CAR CONNECTIVITY BASED ON AUTOMOTIVE ETHERNET

MATEnet interconnection system provides bandwidth, flexibility and reliability

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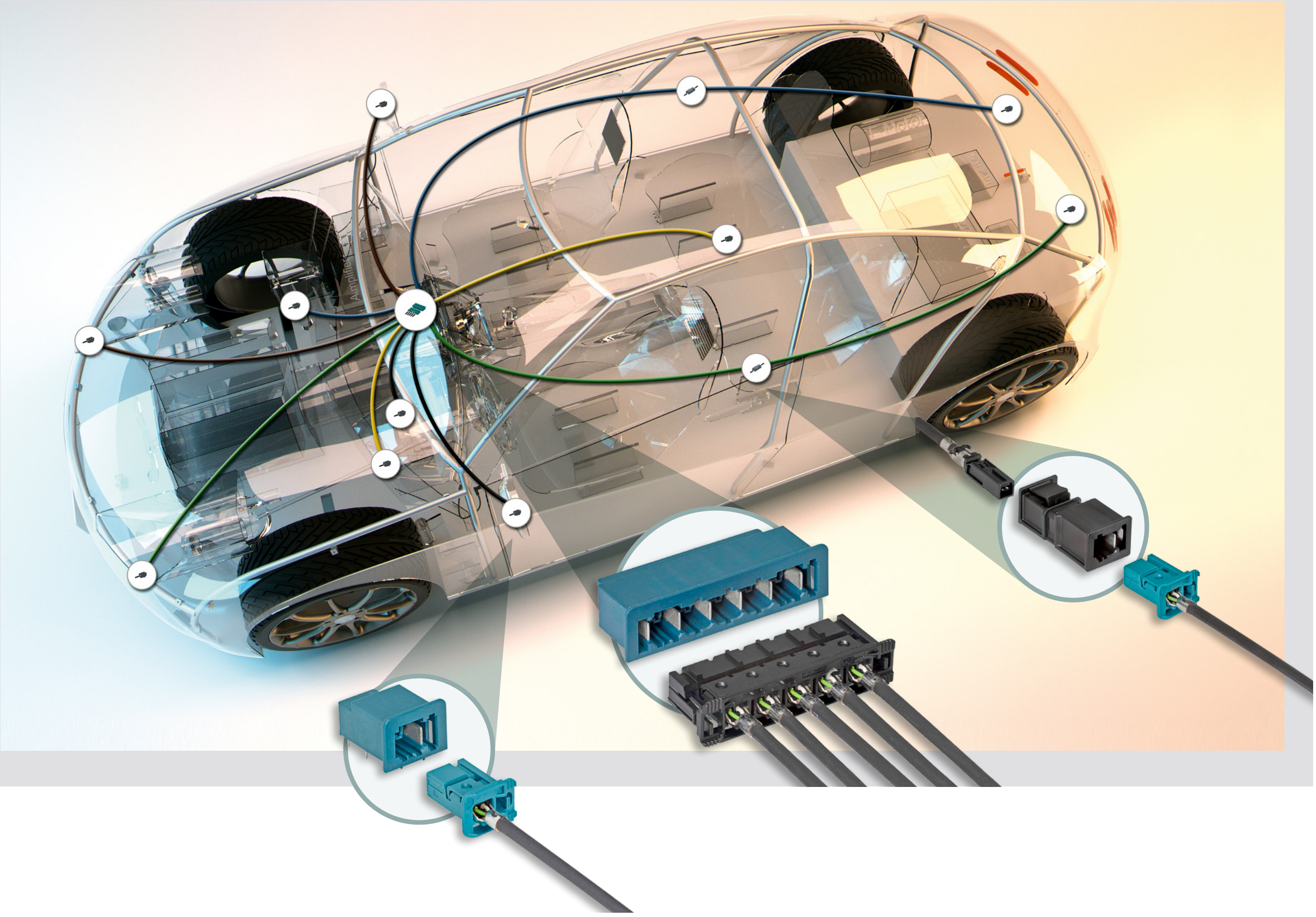
IN AN ONGOING, GLOBAL EVOLUTIONARY PROCESS, SAFER, GREENER AND MORE COMFORTABLE DRIVING INCREASINGLY RELIES ON CONNECTIVITY. THE NUMBER OF INTERCONNECTIONS IN THE CAR GOES UP, AND THE AMOUNT OF TRANSMITTED DATA ALSO INCREASES. AMONG THE GROWING DATA TRAFFIC THERE WILL BE A PROGRESSIVELY BIG SHARE OF LARGE DATA PACKAGES WHICH REQUIRE HIGH BANDWIDTH.

Automotive Ethernet offers the best cost-benefit ratio for this requirement. Utilizing Automotive Ethernet requires an intelligent interconnection solution that provides the flexibility, economy and performance for differing EMC requirement levels. Also the cabling (harness) shall be easily installed.

