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Automotive Ethernet

Third Edition

Learn about the latest developments in Automotive Ethernet technology and implementation with this fully revised third edition. Including 20% new material and greater technical depth, coverage is expanded to include

- Detailed explanations of the new PHY technologies 10BASE-T1S (including multidrop) and 2.5, 5, and 10GBASE-T1
- Discussion of EMC interference models
- Descriptions of the new TSN standards for automotive use
- More on security concepts
- An overview of power saving possibilities with Automotive Ethernet
- Explanation of functional safety in the context of Automotive Ethernet
- An overview of test strategies
- The main lessons learned

Industry pioneers share the technical and non-technical decisions that have led to the success of Automotive Ethernet, covering everything from electromagnetic requirements and physical layer technologies, QoS, and the use of VLANs, IP, and service discovery, to network architecture and testing. *The* guide for engineers, technical managers, and researchers designing components for in-car electronics, and those interested in the strategy of introducing a new technology.

Kirsten Matheus is a communications engineer who is responsible for the in-vehicle networking strategy at BMW and who has established Ethernet-based communication as a standard technology within the automotive industry. She has previously worked for Volkswagen, NXP, and Ericsson. In 2019 she was awarded the IEEE-SA Standards Medallion “For vision, leadership, and contributions to developing automotive Ethernet networking.”

Thomas Königseder is CTO at Technica Engineering, supporting the smooth introduction of Ethernet-based systems for automotive customers. At his former employment at BMW, Thomas was responsible for launching the first serial production car with an Ethernet connection in 2008. He paved the path to today’s Automotive Ethernet by enabling the first automotive Ethernet physical layer for series production start in 2013.

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Automotive Ethernet

Third Edition

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BMW AG

THOMAS KÖNIGSEDER
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Preface to the Third Edition

By the time we were working on the third edition of this book in 2020, Automotive Ethernet had expanded far and wide. All major car manufacturers had Automotive Ethernet in series production cars or were in preparation of their series production start. The physical layer technologies on the road were (in order of introduction) IEEE 100BASE-TX, 100BASE-T1, 1000BASE-T1, and 1000BASE-RH. Furthermore, the IEEE had just published automotive suitable physical layer specifications for 10 Mbps, 2.5 Gbps, 5 Gbps, and 10 Gbps, and was starting the specification work for 10 Gbps plus for optical as well as electrical transmission. Sharing the medium between more than two users had been reintroduced with 10BASE-T1S, and enhancements to this so-called multidrop technology were also being developed.

On layer two, the Time Sensitive Networking (TSN) standardization had completed a number of new standards to extend Quality-of-Service to time-critical control traffic (important features for automated driving) and was well into the specification of a dedicated Automotive TSN Profile. The OPEN Alliance had more than 400 members, and the complete ecosystem had matured with good supporting solutions from tools and test houses to cables and connectors that regularly met at three well established conferences around the world: the IEEE-SA Ethernet&IP@Automotive Technology Day (at worldwide different locations), the Automotive Ethernet Congress (in Munich), and the Nikkei Automotive Ethernet Seminar (at different locations in Japan).

So, all good?

All promising (but not quite there). The technological base has been made available, but true automotive networks are still only at their beginning. They are closely coupled to the shift from hardware-defined cars to software-defined cars, and also here the industry is, with exceptions, only just starting. So, while the industry is expert in physical layer technologies, electromagnetic compatibility, and hardware costs, the chances and choices the protocol layers offer are less explored.

This book has therefore been amended with a description of all new developments within TSN and the physical layer (and because the physical layer chapter would otherwise have become too large, we split it into three chapters: automotive environment, physical layer technologies, and power). We also enhanced the protocol sections above layer two. These layers are what (can) make all the difference. They are what allows the network to support distributed computing and to explore different choices in the EE architecture.

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Furthermore, we added ten important lessons learned. These were generated not only from our own experiences at BMW, but also from what we observed in the industry in general. As Thomas left BMW and joined Technica Engineering, we were in the fortunate position of having broader insights to share on a general basis. We are sure the lessons learned can make a huge difference to those who are still beginning to explore the potential of Automotive Ethernet and to those who are wondering what is going wrong.

As with every new technology, it takes time and experience to find the most suitable way to adopt a technology. Automotive Ethernet offers plenty of choices, and car manufacturers must decide on the most suitable path for themselves. We are looking forward to accompanying and supporting the process. In general, we would like to thank all who are making Automotive Ethernet happen on a daily basis. For this third edition, we would like to thank all who answered many of the smaller and not so small questions that came up during the process of writing. In particular, we would like to thank (in alphabetical order):

- Piergiorgio Beruto, Canovatech. Without Piergiorgio, the IEEE 10BASE-T1S standard would not have been as ground-breaking as it is. He reviewed the 10BASE-T1S section of this edition and provided viable background information.
- Stefany Chourakorn, BMW, who, as a new adopter of IEEE 10BASE-T1S was able to point out those aspects we forgot to explain, but which help tremendously to understand the technology.
- Brian Petersen, Ethernovia, for proof-reading the entire book. With his background, he ironed out some inaccuracies and gave fresh insights from the perspective of someone who knows what networking can be. The reader will greatly benefit from his suggestions and corrections (including those with respect to the English language).
- Lars Völker, Technica Engineering. Lars is one of the key people and early contributors to Automotive Ethernet as such. Lars decisively shaped SOME/IP(-SD) and with that contributed a decisive piece of Automotive Ethernet and all the possibilities it offers to automotive networking, as it allows the integration of modern communication paradigms within the existing automotive infrastructure. Thank you for your contributions to the protocol chapter, especially the reworking of the security section.
- George Zimmerman, CMS consulting, for reviewing the MultiGBASE-T1 and Energy Efficient Ethernet sections and for providing viable background information on both.
- Helge Zinner, Continental. Helge did not only review the complete protocol chapter, but also did a lot of the groundwork that helped structure the new TSN specifications.

Last but not least, I, Kirsten, would like to thank BMW for supporting the work on the book and for giving me the opportunity to make a difference. Thomas, now CTO of Technica Engineering, will simply continue to always make a difference.

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Preface to the Second Edition

In September 2011, Automotive Ethernet was still at its very beginning. BMW was far and wide the only car manufacturer seriously interested. In 2011, BMW had been in production with 100BASE-TX for diagnostics and flash updates for three years, and decided to go into production with what is now called 100BASE-T1 in its new surround view system in 2013.

In September 2011, strong doubts still had the upper hand. The main concern was that transmitting Ethernet packets at 100M bps over a single Unshielded Twisted Pair (UTP) cable would not be possible under the harsh automotive electromagnetic compatibility (EMC) conditions. Another concern was the missing ecosystem. At the time there was only one supplier of the transceiver technology, Broadcom, who had no prior experience with the written and unwritten requirements of the automotive industry. Additionally, BMW was only just starting to involve the supporting industry of test institutions, tool vendors, software houses, etc.

For an outsider, September 2011 was thus a time of uncertainty. From the inside, however, it was the time in which the foundations for the success of Automotive Ethernet were being laid and in which we ensured that the right structural support was in place. In the background we were finalizing the framework of the OPEN Alliance, NXP was in full speed evaluating its chances as a second transceiver supplier, BMW was preparing to congregate the industry at the 1st Ethernet&IP@Automotive Technology Day, while first discussions on starting the next generation standardization project, 1000BASE-T1, concurred.

One of my, Kirsten Matheus', many jobs at the time was to interest more semiconductor vendors in Automotive Ethernet. In September 2011 this meant getting them to negotiate a licensing agreement with Broadcom, one of their competitors, while the market prospects were still foggy. In one of the discussions I had, an executive manager explained to me, in detail, why this was out of question, based on the following experience.

In the past, he had worked for another semiconductor company that was addressed by a powerful customer to be the second supplier for a proprietary Ethernet version (just like 100BASE-T1 was proprietary when it was still BroadR-Reach and not yet published in the OPEN Alliance). This customer offered significantly higher volumes than BMW ever could, and it was even in the position to technically support them with interoperability and other technical questions, which they did not expect BMW to be capable of. They invested and developed a respective Ethernet PHY product.

