUI, pronounced “ziffie”
XGMII	10 Gbps Media Independent Interface	
XNOR	Exclusive Not OR	
XOR	Exclusive OR	
XPE	See also PE-X	
XT or XTALK	Crosstalk	
YANG	Yet Another Next Generation	Data modeling language for network management
YUV		Name for a video color format, where Y is the luminance and U and V carry the chrominance information

1 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.

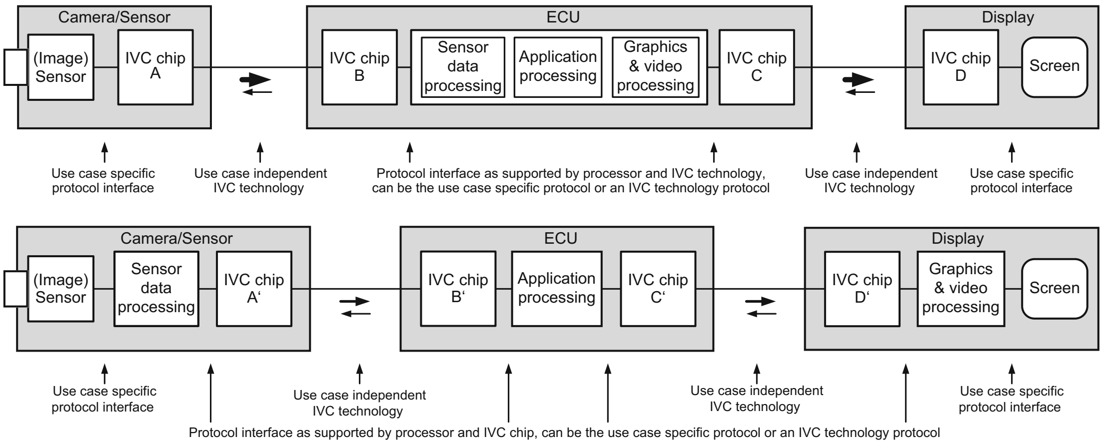

Figure 1.1 Principle architecture options for sensor and display use cases

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”.

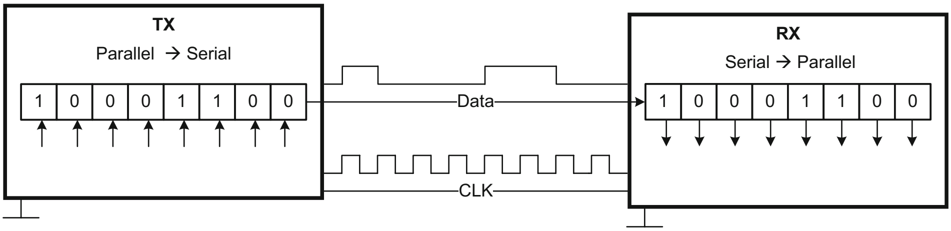

Figure 1.2 The basic principle of SERializer-DESerializer (SerDes) technologies

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.

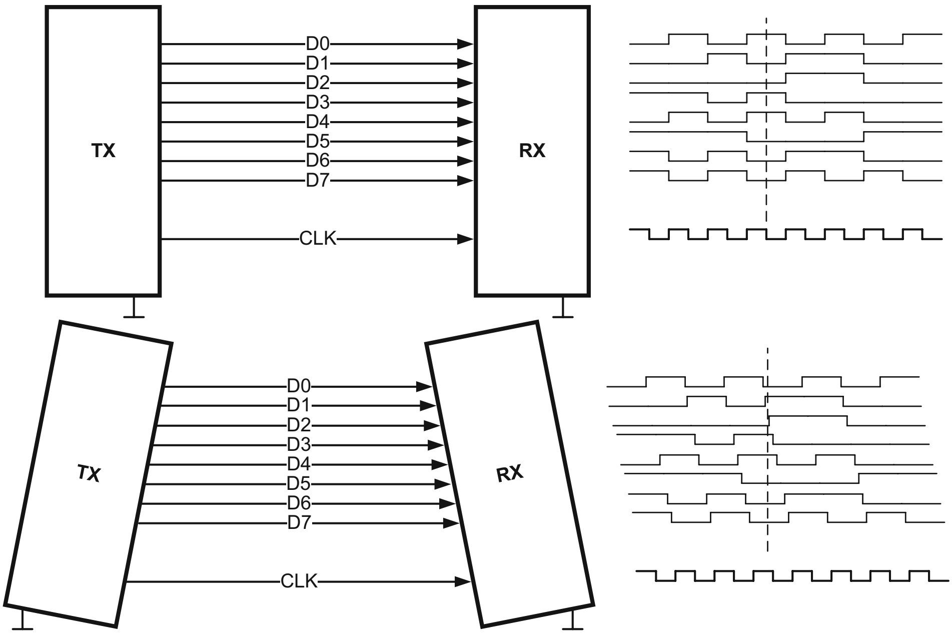

Figure 1.3 Synchronization issue in case of parallel data transmission

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.

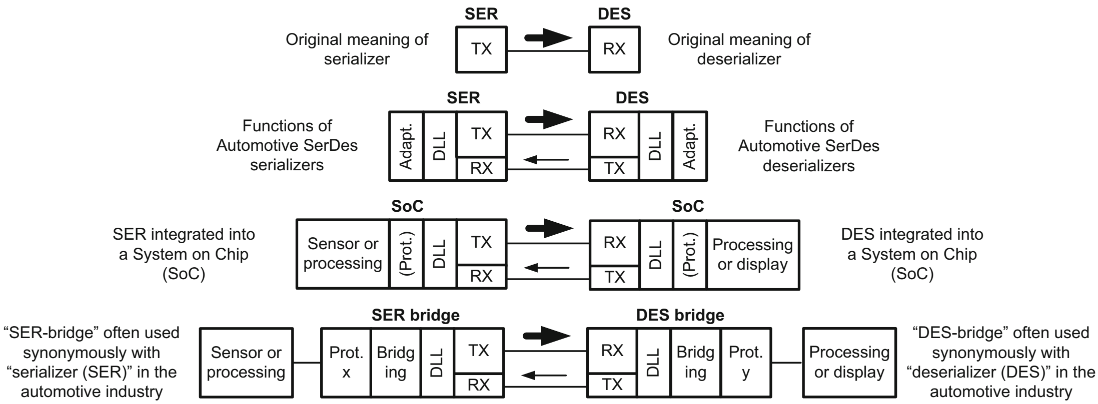

Figure 1.4 Different uses of the terms "SERializer (SER)" and "DESerializer (DES)"

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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