TE Connectivity's new MATEnet interconnection system brings automotive-grade robustness and performance to the industry. It offers reliability, affordability, fully automated handling, quality level, miniaturization, light-weighting, flexibility, and scalability to support economic car connectivity via Automotive Ethernet.



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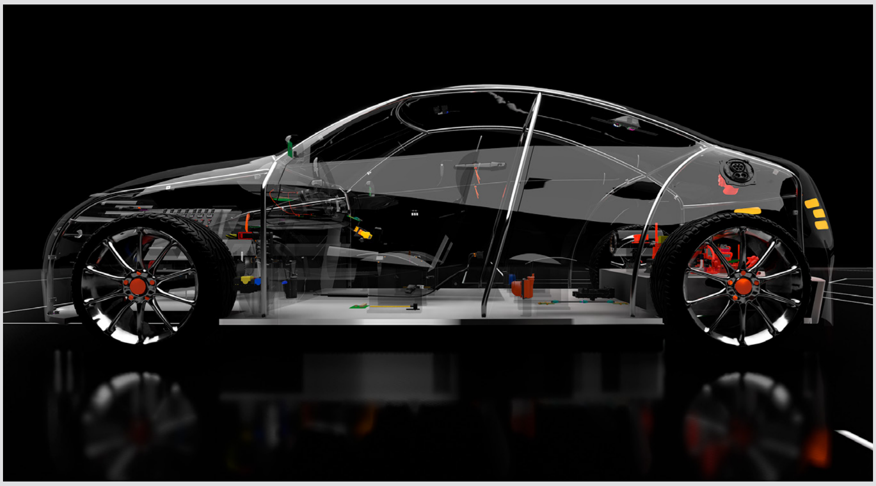
1 | CAR CONNECTIVITY IS A KEY ENABLER – AND A DRIVER OF GROWTH

The evolutionary and revolutionary progress of automobile technology can be summarized by three world-encompassing mega trends: Connectivity, autonomous driving, and electrification. However, connectivity is an essential part of all three because the increasing level of networking within the car, and of linking the car to other cars, to the infrastructure and to the cloud is an essential part of autonomous driving and electrification as well. Automotive Ethernet will be a part of making the car the ultimate mobile device. Why is that so?

Connectivity started small. In its beginnings it was defined by the Global Positioning System (GPS), by the car radio, plus Bluetooth and WiFi connectivity, which serve to connect mobile devices to the car via short-range communication. Put simply, the digital lifestyle was "bolted-on" to the car to give the driver access to his or her familiar information sources and internet-based services. Smartphone integration – not just using the smartphone while driving! – is driven by the need to offer a human machine interface which is better suited to the driving situation than standard smartphone operation. Among other things control actions which require a lot of eye-hand coordination must be avoided. An integrated smartphone can be controlled by the in-vehicle controls optimized for the driving situation.



The next step – which is sweeping through the industry already – is to use smartphone apps to provide useful functions to the driver, for instance, to find parking or to observe the charging status of a battery electric vehicle (BEV) from a distance. But even that is only an intermediate phase. The car itself is becoming a part of the Internet of Everything (IoE). It is turning into the ultimate mobile device. The rationale behind this trend goes far beyond entertainment. In a vehicle capable of autonomous driving, connectivity is necessary to extend the vehicle horizon. After all, there is little point in just replicating the driver's limited line of sight (which is rarely longer than 300 yards and can be impacted by numerous boundary conditions). Depending on the vehicle speed this limited range can translate into a planning and reaction time span between 1 and 5 seconds. Now, the whole point of autonomous driving is to increase driving safety and to free the driver from the burden of the driving task. In order to increase the level of driving safety an autonomous car needs the best possible information database for predictive planning: Things like the current traffic situation and road condition, (adverse) weather, temperature, temporary speed limits and others are ideally factored in by the autonomous driving control unit. Based on a detailed and current data pool the vehicle can plan an optimum route, speed, trajectory – and energy use. It is the latter which makes connectivity a must for BEVs as well because their range is strongly influenced by boundary conditions such as temperature, driving style, route topography, and the availability of suitable charging stations.

To improve mobility, the vehicle of the future will "know" much more about its immediate environment and the route ahead. Advanced Driver Assistant Systems (ADAS), which gradually develop into autonomous driving functions, base their support of the driver or immediate action on an increasingly detailed environmental model of the traffic situation ahead. This kind of model is the result of sensor fusion (camera, radar, LiDAR) which delivers a list of objects (static and dynamic), applicable rules and limitations (lane markings, traffic signs) and accessible trajectories. Networking is the key to facilitating this model. Many in-vehicle systems contribute to a comprehensive understanding of the driving situation. In addition

Vehicle-to-X (V2X) technology will deliver more current information about incidents and situations in the near environment of the vehicle. At the same time the data transmitted from individual vehicles ("I have to brake because of an accident ahead") can be uploaded to the cloud and will be processed and refined in the backend from where the validated information is re-distributed to vehicles in the relevant area. This kind of connectivity will establish a swarm intelligence, which can be used to turn traffic into an intelligent system which regulates itself to a degree. Among other trends, the increasing need for neural networks and artificial intelligence (understanding of complex traffic scenarios) in the car brings about an enormous data traffic – both within the car and beyond it (Fig. 1).