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However, shortly after, the IEEE released an Ethernet specification for the same use case. This IEEE version was seen to be technologically inferior. However, it had one technical advantage over the proprietary technology they had invested in: It was backwards compatible to previously designed IEEE Ethernet technologies. The IEEE technology prevailed, whereas the solution they had invested in never gained any serious traction. In consequence, they would not again invest in a technology that was not a public standard. The prospect of the OPEN Alliance acting as an organization that ensured transparency in respect to licensing and technical questions did not make any difference to them.

Today, five years later, in 2016, we know that if that semiconductor company had invested in 100BASE-T1/BroadR-Reach in 2011, their business prospects today would be excellent. Not only because the technology persevered but also because they would have been early in the market. Was the executive all wrong in his saying it needs to be a public standard? I do not know.

Many things happened in the meantime. Based on the experiences with BroadR-Reach/100BASE-T1, what BMW had wanted to start with became doable: Transmitting 100 Mbps Ethernet over unshielded cables during runtime using 100BASE-TX PHYs. This solution, sometimes called Fast Ethernet For Automotive (FEFA), was based on a public IEEE standard. For BMW it came too late. But many (most) other car manufacturers had not taken any decision yet. For a while, it was not so sure whether the "proprietary" (but licensed) BroadR-Reach would succeed in the market or the tweaked "public" 100BASE-TX.

Well, today we know: BroadR-Reach made it. But, in the meantime, it has also become a public standard, called IEEE 802.3bw or 100BASE-T1. Only three weeks after handing in the manuscript of the first edition for this book, a respective Call for Interest (CFI) successfully passed at IEEE 802.3. The IEEE released a "BroadR-Reach compliant" specification as an IEEE 802.3 standard in October 2015. Maybe BroadR-Reach would have succeeded also without IEEE's blessing. Who knows? The fact is, the IEEE standardization made life easier. It erased the topic of technology ownership from the discussions.

And it was a main motivator to write this second edition. The now publicly available 100BASE-T1 and BroadR-Reach specifications allowed us to go into detail. The reader will thus find a significantly extended PHY chapter. This section now includes a detailed explanation of the 100BASE-T1 technology as well as the 1000BASE-T1 technology, whose standardization has also been completed in the meantime. While the description of the 100BASE-T1 technology includes experiences made while implementing and using the technology, the 1000BASE-T1 description includes the methodology used behind developing a technology in the case of an unknown channel – something new and also useful for potential future development projects.

Furthermore, the PHY chapter now has a distinct power supply section. Specifications on wake-up and Power over Dataline (PoDL) have been released in the meantime and need context. Additionally, power supply impacts the EMC behavior. This influence on Automotive Ethernet is also described. On the protocol layer,

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there are new developments with respect to Time Sensitive Networking which have been included in the protocol chapter. Furthermore, the security section has been extended significantly. Last, but not least, we have updated all chapters with the latest developments and insights.

Like the first edition, this edition would also not have happened without the support of the colleagues who make Automotive Ethernet happen on a daily basis. For this second edition we would like to extend our gratitude to (in alphabetical order):

- Karl Budweiser, BMW, who had the (mis)fortune to start working at BMW just at the right time to proofread the PHY section.
- Thomas Hogenmüller, BOSCH, who did not contribute directly to this book, but who successfully dared to drive the standardization of BroadR-Reach at IEEE, and without whom the main reason for writing this second edition might not have happened.
- Thomas Lindner, BMW, who dissected the BroadR-Reach/100BASE-T1 technology and was thus able to contribute vital insights to the 100BASE-T1 description. The reader will benefit a lot from his scrutiny.
- Brett McClellan, Marvell, who answered many questions on the 1000BASE-T1 specification and helped in understanding the technology.
- Mehmet Tazebay, Broadcom, who, as the key designer of BroadR-Reach/100BASE-T1 and 1000BASE-T1, has not only provided the basis for what happened in Automotive Ethernet as such, but who also answered many questions.
- Michael Ziehensack, Elektrobit, who supported with insights to the security section.
- Helge Zinner, Continental, who relentlessly counterread the complete second edition and made it a significantly more consistent and precise book than it would have been without him.

Last, but not least, we would like to thank BMW for supporting our work on the book and for giving us the opportunity to make a difference.

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Preface to the First Edition

On November 11, 2013, I, Kirsten Matheus, attended a celebration of 40 years since the invention of Ethernet at an IEEE 802 plenary meeting. During the celebration, Robert Metcalfe, David Boggs, Ronald Crane, and Geoff Thompson were honored as the pioneers of Ethernet. If I had to name the people without who Automotive Ethernet would not have happened as it did, I would name Thomas Königseder, technical expert at BMW and co-author of this book, and Neven Pischl, EMC expert at Broadcom.

It all started in 2004, when Thomas received the responsibility for speeding up the software flash process for BMW cars. With the CAN interface used at the time, flashing the 1 Gbyte of data anticipated for 2008 would have required 16 hours to complete. After careful evaluation, Thomas chose and enabled the use of standard 100 Base-TX Ethernet for this purpose. Thus, in 2008, the first serial car with an Ethernet interface, a BMW 7-series, was introduced to the world.

This was only a small beginning though. The problem was that the EMC properties of standard 100Base-TX Ethernet were not good. So the technology was usable with cost competitive unshielded cables only when the car was stationary in the garage for the specific flash use case. To use 100Base-TX also during the runtime of the car would have required shielding the cables, and that was too expensive.

Yet, Thomas was taken with the effectiveness of Ethernet-based communication and therefore investigated ways to use 100Base-TX over unshielded cables. He identified the problem, but could not solve it. So in 2007 he contacted various well-established Ethernet semiconductor suppliers to work with him on a solution. (Only) Broadcom responded positively, and engineers from both companies evaluated the BMW 100Base-TX Ethernet EMC measurements. Then, in January 2008, it happened: BMW performed EMC measurements with boards the Broadcom engineer Neven Pischl had optimized using a 100 Mbps Ethernet PHY variant Broadcom had originally developed for Ethernet in the First Mile and which Broadcom engineers had further adapted for the automotive application. The very first measurements ever performed at a car manufacturer with this technology were well below the limit lines and yielded better EMC performance results than even the existing FlexRay!

This was when Automotive Ethernet was born. Without having had this technology available at the right time, without proving that 100 Mbps can be transmitted over unshielded twisted pair (UTP) cables in the harsh automotive EMC environment, none of all the other exciting, complementary, futuristic, and otherwise useful

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developments in the field would have happened. BMW would likely be using Media Oriented Systems Transport (MOST) 150 and be working on the next speed grade of MOST, together with the rest of the industry.

Naturally, from the discovery of a solution in 2008 to the first ever introduction of the UTP Ethernet in a serial car, a BMW X5, in 2013 and to establishing Automotive Ethernet in the industry was and is a long run. Thomas and I would therefore like to thank all those who helped to make this happen up till now, and those who are today fervently preparing the bright future Ethernet has in the automotive industry, inside and outside of BMW, with a special mention of Stefan Singer (Freescale), who, among other things, established the first contact between BMW and Broadcom. Using Ethernet for in-car networking is a revolution, and it is an unparalleled experience to be able to participate in its development.

This book explains the history of Automotive Ethernet in more detail and, also, how Automotive Ethernet can technically be realized. We would like to thank all those who supported us with knowhow and feedback in the process of writing this book. First, we thank Thilo Streichert (Daimler), who made it his task to review it all, and who saved the readers from some of the blindness that occurs to authors having worked on a particular section for too long. Then there are (in alphabetical order): Christoph Arndt (FH Deggendorf), Jürgen Bos (Ericsson, EPO), Karl Budweiser (TU München), Steve Carlson (HSPdesign), Bob Grow (RMG Consulting), Mickael Guilcher (BMW), Robert von Häfen (BMW), Florian Hartwich (BOSCH), Thomas Hogenmüller (BOSCH), Michael Johas Teener (Broadcom), Michael Kaindl (BMW), Oliver Kalweit (BMW), Ramona Kerscher (FH Deggendorf), Matthias Kessler (ESR Labs), Max Kicherer (BMW), Yong Kim (Broadcom), Rick Kreifeld (Harman), Thomas Lindenkreuz (BOSCH), Thomas Lindner (BMW), Stefan Schneele (EADS), Mehmet Tazebay (Broadcom), Lars Völker (BMW), Ludwig Winkel (Siemens), Helge Zinner (Continental). Last, but not least, we would like to thank BMW for supporting our work on the book.