In an era where vehicle efficiency (higher fuel efficiency and lower CO2 emission) and a general emission reduction are at the top of the priority list, the data pool used for (autonomous) driving is the most valuable asset because it will give the driver (man) and the car (machine) a clearer idea of how to achieve an efficient, safe and comfortable mobility. Because the data that is relevant for this comes from a growing list of sources, former boundaries between domains (e.g. safety, infotainment and comfort systems) begin to blur. Everything in the vehicle and beyond it is becoming connected.

Fig. 1: Levels of automotive data connectivity

The magnitude of networking is summarized by a McKinsey study, focusing on the connected car:

"Today's car has the computing power of 20 modern PCs, features about 100 million lines of code, and processes up to 25 gigabytes of data per hour. As the computing capacity of cars develops further, not only is programming becoming more complex and processing speeds becoming faster, but the entire nature of the technology is shifting. While automotive digital technology once focused on optimizing the vehicle's internal functions, the computing evolution is now developing the car's ability to digitally connect with the outside world and enhance the in-car experience." [1]

Once the vehicle becomes an integral part of the IoE, the amount of software in the car will continue to go up – and its scope will widen. One of the drivers behind this trend is cyber security: A connected car needs protection against hacking and data theft. To stay abreast of hacking, the vehicle software will need to be updated, e.g. by software patches eliminating weak spots. This will be done by software-over-the-air (SOTA) distribution, which means even more data traffic to the car and within the car.

The McKinsey 2014 figures illustrate the fact that the car already is probably one of the most underrated technical systems of our time. And it is becoming more complex. Networking and connectivity are moving to the center of attention because new functions and services add to the vehicles attractiveness. It is a big market: In 2015, the US auto market alone accounted for 17.5 million vehicles, or approximately 20 % of global sales [2]. As America's automobile industry, for instance, is one of the most powerful engines driving the US economy, connectivity is a cornerstone of future success. The same applies to every major automotive world market. Bearing in mind that every modern car is a rolling network already, the bottom line can only be: The car has entered into the age of software and connectivity. There is a whole new value chain forming around it in the global automotive industry.

2 | MEETING THE REQUIREMENTS

– Bandwidth –

At the very core of in-vehicle networking and connectivity is the physical layer of networking – the interconnection system and cabling/harness. Existing vehicle bus standards such as CAN, LIN, FlexRay, and MOST are the response to specific requirements and the answer to the need of finding a balance between cost and performance for each networking application. This is exactly why Automotive Ethernet will contribute a growing share of the in-vehicle networking. Standards such as IEEE 100BASE-T1 (IEEE802.3bw) with 100 Mbit/sec at 66 MHz (or up to 200) MHz and IEEE 1000BASE-T1 (IEEE802.3bp) with 1 Gbit/sec at up to 600 MHz offer the bandwidth which is increasingly needed to transmit data in the car. At the same time the simple Automotive Ethernet cabling avoids all the downsides of optical fiber networks (MOST), for instance. In the near future cars will likely have between 5 and 15 Automotive Ethernet lines with 100 Mbit/sec, and up to 5 lines with 1 Gbit/sec.

– Flexibility –

Part of the challenge, however, is not "just" to provide more bandwidth for bigger data packages, it is also a challenge to meet the OEMs' different approaches to vehicle Electronic/Electrical architecture. Some, for instance use more local intelligence (distributed over various ECUs or sensors) while others opt for a centralized architecture with more computing power in fewer but larger domain ECUs. An additional challenge lies in the Electromagnetic Compatibility (EMC) specifications. Some applications require a higher level of shielding while others work well with a simple unshielded cable. Now, shielding requirements translate into different cable types – and different cost levels. Also, different types of cables may require different types of interconnection technology. Utilizing Automotive Ethernet therefore requires an intelligent interconnection solution that offers the flexibility, economy and performance for differing EMC requirement levels.

– Automotive-grade robustness –

However, the car is not a "normal" environment for networking and data traffic: Vibration, impact, heat, cold, dampness, aggressive fluids, and voltage fluctuations in the on-board electrical infrastructure pose tough requirements to managing data flows. Also the cabling (harness) shall be easily installed. In other words, connectivity is the key to the future of mobility, however, vehicle networks require very specific solutions to make all the future dreams of mobility come true.

3 | INTERMEDIATE CONCLUSION – DATA AND CONNECTIVITY

In the future, safer, greener and more comfortable driving will strongly rely on connectivity. The number of interconnections in the car will go up and the amount of transmitted data will also increase. Many of these data will originate within the vehicle (e.g. in sensors and ECUs), some will come from the air interface (e.g. dynamic map data, software patches, downloads etc.) and will have to be distributed in the car from an entry gateway. Among this growing data traffic there will be a progressively big share of large data packages which require high bandwidth.