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Abbreviations and Glossary

#	Number of
1PPoDL	One Pair Power over Data Line (name of IEEE 802.3 study group)
2D	Two-Dimensional
3B2T	Three Bits to Two Ternary conversion
3D	Three-Dimensional
4B3B	Four Bits to Three Bits conversion
4D	Four-Dimensional
4D-PAM5	Four-Dimensional Five-Level Pulse-Amplitude Modulation
AAA2C	Avnu sponsored Automotive Avb gen 2 Council (name of an Avnu initiative to gauge and channel interest for TSN; shifted to IEEE P802.1DG)
AAF	AVTP Audio Format (part of TSN)
ACK	Acknowledgment
ACL	Access Control List
ACR-F	Attenuation to Cross talk Ratio at Far end
ACR-N	Attenuation to Cross talk Ratio at Near end
ADAS	Advanced Driver Assist System
ADC or A/D	Analog to Digital Converter
ADSL	Asymmetric Digital Subscriber Line
AEC	Automotive Electronics Council (name of US based organization that standardizes the qualification of electronic components)
AFDX	Avionics Full-Duplex Switched Ethernet
AFEXT	Alien Far End Cross Talk (part of EMC)
AGC	Adaptive Gain Control
AH	Authentication Header (part of IPsec)
AIDA	AutomatisierungsInitiative der Deutschen Automobilhersteller (Automation Initiative of German Automobile Manufacturers)
ALOHA	Hawaiian greeting (name for the multiple user access method developed at the University of Hawaii)
AM	Amplitude Modulation
AMIC	Automotive Multimedia Interface Corporation (discontinued early automotive initiative to standardize multimedia interfaces for automotive use)

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Amp. or AMP	Amplifier
ANEXT	Alien Near End Cross Talk (part of EMC)
ANSI	American National Standards Institute
API	Application Programming Interface
APIX	Automotive PIXel link (name for a proprietary SerDes interface)
ARINC	Aeronautical Radio, Inc. (a company founded in 1929 that is known for its ARINC standards, since 2018 part of Collins Aerospace [1])
ARP	Address Resolution Protocol (used with IPv4)
ARPANET	Advanced Research Projects Agency Network (discontinued predecessor of the Internet)
ASA	Automotive SerDes Alliance
ASIC	Application Specific Integrated Circuit
ASIL	Automotive Safety Integrity Level (part of functional safety/ ISO 26262)
ASN	Avionics Systems Network
ATM	Asynchronous Transfer Mode (telecommunications protocol used at layer two)
ATS	Asynchronous Traffic Shaping (part of TSN)
AUTOSAR	AUTomotive Open System Architecture (organization dedicated to the development of software development standards in the automotive industry)
AV, A/V	Audio and Video
AVB	Audio Video Bridging (early name of a set of IEEE standards enabling QoS for Ethernet-based communication)
AVBgen1	First generation of IEEE AVB standards
AVBgen2	Second generation of IEEE AVB standards, renamed TSN
Avnu	Includes the AV for Audio Video and also means road in Creole [2] (organization to industrialize AVB/TSN)
AVS	Audio Video Source
AVTP	AVB Transport Protocol (part of IEEE 1722)
AWGN	Additive White Gaussian Noise
AXE	Name of Ericsson's digital telephone exchange/switching product
B	Billion
BAG	Bandwidth Allocation Gap (part of AFDX)
BCI	Bulk Current Injection (part of EMC)
BER	Bit Error Rate
BLW	BaseLine Wander correction
BM	Bus Minus (FlexRay terminology)
BMCA	Best Master Clock selection Algorithm (part of TSN)
BP	Bus Plus (FlexRay terminology)
BPDU	Bridge Protocol Data Unit
BSD	Berkeley Standard Distribution or Berkeley Software Distribution (operating system based on early Unix)
C2C	Car-to-Car communication

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C2X	Car-to-anything communication
CA	Coupling Attenuation (part of EMC)
CaaS	Car-as-a-Service
CAGR	Compound Annual Growth Rate (constant rate of growth over a time period CAGR = $(\text{Volume}_{t2}/\text{Volume}_{t1})^{(1/(t2\ -\ t1))} - 1$)
CAN	Controller Area Network
CAN FD	CAN with Flexible Data rate
CC	Communication Controller (part of FlexRay)
CCITT	Comité Consultatif International Téléphonique et Télégraphique (renamed ITU-T in 1993 [3])
CD	Compact Disc
CDM	Charged Device Model (part of ESD)
CE	Consumer Electronics or Carrier Ethernet (the latter is a marketing name for extensions to Ethernet for the telecommunications industry)
CFI	Call for Interest (part of the IEEE 802.3 process to establish new standardization projects)
CIA	Confidentiality, Integrity, and Availability (part of security)
CIDR	Classless Inter-Domain Routing (part of IPv4)
CISPR	Comité International Spécial des Perturbations Radioélectriques (International Special Committee on Radio Interference, belongs to IEC)
CM	Common Mode
CMC	Common Mode Choke
cmd	command
CML	Current Mode Logic (one technical principle to realize SerDes interfaces)
COL	COLlision (signal needed with CSMA/CD Ethernet)
COTS	Commercial-Off-The-Shelf
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check (a form of channel coding used to detect and sometimes correct errors in a transmission)
CRF	Clock Reference Format (part of IEEE 1722)
CRS	CaRrier Sense (signal needed with CSMA/CD Ethernet)
CSMA/CD	Carrier Sense Multiple Access with Collision Detection
CSN	Coordinated Shared Network
CW	Continuous Wave
D^2B	Domestic Digital Bus
DAC or D/A	Digital to Analog Converter
DAS	Driver Assist Systems or Driver ASsist
DC	Direct Current or Daisy Chain
DDS	Data Distribution Service (name for a middleware)
DEC	Digital Equipment Corporation
DEI	Drop Eligible Indicator (part of the 802.1Q header)
DFE	Decision Feedback Equalizer

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DHCP	Dynamic Host Configuration Protocol (used with IP)
DIX	DEC Intel Xerox (name for the early Ethernet promoter companies)
DLL	Data Link Layer
DLNA	Digital Living Network Alliance
DM	Differential Mode
DMA	Direct Memory Access
DME	Differential Manchester Encoding
DMIPS	Dhrystone Million Instructions Per Second
DMLT	Distinguished Minimum Latency Traffic
DNS	Domain Name System (part of IP)
DoIP	Diagnostic over IP
DoS	Denial of Service
DPI	Direct Power Injection (part of EMC)
DRM	Digital Rights Management
DSP	Digital Signal Processor
DSQ 128	Double SQuare constellation, 2-times 16 discrete levels of PAM16 mapped on a 2-dimensional checkerboard (one variant of Ethernet signaling)
DTLS	Datagram Transport Layer Security
DUT	Device Under Test
EADS	European Aeronautic Defence and Space company (Airbus is a division of EADS)
EAP	Extensible Authentication Protocol (part of IEEE 802.1x)
ECN	Explicit Congestion Notification (part of IP)
ECU	Electronic Control Unit
EE or E/E	Electric Electronic
EEE	Energy-Efficient Ethernet (defined in IEEE 802.3af)
EFM	Ethernet in the First Mile (defined in IEEE 802.3ah)
EIA	Electronic Industries Alliance (US-based standards and trade association that ceased operations in 2011, standardized – among other – inexpensive wiring used with Ethernet [4])
ELFR	Early Life Failure Rate (part of AEC-Q100 qualification)
ELTCTL	Equal Level Transverse Conversion Transfer Loss (part of EMC)
EMC	ElectroMagnetic Compatibility
EMD	Electronic Master Device
EME	ElectroMagnetic Emissions
EMI	ElectroMagnetic Immunity (in other documents sometimes also used for ElectroMagnetic Interference!)
EMS	Electro Magnetic Susceptibility (more common: EMI)
EPO	European Patent Office
EPON	Ethernet Passive Optical Network (part of EFM)
ESD	ElectroStatic Discharge or End Stream Delimiter (the latter is explained with 100BASE-T1)
Eth.	Ethernet