Connectivity will be at the core of new functions and capabilities which include autonomous driving and electrification but also a new level of function servitization through new backend-based services, e.g. intelligent traffic solutions, predictive lighting functions and many more.

To utilize the present and future wealth of data, the in-vehicle networking needs to be fast with high bandwidth. It needs to be reliable, robust, affordable, and easy to install. Considering the relevance of data flows in the car, an interconnection technology that meets this list of requirements is a true enabler and will become a regular feature of the new value chain.

4 | THE MATENET INTERCONNECTION SYSTEM

TE Connectivity's MATEnet interconnection system is a proactive answer to today's and tomorrow's requirements of vehicle connectivity. MATEnet was specifically developed for IEEE Automotive Ethernet networking. It relies on automotive-grade, miniaturized, robust and proven interconnection technology

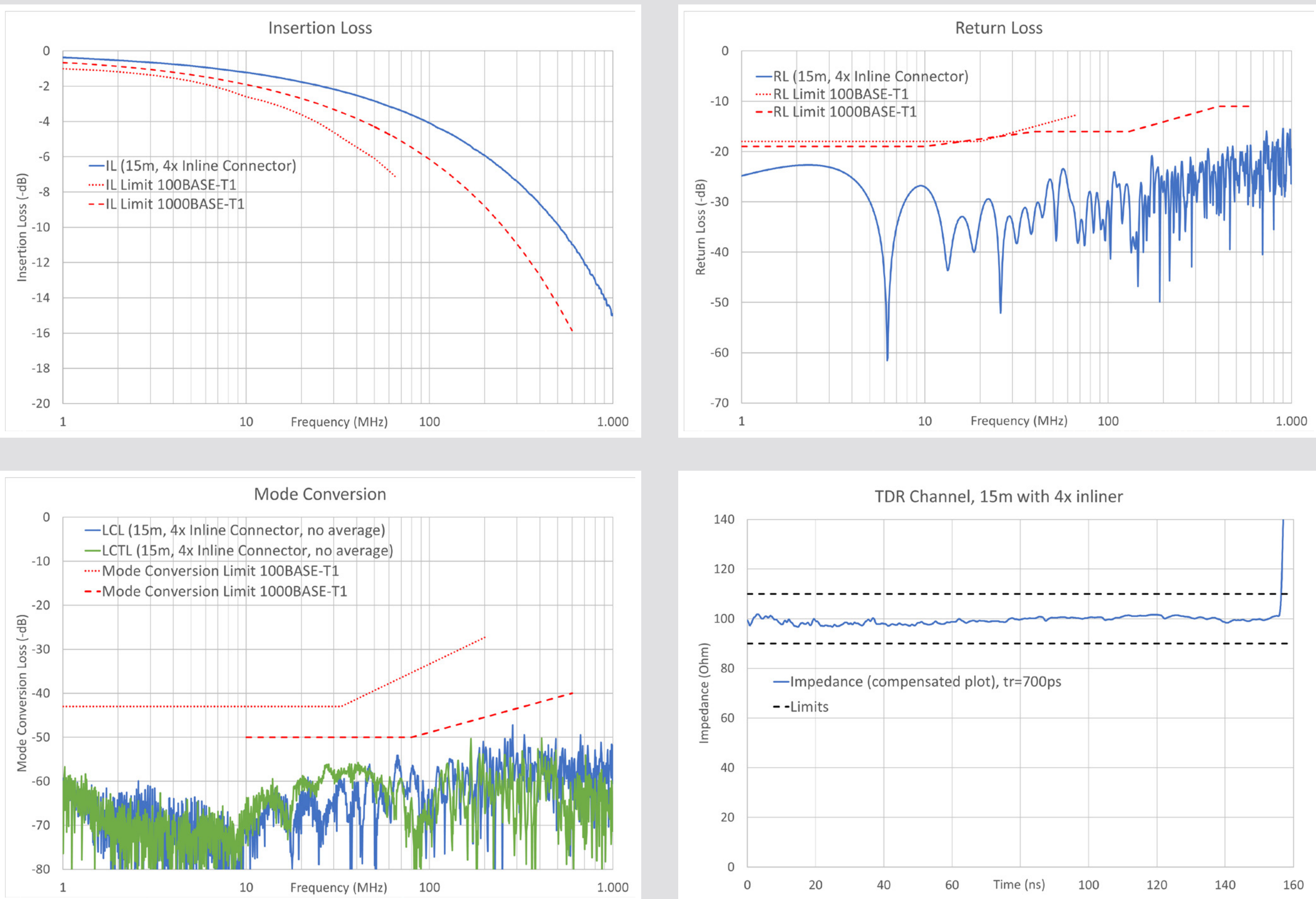


Fig. 2: 1000BASE-T1 (1 Gbps) link performance proven with 15 m of UTP wire with jacket and four inline MATEnet connectors

(NanoMQS terminals; for more details cf. chapter 5) and has successfully passed severe testing and validation at the TE Bensheim testing facility (near Frankfurt). During this testing phase MATEnet has not only demonstrated the 1 Gbps performance of 1000BASE-T1 specifications (Fig. 2) but has also demonstrated future potential for 5 Gbps (with alternative technologies).