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Euro NCAP	European New Car Assessment Program (a European car safety performance assessment program)
EWSD	Elektronisches Wählsystem Digital (Electronic Digital Switching System/Electronic World Switch Digital, telephone exchange system discontinued in 2017 [5])
FBAS	FarbBildAustastSynchron signal (analog video signal format, English equivalent is CVBS: Color, Video, Blanking, and Synchronous Signal)
FCC	Federal Communications Commission
FCDM	Field induced Charge Device Model (part of ESD)
FCS	Frame Check Sequence (CRC at the end of an Ethernet packet)
FEC	Forward Error Correction
FEFA	Fast Ethernet For Automotive
FEXT	Far End Cross Talk
FFE	Feed Forward Equalizer
FIFO	First In First Out
FlexRay	Name for a serial, deterministic and fault tolerant fieldbus for automotive use
FOT	Fiber Optical Transmitter
FPD	Flat Panel Display
fps	Frames per second
FRAND	Fair, Reasonable And Non-Discriminatory (the European equivalent of RAND)
FTZ	Forschungs- und Transfer Zentrum (research and transfer center, part of the University of Applied Science in Zwickau, Germany)
GB	Giga bytes (i.e., 2^{30} bytes)
Gbps	Giga bits per second (i.e., 10^9 bits per second)
GDP	Gross Domestic Product
GENIVI	(name of an automotive industry alliance dedicated to open source software in the in-vehicle infotainment. GENIVI is a word construct taken from Geneva, the international city of peace, in which apparently the concept of GENIVI was publicly presented for the first time, and In-Vehicle Infotainment [6])
GEPOF	Gigabit Ethernet over Plastic Optical Fiber (1000BASE-RH defined in IEEE802.3bv)
GMII	Gigabit Media Independent Interface
GND	GrouND
GOF	Glass Optical Fiber
GPS	Global Positioning System
gPTP	Generalized Precision Time Protocol (part of TSN)
h	Hour
H.264	(Name for MPEG-4 Part 10 or Advanced Video Coding, video compression standard of ITU-T)
HB	HeartBeat

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HBM	Human Body Model (part of ESD)
HD	High Definition
HDCP	High-bandwidth Digital Content Protection
HDMI	High-Definition Multimedia Interface (proprietary audio/video interface)
HE	High End
HF	High Frequency
hi-fi	High Fidelity (term used to refer to high-quality reproduction of sound in the home, invented in 1927 [7])
HMI	Human Machine Interface
HPF	High Pass Filter
Hres	Horizontal RESolution
HS CAN	High Speed CAN
HSE	High Speed Ethernet (Industrial Ethernet variant of the Fieldbus Foundation)
HSFZ	High Speed Fahrzeug Zugang (BMW term for first High Speed Car Access supporting Ethernet)
HSM	Hardware Security Module
HTTP	HyperText Transfer Protocol (loads website into a browser)
HU	Head Unit (main infotainment unit inside the car, former radio)
I^2C	Inter-Integrated Circuit (referred to also as I-two-C or IIC, used especially for intra PCB communication)
I^2S	Inter-IC Sound (referred to also as Integrated Interchip Sound, or IIS, used especially for connecting digital audio devices on PCB)
IANA	Internet Assigned Numbers Authority (oversees global IP address allocation)
IC	Integrated Circuit
ICMP	Internet Control Message Protocol (part of IP)
ID	IDentifier, IDentification
IDL	Interface Definition Language or Interface Description Language
IEC	International Electrotechnical Commission (headquarter in Geneva)
IEEE	Institute of Electrical and Electronics Engineers (headquarter in New York)
IEEE-RA	IEEE Registration Authority
IEEE SA	IEEE Standards Association
IET	Interspersing Express Traffic (see IEEE 802.3br)
IETF	Internet Engineering Task Force (releases standards especially for the TCP/IP protocol suite)
IFE	In-Flight Entertainment
IGMP	Internet Group Management Protocol (part of IP)
IL	Insertion Loss or Attenuation (part of channel definition)
IMAP	Internet Message Application Protocol (part of IP)
infotainment	INFOrmation and enterTAINMENT

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INIC	Intelligent Network Interface Controller (used for MOST to control the higher layers of the ISO/OSI layering model)
I/O	Input/Output
IoT	Internet of Things
IP	Industrial Protocol or Internet Protocol
IPC	InterProcess Communication
IPG	InterPacket Gap (follows every Ethernet packet)
IP(R)	Intellectual Property (Rights)
IPsec	Internet Protocol SECurity
IRQ	Interrupt ReQuest (part of the OA-SPI)
ISI	InterSymbol Interference
ISO	International Organization for Standardization (headquarters in Geneva)
IT	Information Technology
ITU-T	International Telecommunication Union – Telecommunications standardization sector (headquarters in Geneva)
IVN	In-Vehicle Networking
JASPAR	Japan Automotive Software Platform and ARchitecture
JPEG	Joint Photographic Experts Group (standardized in ISO/IEC 10918-1, CCITT Recommendation T.81, describes different methods for image compression)
K-Line	Name for a single-ended, RS-232 similar technology standardized in ISO 9141-2
kbps	Kilo bits per second (i.e., 10^3 bits per second)
LAN	Local Area Network
LCL	Longitudinal Conversion Loss (part of EMC)
LCTL	Longitudinal Conversion Transmission Loss (part of EMC)
LED	Light Emitting Diode
LFSR	Linear Feedback Shift Register
Lidar	LIght Detection And Ranging (method for measuring distances using laser light)
LIN	Local Interconnect Network (single ended automotive bus)
LLC	Logical Link Control (ISO/OSI layer 2)
LLDP	Link Layer Discovery Protocol (used with IET)
LPF	Low Pass Filter
LPI	Low Power Idle (part of EEE)
LS CAN	Low Speed CAN
LVDS	Low Voltage Differential Signaling (physical principle for SerDes interfaces often used synonymously for SerDes)
MAAP	MAC Address Acquisition Protocol (for dynamic allocation of multicast addresses with IEEE 1722)
MaaS	Mobility-as-a-Service (from owning to using)
MAC	Media Access Control
MB	Mega Bytes (i.e., 2^{20} bytes)

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Mbps	Mega bits per second (i.e., 10^6 bits per second)
MCL	Mode Conversion Loss (part of EMC)
MDC	Management Data Clock (used with the Ethernet PHY management)
MDI	Media Dependent Interface
MDIO	Management Data Input/Output
MEF	Metro Ethernet Forum (combines of marketing and specification work for connectivity services, was originally dedicated to Carrier Ethernet/telecommunication only)
MGbps	MultiGigabit per second
MHL	Mobile High-definition Link (evolution of HDMI)
MIB	Management Information Base (IEEE 802.3 standardization project)
MIDI	Musical Instrument Digital Interface manufacturers association (standard to connect electronic instruments)
MII	Media Independent Interface
min	Minutes
Mio	Millions
MIPI	Mobile Industry Processor Interface (develops specifications for the mobile eco-system)
MIPS	Million Instructions Per Second
MISRA	Motor Industry Software Reliable Association
MJPEG	Motion JPEG (video compression format)
MLB	Media Local Bus (interface to INIC specified for MOST)
MLD	Multicast Listener Discovery
MM	Machine Model (part of ESD)
MMRP	Multiple MAC Registration Protocol (used with TSN)
MoCa	Multimedia over Coax
MOST	Media Oriented Systems Transport (automotive bus system)
MOST Co	MOST Cooperation (organization that industrialized MOST)
MP3	MPEG-1 Audio Layer III (MPEG 1 Part 3) or MPEG-2 Audio Layer III (MPEG-2 Part 3)
MPEG	Moving Picture Experts Group (sets standards for audio/video compression and transmission)
MPEG2-TS	MPEG No. 2-Transport Stream (one of the formats of MPEG)
MPLS	Multi-Protocol Label Switching (used, e.g., within telecommunication networks)
MQS	Micro Quadlock System (type of connector common in the automotive industry)
MSE	Mean Square Error
Msps	Mega symbols per second, equals MBaud
MSRP	Multiple Stream Reservation Protocol (part of TSN)
MVRP	Multiple VLAN Registration Protocol (used with TSN)
µC	MicroController
n/a	Not available or not applicable
NACK	Negative ACK (packet was not received as expected)

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NAT	Network Address Translation (part of IP)
NBI	Narrow Band Interference (part of EMC)
NC	Numerically Controlled
NDP	Neighbor Discovery Protocol (used with IPv6)
NEXT	Near End Cross Talk (part of EMC)
NFV	Network Function Virtualization (used with SDN in the telecom industry)
NIC	Network Interface Controller
NM	Network Management
nMQS	Nano MQS (smaller version of the MQS connector)
NRO	Number Resource Organization (protects the unallocated IP numbers)
NRZ	Non Return to Zero (two level signaling)
ns	Nanoseconds
OA-SPI	OPEN Alliance Serial Peripheral Interface (defined by the OPEN Alliance for the 10BASE-T1S MACPHY)
OA3p	OPEN Alliance 3-pin interface (for 10BASE-T1S transceivers)
OABR	Open Alliance BroadR-Reach (sometimes also referred to as UTSP Ethernet or as simply as BroadR-Reach, now IEEE 100BASE-T1)
OAM	Operation, Administration, and Management (side channel for those purposes available with many transceiver specifications)
OBD	OnBoard Diagnostic (automotive interface for diagnosis)
OCF	Open Connectivity Foundation
OEM	Original Equipment Manufacturer (in the automotive industry often used as a synonym for car manufacturer)
OPEN	One Pair EtherNet alliance (SIG founded to support the Automotive Ethernet eco-system)
OS	Operating System
OSEK	"Offene Systeme und deren Schnittstellen für die Elektronik im Kraftfahrzeug" ("Open systems and their interfaces for electronics in automobiles" is a consortium that describes an OS suitable for embedded systems)
OSI	Open Systems Interconnection (used in ISO/OSI layering)
OTN	Optical Transport Network
P2MP	Point-to-MultiPoint (refers to a form of sharing a medium)
P2P	Point-to-Point (represents a medium that is not shared; can, in another context, also mean Peer-to-Peer)
PAM	Pulse Amplitude Modulation
PAMx	x-level Pulse Amplitude Modulation
PAN	Personal Area Network
PC	Personal Computer
PCB	Printed Circuit Board
PCS	Physical Coding Sublayer
PD	PhotoDiode or Powered Device

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PFS	Perfect Forward Secrecy
PHY	Physical Layer (refers to the physical signaling and media, layer one of the ISO/OSI layering model)
PLC	Programmable Logic Controller or Power Line Communication
PLCA	Physical Layer Collision Avoidance (renamed from Physical Layer Carrier Access) (method organizing medium access for shared 10BASE-T1S)
PLL	Phase-Locked Loop
PLS	PhysicaL Signaling sublayer (used with the MAC)
PMA	Physical Medium Attachment
PMD	Physical Medium Dependent (additional sublayer needed in case of optical transmission)
PoC	Power over Coaxial cabling
PoDL	Power over DataLine (often used for transmission of power over single pair technologies but is actually independent from the number of pairs needed)
PoE	Power-over-Ethernet (refers directly to the implementation described in IEEE 802.3af focusing on 2 pair 100Base-TX Ethernet, was later incorporated as clause 33 into the revision document IEEE 802.3-2005)
POF	Polymeric/Plastic Optical Fiber
PoMD	Power over MultiDrop (used for power over a 10BASE-T1S multidrop segment)
PON	Passive Optical Network
POSIX	Portable Operating System Interface
PPM	Parts Per Million, sometimes also called Defects Per Million (DPM)
PS-ACR-F	Power Sum Attenuation to Cross talk Ratio at Far end (part of EMC)
PS-ACR-N	Power Sum Attenuation to Cross talk Ratio at Near end (part of EMC)
PS-NEXT	Power Sum for Near End Cross Talk (part of EMC)
PSA	Peugeot Société Anonyme
PSAACRF	Power Sum for Alien Attenuation to Cross talk Ratio at Far end (part of EMC)
PSANEXT	Power Sum for Alien Near End Cross Talk (part of EMC)
PSD	Power Spectral Density
PSE	Power Sourcing Equipment
PSTN	Public Switched Telephone Network
PTP	Precision Time Protocol (IEEE 1588-2002, part of TSN)
PTPv2	PTP version 2 (IEEE 1588-2008, part of TSN)
QM	Quality Management
QoS	Quality of Service
RAND	Reasonable and Non-Discriminatory
RARP	Reverse Address Resolution Protocol (part of IPv4)
RDMA	Remote Direct Memory Access

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RF	Radio Frequency
RFC	Request For Comment
RFI	Radio Frequency Interference
RfQ	Request for Quote
RGB	Red Green Blue (analog video transmission based on transmitting one color per cable)
RIR	Regional Internet Registry (administers and registers IP addresses)
RL	Return Loss or echo (part of channel definition)
RMII	Reduced Media Independent Interface
RoCE	RDMA over Converged Ethernet
ROM	Read Only Memory
RPC	Remote Procedure Call
RS	Reconciliation Sublayer
RS-232	Binary, serial interface first introduced by the EIA in 1962
RS-FEC	Reed Solomon Forward Error Correction
RSE	Rear Seat Entertainment
RSTP	Rapid STP
RTP	Real-time Transport Protocol (part of TSN)
RTPGE	Reduced Twisted Pair Gigabit Ethernet (study group name for IEEE 1000BASE-T1)
RTPS	Real-Time Publish Subscribe (used with DDS)
Rx / RxD	Receiver ingress
S-parameter	Scattering parameter
SA	Screening Attenuation (part of EMC)
SAE	Society of Automotive Engineers (US-based industry association)
SD	Service Discovery
SD-DVCR	Standard Definition Digital Video Cassette Recorder (one of the formats supported with IEEE 1722)
SDH	Synchronous Digital Hierarchy (technology for core telecommunications networks)
SDN	Software Defined Networks
SecOC	SECure Onboard Communication (AUTOSAR specification for security)
SEIS	Sicherheit in Eingebetteten IP-basierten Systemen (Security in Embedded IP-based Systems, early Germany-based research project that addressed Ethernet in automotive use)
Semicond.	Semiconductor(s)
SER	Symbol Error Rate
SerDes	SERializer DESerializer (SerDes links are sometimes also called “pixel links,” “High Speed Video links,” or – incorrectly – “LVDS”)
SFD	Start Frame Delimiter (part of an Ethernet packet)
SG	Study Group
SIG	Special Interest Group
SL	StripLine (part of EMC)

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SMTP	Simple Mail Transfer Protocol (first protocol for transporting emails)
SNR	Signal-to-Noise Ratio
SOA	Service Oriented Architecture
SoC	System on Chip
SOME/IP	Scalable service-Oriented MiddlewarE over IP
SONET	Synchronous Optical NETworking (technology for core telecommunications networks)
SOP	Start of Production
SPI	Serial Peripheral Interface
SQI	Signal Quality Indicator
SR	Stream Reservation (part of TSN)
SRP	Stream Reservation Protocol (part of TSN)
SRR	Substitute Remote Request (part of CAN)
SSD	Start Stream Delimiter (part of the Ethernet packet)
SSL	Secure Sockets Layer (replaced by TLS)
SSO	Standard Setting Organization
STP	Shielded Twisted Pair or Spanning Tree Protocol
SUV	Service or Sport Utility Vehicle
SVS	Surround View System
SW	SoftWare
TAS	Time Aware Shaping (part of TSN)
tbd	to be defined
TC	Technical Committee
TCI	Tag Control Information (part of the IEEE 802.1Q header)
TCL	Transverse Conversion Loss (part of EMC)
TCM	Trellis Coded Modulation
TCP	Transmission Control Protocol
TCTL	Transverse Conversion Transfer Loss (part of EMC)
TDM	Time Division Multiplexing (also used as a synonym for circuit switched networks)
TEM	Transversal ElectroMagnetic wave (part of EMC)
TF	Task Force
TIA	Telecommunications Industry Association or TransImpedance Amplifier
TLS	Transport Layer Security
TLV	Type Length Value or Tag Length Value (discussed with SOME/IP)
TO	Transmit Opportunity (part of 10BASE-T1S)
TP	Twisted Pair or Transport Protocol
TSMC	Taiwan Semiconductor Manufacturing Company
TSN	Time Sensitive Networking
TTL	Time-To-Live (part of IP)
Tx / TxD	Transmitter Egress
UBAT	Battery Voltage
UBS	Urgency Based Scheduler (part of TSN)