MATEnet is a comprehensive end-to-end interconnection platform solution that offers many benefits: It is a modular and scalable system which uses a core module based on a standardized NanoMQS terminal/housing and can be used in different configurations like multiport or sealed/shielded applications. One particular benefit is MATEnet's capability to interconnect Twisted Pair (TP), Unshielded Twisted Pair (UTP) and Shielded Twisted Pair (STP) within one interconnection system.

MATEnet supports the trend of in-vehicle network links as a cost efficient solution for distributing networking architecture with mid-size data volumes and low latencies and can be used for ADAS sensors, 360° camera systems, telematics units (data traffic to the head unit), onboard diagnostics, infotainment applications in the dashboard and domain architecture applications.

The scope of TE Connectivity expertise that has gone into developing MATEnet spans connector design, Including worst case tolerance analysis along with cable definitions, in-depth signal integrity analysis with respective board level design and EMC, the needed processing development for cable termination and finally the system testing with TE's end customers. TE is also active in the Technical Committees for TC 2 (100 Mbps) and TC 9 (1 Gbps) and has harnessed its expertise stemming from the previous committee discussions.

The interconnection system is currently (2017) in its B sample phase. The SOP will be in 2018. All major chip makers have been provided with samples

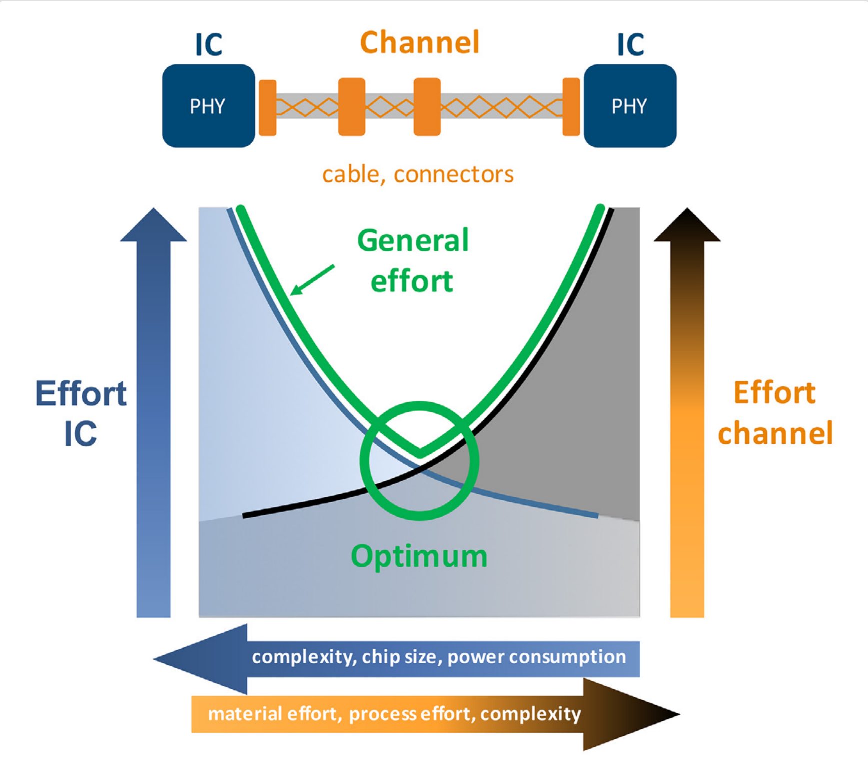


Fig. 3: MATEnet is designed to deliver the optimum cost balance between chip and channel efforts

4.1 | THE UNDERLYING APPROACH TO MATENET

High-frequency, high-bandwidth data transfer poses strict requirements to signal integrity. The effort and cost required to fulfill individual Automotive Ethernet application needs is typically a product of measures which are integrated in the chip and the effort that goes into the channel (cable and connectors). MATEnet was designed to offer an optimum balance between both cost curves (Fig. 3).

MATEnet delivers an excellent cost-performance ratio because it neither places a high burden on chip capabilities (size, power consumption) nor does it require high-end cabling (materials, processes, complexity). To offer this balance, TE Connectivity has specified suitable round cables together with a cable vendor.