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UDP	User Datagram Protocol
UDS	Unified Diagnostic Services
UNECE	United Nations Economic Commision for Europe
UNFCCC	United Nations Framework Convention on Climate Change
UNH-IOL	University of New Hampshire InterOperability Lab
UNI	User Network Interface
Unix	Derived from Uniplexed Information and Computing Service (UNICS)
UPnP	Universal Plug and Play
USB	Universal Serial Bus
USP	Unique Selling Proposition, Unique Selling Point
UTP	Unshielded Twisted Pair
UTSP	Unshielded Twisted Single Pair (if combined with Ethernet, this often also refers to OABR)
UWB	Ultra Wide Band (IEEE 802.15.4a)
VAN	Vehicle Area Network
VCC	Pin for IC voltage supply
VCIC	Video Communication Interface for Cameras (ISO 17215)
VDA	Verband der Automobilindustrie (German Association of the Automotive Industry)
VDD	Pin for IC voltage supply
VDE	Verband Deutscher Elektrotechniker (Association for Electrical, Electronic & Information Technologies based in Germany)
VID	VLAN Identifier
VIN	Vehicle Identification Number
VL	Virtual Link
VLAN	Virtual LAN
VLSM	Variable Length Subnet Mask (used with IP)
VoIP	Voice over IP
Vpp	Volts peak to peak
Vres	Vertical RESolution
WAN	Wide Area Network
WiFi	Marketing name invented by the WiFi Alliance for IEEE 802.11 enabled WLAN products, often synonymously used for WLAN [8])
WLAN	Wireless LAN
WPAN	Wireless PAN
WRAN	Wireless Regional Area Network
WUP	Wake-Up Pattern (part of CAN partial networking)
WUR	Wake-Up Request (part of CAN partial networking)
WWH-OBD	World Wide Harmonized OnBoard Diagnostics
www	World Wide Web
xMII	any of the many MII variants
xor	either or (exclusive or)
XTALK	Crosstalk (part of the channel definition and EMC)

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Timeline

1965	AT&T installs the world's first electronic telephone switch (special purpose computer) in a local telephone exchange [1].
1968	Invention of Programmable Logic Controllers (PLCs) [2].
1969	AT&T employees at Bell Labs develop the operating system Unix, which eventually enabled distributed computing with remote procedure calls and the use of remote resources. For antitrust reasons, AT&T was neither allowed to sell Unix nor to keep it to itself. In consequence, they shipped it to everyone interested [3].
1969 Apr. 7	The RFC 1 is published [4]. It discusses the host software for ARPANET's switching nodes. ARPANET represents one of the world's first operational packet switching networks [5].
1969 Oct. 29	The first ARPANET link is established between University of California, Los Angeles, and Stanford Research Institute [6].
1971 Nov. 3	Publication of the first *UNIX Programmer's Manual* [7].
By 1973	Unix was recoded in C (it was first developed in [an] Assembly language) [8]. This greatly enhanced Unix' portability to different hardware and further incited its distribution.
1973	The International Electrotechnical Commission (IEC) creates a technical committee (TC77) to specifically handle questions of electromagnetic compatibility [9].
1973 May 22	First documentation of Ethernet as an idea in a memo from Robert Metcalfe at Xerox PARC [10]. At that time, Xerox PARC was selling the first personal computer workstations (called "Xerox Alto") and had invented the first laser printers [11]. Metcalfe was working on a solution for data transmission between these products and the early Internet.
1973 Oct.	Unix was presented publicly to the Fourth Association for Computer Machinery on Operating System Principles [3].
1973 Nov. 11	First Xerox internal demonstration of Ethernet [10].
1974 Dec.	Release of the "Specification of Internet Transmission Control Program," RFC 675 [12], which was a monolithic specification that covered both network (Internet Protocol, IP) and connection (Transmission Control Protocol, TCP) protocols. It was initiated by

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	the Defense Advanced Research Projects Agency (DARPA), influenced by early networking protocols from Xerox PARC, and refined by the Networking Research Group of the University of Stanford [13].
1975	Honeywell and Yokogawa introduce the first distributed computer control systems for industrial automation [14].
1975 Mar. 31	Xerox files a patent application listing Robert Metcalfe, David Boggs, Charles Thacker, and Butler Lampson as inventors of Ethernet [15].
1976 Jul.	First paper published on Ethernet [16].
1977	The ISO formed a committee on Open System Interconnection (OSI) [17]. Somewhat later a group from Honeywell Information Systems presented their seven-layer model to the ISO OSI group [18].
1978 Mar. 9	The Computer System Research Group of the University of California, Berkeley, released its first Unix derivative, the Berkeley Software Distribution (BSD) [19].
1978 Apr. 1	ARINC publishes the first ARINC 429 communication standard for avionic equipment [20].
1979 Jun.	ISO publishes the OSI layering model [18].
1979 Jun. 4	Metcalfe founds 3Com to build Ethernet competitive products and convinces DEC, Intel, and Xerox (referred to as DIX) to use and promote Ethernet as a standard for their products [10, 21].
1979–82	Next to 3Com, several start-up companies were founded that built Ethernet products. The most successful ones in the mid-1980s were Ungermann-Bass (U-B), Interlan, Bridge Communications, and Excelan [21].
1980 Feb.	IEEE starts the 802 project to standardize LANs [21].
1980 May	The DIX group joins the IEEE 802 project and offers Ethernet for adoption while still working on it [21].
1980 Aug. 29	The User Datagram Protocol (UDP) was published as RFC 768 [22].
1980 Sep. 30	Publication of the first version of the so-called DIX Standard (from DEC/Intel/Xerox) on Ethernet. Operating at 2.94 Mbps, it was able to support 256 devices [23].
1980 Dec.	IEEE 802 LAN effort was split into three groups: 802.3 for CSMA/CD (Ethernet), 802.4 for Token Bus (for the factory automation vendors), and 802.5 for Token Ring (driven by IBM) [21].
1981 Mar.	3Com shipped its first 10 Mbps Ethernet 3C100 transceiver [24].
1981 Sept.	With the fourth version the Transmission Control Protocol (TCP) and the Internet Protocol are published in separate documents, RFC 793 [25] and RFC 791 [26].
1982 Aug.	Simple Mail Transfer Protocol (SMTP) is published as RFC 821 [27].
1982 Sep.	3Com ships the first Ethernet adapter for IBM PCs [10].
1982 Nov.	The second version of the DIX Ethernet Standard is published [28].

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1983	IEEE publishes 802.3 10BASE-5 for 10 Mbps over thick coax cable [29].
1983	The trade press names at least 21 companies either developing or manufacturing Ethernet products: The five startups (3Com, U-B, Interlan, Bridge Communications, and Excelan), eight computer manufacturers (DEC, HP, Data General, Siemens, Tektronix, Xerox, ICL, and NCR), and seven chip manufacturers (Intel, AMD, Mostek, Seeq, Fujitsu, Rockwell, and National Semiconductors), all fiercely competing [21].
1983	BOSCH starts a company internal project to develop CAN [30].
1984 Jan. 1	AT&T monopoly is broken up, existing installed telephone wiring is usable by competing companies for their services [1].
By 1985	Approximately 30,000 Ethernet networks have been installed, connecting at least 419,000 nodes [21].
1985	IEEE publishes 802.3 10BASE-2 for 10 Mbps over thin coax cable [29].
1986	Market introduction of Token Ring, quickly gaining momentum as it is able to use telephone wires, is more reliable, and easier to trouble shoot [21].
1987	200 vendors of Ethernet equipment counted [21].
Mid-1987	SynOptics (Xerox spinout) shipped the first (proprietary) 10 Mbps Ethernet version for telephone wire. Even if this solution was proprietary, it proved the feasibility [21].
1987 Dec.	BMW introduces the first car with a communication bus for diagnostic purposes.
1988	The all-electronic fly-by-wire system is introduced into commercial airplane service (on the Airbus A320) [31].
1989 Oct.	Publication of the TCP/IP Internet Protocol (IP) suite as "Requirements for Internet Hosts – Communication Layers," RFC 1122 [32] and "Requirements for Internet Hosts – Application and Support," RFC 1123 [33].
1989–90	The World Wide Web is invented at CERN [34].
1990 Sep.	IEEE 802.3 ratified 10BASE-T [29] (with some effort, as various proprietary solutions had evolved [21]). Ethernet had won the battle against competing technologies, by adapting to market realities and shifting from coax to twisted pair cabling [10].
1991	TIA publishes TIA-568. It describes an inexpensive and easy to maintain UTP structured wiring plant. This includes the definition of pin/pair assignments for eight-conductor 100-Ohm balanced twisted-pair cabling for wires in 8P8C/RJ-45 eight-pin modular connector plugs and sockets [35].
1992	The first cars using CAN roll off the assembly line at Mercedes Benz [30].