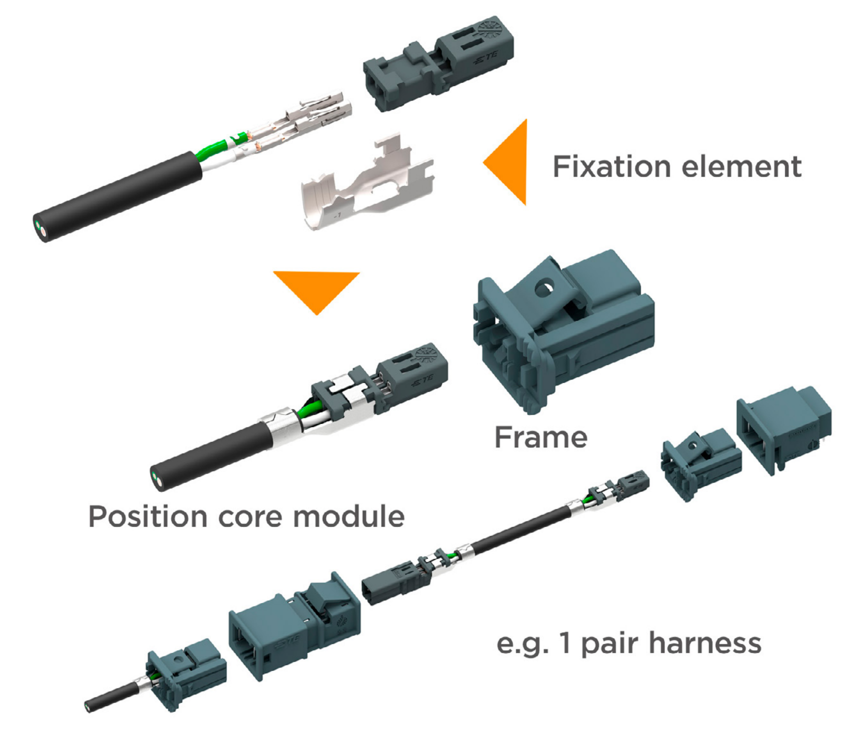


Fig. 4: A 2-position MATEnet interconnection shows the elements of the core module

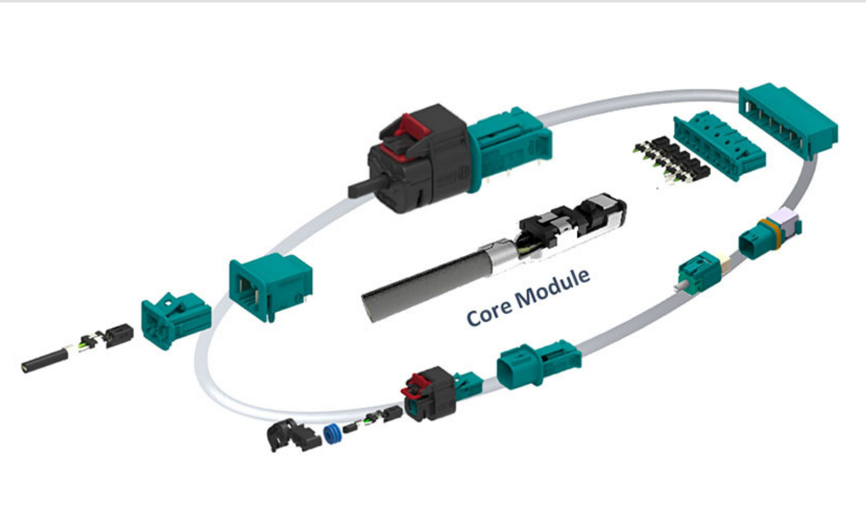


Fig. 5: Examples from the MATEnet modular interconnection system portfolio

4.2 | THE COMPONENT OF MATENET

Fig 4. shows the core design features of MATEnet. At the center of the interconnection system is the core module. It comprises the cable (TP, UTP, STP), the terminals (NanoMQS receptacle contacts), and the fixation element. Two NanoMQS contacts are crimped onto the two wires for termination. After that the metal fixation element is crimped onto the insulation and the 2 position module holding the NanoMQS terminals. This module gets inserted into the frame. The frame gets inserted into the connector/header.

The scalable approach (Fig. 5) makes it possible to combine any wire type (TP, UTP, STP) and shielding level within one layout. This approach was chosen to give the OEM a maximum of flexibility: Ideally Automotive Ethernet networking shall be done with simple and cost-efficient TP or UTP cable.

This can be done neither with upscaling nor with downscaling efforts. This enables high flexibility for TE's customers in regards to implementation strategies depending on the required EMC levels needed. From a cabling perspective and using MATEnet interconnection technology, all the OEM needs to do now is to replace the cable and the frame to use the higher shielding within the installed system. The header/connector on the ECU remains the same. On the other hand an OEM may start with STP cable but testing might reveal that UTP would meet the application requirements just as well. In that case the cable can simply be downgraded without any layout changes at the ECU interface because again, the only change required is using a different MATEnet frame and cable. The core module with the terminals and crimps always remains the same. MATEnet connectors support different wire gauges (from 0.13 mm² to 0.35 mm²), but 0.13 mm² is currently considered to be the most relevant.

Currently the MATEnet connector portfolio comprises 90° headers (wire-to-board) with 1, 2 or 5 port inline connectors and 180° headers – all in UTP and STP variations. Other versions of headers/frames will follow later as the portfolio is still under development and will be expanded according to market needs.

MATEnet products can be ordered either as an assembled cabling or as individual products. A fully automated termination and insertion process complete with tooling has also been developed and validated to meet the most exacting quality specifications.

4.3 | ROBUSTNESS AND CONTACT PHYSICS

MATEnet relies on the proven NanoMQS terminals, which are automotive-grade contacts, proven in vehicle applications. These miniaturized contacts offer a particularly high robustness against vibration (for more details see below in chapter 5). For the use in the MATEnet interconnection system TE has utilized this strength and extended it by keeping all mechanical loading away from the crimp through the fixation unit. Despite this robustness the rectangular NanoMQS contact is easily inserted into the frame thanks to lead-in chamfers and a self-centering, polarized design. With permissible ambient temperatures of between -40 °C and up to 105 °C the terminals can be used in a wide scope of automotive applications.

4.4 | SELECTED PERFORMANCE DATA

The selected performance data below are preliminary figures. Adjustments caused by different test results are possible. More details can be found in the MATEnet connector data sheet which is part of the TE test specification 108-94568.

MECHANICAL DATA

Mating force	
- 1 port (= 2 wires)	Max. 20 N
- Multiport (max. 6 ports)	Max. 75 N
Mating cycles	Min. 20
Retention force connector lock	
- 1 latch (1 & 2 port)	Min. 80 N
- 2 latches (> 2 ports)	Min. 100 N
Wire retention force @ 0.13 mm² CuMg / CuSn wire or 0.35 mm² Cu wire	Min 50 N each
Cable retention force with fixation element	Min. 80 N
Contact Overlap	
- signal	> 1.0 mm
- ground (STP)	> 0.7 mm

ELECTRICAL DATA

Contact resistance before aging	
- signal	Max. 10 mOhm
- ground (STP)	Max. 40 mOhm
Contact resistance after aging	
- signal	Max. 40 mOhm
- ground (STP)	Max. 100 mOhm
Operating voltage	Max. 60 VDC
Current capability @ 80 °C (depending on cable size and loading)	Max. 3 A

ENVIRONMENTAL DATA

Mechanical shock	
- unsealed	DIN IEC 60068-2-27 Class 1
- sealed	DIN IEC 60068-2-27 Class 2
Vibration	
- unsealed	DIN IEC 60068-2-64 Class 1
- sealed	DIN IEC 60068-2-64 Class 2
Thermal shock passed	
DIN IEC 60068-2-14	-40° C - +105° C
Dry Heat (Sn)	+105° C

MATERIALS

Signal contact NanoMQS	Cu alloy
Ground contact (STP)	Cu alloy or ST
Seals	Silicone
Housings and locks	PA, PBT

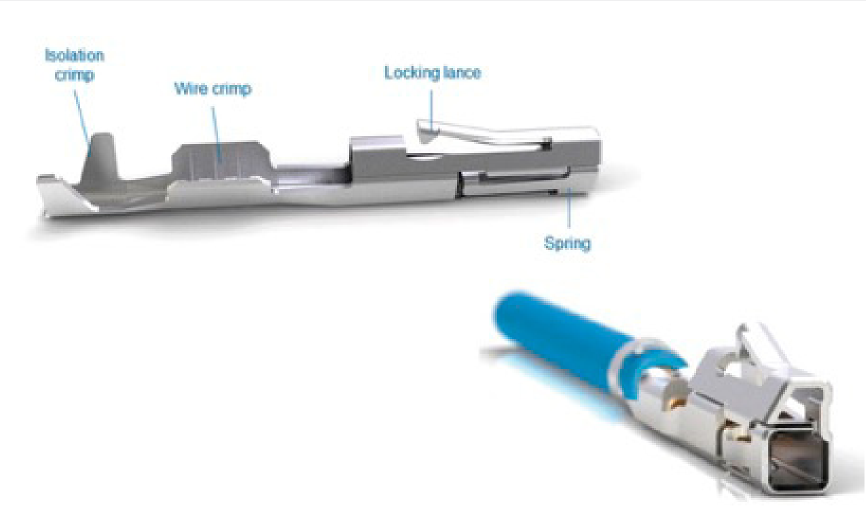


Fig. 6: The NanoMQS receptacle contact mates with 0.5 x 0.4 mm tabs

5 | THE NANOMQS TERMINAL

NanoMQS interconnection technology was developed for motor vehicle connectors. The core of the technology is the receptacle contact (or terminal). The miniaturized NanoMQS receptacle contacts are designed for a 1.8 millimeter nominal pitch, (Fig. 6). They can be used to terminate very fine wires with cross sections as small as 0.13 mm^2. Multiple design features ensure that the interconnection system can be handled safely in a fully automated process despite small wire cross sections and compact crimp terminals. NanoMQS connectors are very robust, as standard unsealed NanoMQS connectors meet severity level 2 vibration requirements (around 3g effective random and 30g shock). Sealed connector versions can also meet vibration level 3 (“close to powertrain”) and 4 (“engine mounting”).