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1993	IEEE 802.3 releases 10BASE-F, its first of a large number of optical versions [29].
1994 Jun.	Initial release of the first automotive quality specification for integrated circuits AEC-Q100 [36].
1995	The first commercial VoIP product allows real-time, full-duplex voice communication over the Internet using 1995 available hardware and bandwidth [37].
1995	IEEE 802.3 releases 100BASE-TX (-T4, -FX) including auto-negotiation [29].
1995	The ISO/IEC publishes a backwards compatible MPEG-2 Audio (MPEG-2 Part 3) specification – commonly referred to as MP3 – with additional bit and sample rates [38].
1995 Jun.	IETF releases the IPv4 specification “Requirements for IP Version 4 Routers,” RFC 1812 [39].
1995 Aug.	IETF releases the first IPsec specification, RFC 1825 [40].
1995 Dec.	IETF release the first specification for IPv6 as RFC 1883 [41].
1996 Feb. 14	The Windows 95 Service Pack-1 includes Explorer 2.0 (i.e., built-in TCP/IP networking) [13, 42, 43].
1996 May	HTTP/1.0 is published as RFC 1945 [44].
1997	IEEE 802.3 releases 802.3x full-duplex and flow control [29].
1997 Apr.	The Fieldbus Foundation funds the project to develop the “High Speed Ethernet (HSE)” Industrial Ethernet version [45].
1998	IEEE 802.1 publishes the IEEE 802.1D-1998 revision that incorporates IEEE 802.1p with new priority classes [46] and IEEE 802.1Q, which enables VLANs [47].
1998	IEEE 802.3 releases 802.3ac, which extends the maximum frame size to 1522 bytes, in order to allow 802.1Q VLAN information and 802.1p priority information to be included (“Q-tag”) [29].
1998	Founding of the LIN consortium by Audi, BMW, Daimler, Volkswagen, Volvo, Freescale (erstwhile Motorola), and Mentor Graphics (erstwhile Volcano) [48].
1998 Sep. 10	Founding of the MOST corporation by BMW, Daimler, Oasis (now Microchip), and (Harman) Becker [49].
1998 Dec.	IETF publishes the “Internet Protocol, Version 6 (IPv6) Specification,” RFC 2460 [50].
1999	IEEE 802.3 releases the 1000BASE-T specification 802.3ab [29].
1999 May	Napster launches and significantly simplifies MP3 music sharing. It was closed in February 2001 [51].
2000 May	Boeing delivers its first 747-400 with an advanced flight deck display system that uses the Rockwell Collins-developed, Ethernet-based Avionics Systems Network (ASN) as a communication system [52].
2000 Dec. 31	IEC adopts its IEC 61158 standard on fieldbusses. It contains no less than 18 variants. The Ethernet-based variants HSE, EtherNet/IP, and ProfiNet represent three of them [53].

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2000	Freescale (formerly Motorola, now NXP), NXP (formerly Philips), BMW, and DaimlerChrysler (today again Daimler) found the FlexRay Consortium [54].
2001 Oct.	DaimlerChrysler (today again Daimler) introduces LIN as the first car manufacturer [55].
2001 Nov.	The first (BMW) car with MOST25 bus and an LVDS-based SerDes goes into production.
2002 Nov.	Release of the IEEE 1588 PTP standard, which had been initiated a few years earlier by Agilent Technologies [56].
2003	IEEE 802.3 releases the first Power over Ethernet (PoE) specification (IEEE802.3af) [29].
2003	The AUTOSAR consortium is founded by BMW, BOSCH, Continental, DaimlerChrysler (today Daimler), Siemens VDO (today Continental), and Volkswagen [57].
2003 Jun. 10	Release of the ARINC Specification 664 Part 2 “Ethernet Physical and Data-Link Layer Specification” [58].
2003 Nov.	LIN 1.3 is published [48].
2004	Start of investigations at BMW to use Ethernet as an in-vehicle networking technology.
2004 Feb.	The Metro Ethernet Forum releases the first of a number of standards for the deployment of Carrier Ethernet [59].
2004 Jul.	IEEE 802.3 passes a CFI on “Residential Ethernet” and starts a respective SG, i.e., the Audio Video Bridging (AVB) activities [60].
2004 Sep.	IEEE 802.3 releases the first Ethernet in the first Mile (EFM) specification (IEEE 802.3ah) [29].
2005 Apr. 27	First flight of the A380 using an AFDX network for its avionics system, see e.g. [61, 62].
2005 Jun. 27	Publication of the ARINC 664 Part 7 specification on “Avionics full-duplex switched Ethernet (AFDX) network” [58].
2005 Nov. 21	The AVB activities are shifted from IEEE 802.3 to IEEE 802.1 [63].
2006	IEEE 802.3 releases the 10GBASE-T specification (IEEE 802.3an) [29].
2006 Feb.	First cars with built-in USB interface for connecting consumer devices are being sold [64, 65].
2006 Aug. 18	IEEE 802.1 releases the 802.1AE specification, also known as MACsec [66].
2006 Nov.	BMW has the first car with a FlexRay bus in production [67].
2007	Toyota introduces the first car with MOST50 [68].
2007 Jul. 20	IEEE 802 confirms the renaming of the 802.3 group from “CSMA/CD (Ethernet)” to “Ethernet” [69].
2008 Jan.	First automotive EMC measurements of Broadcom’s BroadR-Reach, today referred to as IEEE 100BASE-T1 Ethernet, at BMW.
2008 Oct.	SOP of the BMW 7 series using 100BASE-TX unshielded as a diagnostic interface and using 100BASE-TX shielded for the communication between HU and RSE [70].

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2009	The development of FlexRay is completed. The work in the FlexRay Consortium is terminated [71] and the specifications are transferred to ISO 17458.
2009 Mar.	The GENIVI Alliance is founded by BMW, Delphi, General Motors, Intel, Magneti Marelli, PSA Peugeot Citroën, Visteon, and Wind River [72].
2009 Aug. 25	The AVnu Alliance is founded by Broadcom, Cisco, Harman, Intel, and Xilinx [73].
2009 Dec. 7	AUTOSAR 4.0 is published and provides means to support Diagnostics over IP (DoIP), i.e., Ethernet communication-based diagnosis and software flashing via IP and UDP [74].
2010	IEEE 802.3 releases 802.3az on Energy Efficient Ethernet (EEE) [29].
2010 Jan	First informal discussion among various car manufacturers and FTZ on UTSP Ethernet [75].
2010 Mar.	BMW internal decision on using Broadcom's BroadR-Reach (which later became IEEE 100BASE-T1) Ethernet for the next surround view system [75].
2011 Jan.	First discussion between Broadcom, NXP, and BMW on founding the OPEN Alliance [75].
2011 Jan. 31	The IANA assigns the last available blocks of IPv4 addresses to the Regional Internet Registries (RIR) [76]. This means that there are no longer any IPv4 addresses available for allocation from the IANA to the five RIRs.
2011 Mar.	BMW internal decision on using BroadR-Reach/100BASE-T1 Ethernet for the infotainment domain [75].
2011 Aug. 8	The FlexRay Consortium is officially dissolved.
2011 Oct. 15	ISO publishes the DoIP standard part 1 [77].
2011 Nov. 9	NXP, Broadcom, and BMW start the OPEN Alliance. In the same month C&S, Freescale (now NXP), Harman, Hyundai, Jaguar Land Rover, and UNH-IOL join [78].
2011 Nov. 9	NXP announces the development of a BroadR-Reach/100BASE-T1 Ethernet compliant PHY [79].
2011 Nov. 14	First Ethernet&IP@Automotive Technology Day at BMW in Munich [80].
2011 Sep. 30	The IEEE ratifies and publishes the last of its "Audio Video Bridging (AVB)" standards (IEEE 802.1BA) [81].
2012 Feb.	The Metro Ethernet Forum publishes a suite of specifications as Carrier Ethernet 2.0 [82].
2012 Mar. 15	Call for Interest (CFI) passes for Reduced Twisted Pair Gigabit Ethernet (RTPGE, later called 1000BASE-T1) at IEEE 802.3 [83].
2012 Jun.	ISO publishes the DoIP standard part 2 [84].
2012 Sep. 19	Second Ethernet&IP@Automotive Technology Day, hosted by Continental in Regensburg [85].