6 | FUTURE POTENTIAL

— PoDL —

Currently electronic devices in the car are supplied with electricity over separate cables. However, the additional cables make the harness heavier and more complex and make it more difficult to feed parts of the harness through narrow passageways in the vehicle body. It would therefore be a contribution to downsizing and light-weighting of the harness, if separate power lines were not necessary. The new concept of Power-over-Data-Line (PoDL) supports this strategy in vehicle applications. It uses the 100Base-T1 und 1000Base-T1 interfaces to supply power parallel to the signal on a single unshielded twisted pair. The standard for PoDL was defined by the IEEE Task Force 802.3bu. Its work was completed with the approval of IEEE Std 802.3bu-2016 by the IEEE-SA Standards Board on 7 December 2016.

By using an additional filter circuit signal and power can be transmitted with minimal interferences via 1 wire pair and can be separated at the device. TE is testing PoDL in combination with MATEnet and will validate this option within the MATEnet interconnection system. Testing so far has been very positive and indicates a beneficial use with up to 48 VDC.

— Automotive Audio Bus® —

TE also sees potential for MATEnet as interconnection technology for the Automotive Audio Bus® (A2B), developed by Analog Devices. This digital audio bus with up to 50 Mbit bandwidth was designed to reduce the weight of high fidelity wiring for automobiles while significantly reducing the weight of existing cable harnesses.

One application area are multiple microphone arrays in vehicles to enable different applications such as voice recognition, active noise cancellation, and in-car communications. In contrast to conventional expensive and heavy high fidelity cabling, the AD242x family of enhanced A2B transceivers works with low cost twisted-pair wire and connects devices in a daisy chain master-slave topography. Like PoDL, A2B can also supply power to other devices in the daisy chain. TE has begun to investigate the potential of MATEnet technology for A2B applications.

— HDBASET —

HDBASET is an emerging technology, providing up to 6Gbps full duplex data transmission through a 15 m link segment with up to 4 inline connectors at near zero latency. It includes various protocols like Audio / Video, Ethernet, Power and consumer applications like USB and HDMI. TE has an active part in the HDBASET Alliance, where automotive stakeholders collaborate in various technical committees to define appropriate automotive requirements and specifications. Native Networking Capabilities demonstrates the usability of unshielded twisted pair cabling, which can be compared to 100 / 1000 BASET1 applications. Addressing multiple challenges, HDBASET with its unprecedented bandwidth and suitability for existing UTP cabling systems like TE's MATEnet is a key enabler for future in-vehicle connectivity.

7 | SUMMARY AND OUTLOOK

Digitization and connectivity are sweeping across the automotive industry because they are the enablers of every individual mobility mega trend: Integrating the car into the Internet of Everything, increasing vehicle efficiency, powertrain electrification and intelligent (predictive) hybrid operating strategies, establishing intelligent traffic solutions, and facilitating automated driving. Many new functions are based on networking individual functions/systems, on re-using sensor signals and on communicating with a backend (services) via the cloud and making vehicles part of a swarm intelligence. High-bandwidth, high-frequency data transmission will be a key enabler of connectivity. Automotive Ethernet offers the best cost-benefit ratio.

MATEnet offers the robustness, reliability, affordability, fully automated handling, quality level, miniaturization, light-weighting, flexibility, and scalability to support car connectivity via Automotive Ethernet. MATEnet components are manufactured in TE plants which operate according to extremely high manufacturing standards to ensure uncompromising product quality.

8 | GLOSSARY OF TERMS

A2B = Automotive Audio Bus® (Analog Devices)
ADAS = Advanced Driver Assistant Systems
BEV = Battery Electric Vehicle
ECU = Electronic Control Unit
EMC = Electromagnetic Compatibility
EMI = Electromagnetic Interference
Gbps = Gigabit per second
IoE = Internet of Everything
LiDAR = Light Detection And Ranging (Laser)
Mbps = Megabit per second
OEM = Original Equipment Manufacturer (= car maker)
PA = Polyamide
PBT = Polybutylene Terephthalate
PoDL = Power over Data Line
SOTA = Software Over-The-Air
STP = Shielded Twisted Pair
TP = Twisted Pair
UTP = Unshielded Twisted Pair
V2X = Vehicle-to-Anything (connectivity)

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ABOUT TE CONNECTIVITY

TE Connectivity (NYSE: TEL) is a $12 billion global technology leader. Our commitment to innovation enables advancements in transportation, industrial applications, medical technology, energy, data communications, and the home. TE's unmatched breadth of connectivity and sensor solutions, proven in the harshest of environments, helps build a safer, greener, smarter and more connected world. With 75,000 people – including more than 7,000 engineers – working alongside customers in nearly 150 countries, we help ensure that EVERY CONNECTION COUNTS – www.TE.com

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