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2012 Sep.	Audi starts the production of its first car with a MOST150 network [86].
2012 Nov.	IEEE renames the AVB activities as Time Sensitive Networking (TSN) [87].
2012 Nov. 15	CFI passes for “distinguished minimum latency traffic in a converged traffic environment,” later called Interspersing Express Traffic (IET)/IEEE802.3br, at IEEE 802.3 [88] after it had failed its first attempt on March 12 [89].
2013 Jan.	Start of RTPGE/1000BASE-T1 task force at IEEE 802.3 [88].
2013 Jul.	The LIN standardization is seen as completed. The LIN specifications are transferred to ISO 17987 [90] and the LIN Consortium is dissolved.
2013 Jul. 16	CFI passes for Power over Data Line (PoDL) at IEEE 802.3 [91].
2013 Sep.	SOP of the BMW X5 using BroadR-Reach/100BASE-T1 Ethernet for connecting the cameras to the surround view system [75].
2013 Sep. 25	Third Ethernet&IP@Automotive Technology Day, hosted by BOSCH in Stuttgart [92].
2013 Nov.	Acceptance of Interspersing Express Traffic (IET)/IEEE 802.3br Task Force at IEEE 802.3 [93] after failing the attempt in July [94].
2014 Jan.	Start of PoDL Task Force at IEEE 802.3 [95]
2014 Mar. 20	CFI for 1 Twisted Pair 100 Mbps Ethernet (1TPCE) PHY at IEEE 802.3, i.e., the transfer of BroadR-Reach to the IEEE standard 100BASE-T1 [96].
2014 Mar. 20	CFI for Gigabit Ethernet over Plastic Optical Fiber, later named 1000BASE-RH, at IEEE 802.3 [97].
2014 Mar. 31	AUTOSAR Version 4.1 is published and supports TCP, Service Discovery (SD), and the connection to the MAC and PHY layers (including BroadR-Reach/100BASE-T1) [98].
2014 Jun. 9	The OPEN Alliance has more than 200 members [99].
2014 Sep.	Start of 100BASE-T1 Task Force at IEEE 802.3 [100].
2014 Oct. 23	IEEE-SA (4th) Ethernet&IP@Automotive Technology Day, hosted by General Motors in Detroit [101] and organized by IEEE-SA.
2015 Jan.	Start of GEPOF/1000BASE-RH Task Force at IEEE 802.3 [102] after failing to move into Task Force in July [103].
2015 May 12	Publication update of the Automotive Ethernet AVB specification [104].
2015 Sep.	SOP of 7-series BMW using 100BASE-T1 Ethernet as system bus to connect a variety of ECUs [75].
2015 Oct. 14	Among other car manufacturers, Volkswagen and Jaguar Land Rover publicly announce the use of BroadR-Reach/100BASE-T1 Ethernet in their cars [105].
2015 Oct. 26	Publication date of 100BASE-T1 specification by IEEE [106].
2015 Oct. 27	Fifth Ethernet&IP@Automotive Technology Day, hosted by Jaspar in Yokohama [107] and organized by Nikkei BP.

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2015 Dec. 12	The United Nations Framework Convention on Climate Change (UNFCCC) adopts the so-called Paris agreement. Its goal is to limit global warming to below 2°C (ideally to 1.5°C) above preindustrial level [108]. This leads to stringent CO_2 targets for the car industry.
2016 Jan.	ISO starts Project 21111 Part 1 and 3 on “Road vehicles – In-vehicle Gigabit Ethernet system” with focus on specifications to support the optical Gbps Ethernet standard 1000BASE-RH [109, 110].
2016 Mar. 4	A significantly amended IEEE 1722 specification is published [111].
2016 Mar. 22	OPEN Alliance has more than 300 members [112].
2016 Jun.	The ISO registers ISO 21806 in order to accommodate the completed MOST specifications at ISO.
2016 Jun. 30	Publication date of the 1000BASE-T1 specification by IEEE [113].
2016 Jun. 30	Publication date of the Interspersing Express Traffic (IET) specification by IEEE [114].
2016 Jul. 28	CFI passes at IEEE 802.3 in order to establish a study group to investigate the standardization of a 10 Mbps Ethernet for use in automotive and industrial applications [115].
2016 Sep. 20	IEEE-SA (6th) Ethernet&IP@Automotive Technology Day, hosted by Renault in Paris [116] and organized by IEEE-SA.
2016 Sep.	The ISO project 21111 is renamed from “Road vehicles – In-vehicle Gigabit Ethernet system” to “Road vehicles – In-vehicle Ethernet system” in order to be able to comprise future Automotive Ethernet support specifications for different PHY technologies. The original parts 1 and 3 are split into part 1 to part 4, with the new parts 1 and 2 containing information that is applicable to all Automotive Ethernet PHY variants.
2016 Nov. 10	IEEE 802.3 agrees on requesting to move the 10 Mbps PHY activity for industrial and automotive applications to Task Force [117]. This effort receives the number IEEE 802.3cg and the two PHYs developed are called 10BASE-T1S and 10BASE-T1L.
2016 Nov. 10	CFI passes at IEEE 802.3 in order to establish a study group to investigate the standardization of a multi-Gbps Ethernet for use in the automotive industry [118].
2017 May 22	First Task Force meeting of IEEE 802.3ch [119].
2017 Oct. 31	IEEE-SA (7th) Ethernet&IP@Automotive Technology Day, hosted by US Car in San Jose [120] and organized by IEEE-SA.
2018 Jul. 9	Initiation slides for starting the development of a Time Sensitive Networking (TSN) Automotive Profile for Automotive at IEEE 802.1 [121].
2018 Oct. 8	IEEE-SA (8th) Ethernet&IP@Automotive Technology Day, hosted by JLR in London [122] and organized by IEEE-SA.
2019 Feb. 8	Approval of the Project Authorization Request for the Time-Sensitive Networking Profile for Automotive In-Vehicle Ethernet Communications, IEEE P802.1DG [123].

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2019 Mar. 14	CFI presentation at IEEE 802.3 in order to establish a Study Group to investigate the standardization of a >10G Automotive electrical Ethernet PHY [124]. CFI passes [125].
2019 Jul.	The OPEN Alliance has more than 400 Members [126].
2019 Jul. 18	CFI passes at IEEE 802.3 in order to establish a study group to investigate the standardization of multidrop enhancements for 10BASE-T1S [127].
2019 Jul. 18	CFI passes IEEE 802.3 in order to establish a study group to investigate the standardization of a ≥10G optical Automotive Ethernet PHY [127, 128].
2019 Sep. 24	IEEE-SA (9th) Ethernet&IP@Automotive Technology Day, hosted by Ford in Detroit [129] and organized by IEEE-SA.
2019 Nov. 19	Approval date of the IEEE 802.3cg 10BASE-T1S and 10BASE-T1L specification [130].
2019 Nov. 25	As the last of the five RIRs the PIRE NCC responsible for Europe, the Middle East, and Central Asia has run out of IPv4 addresses [131]. The pool for original IPv4 addresses has thus been completely exhausted, and new assignments are only possible should IPv4 addresses be recovered.
2020 Jun. 24	First meeting of the greater than 10Gb/s Electrical Automotive Ethernet PHYs Task Force [132].
2020 Jul. 14	First meeting of the Multi-Gigabit Optical Automotive Ethernet Task Force [133].
2020 Sep. 15	The IEEE-SA holds the IEEE-SA Ethernet&IP@Automotive Technology Day as a virtual event.

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