MINIATURIZED AUTOMOTIVE COAX TERMINALS

MATE-AX is an automotive-grade RF interconnection solution for 9 GHz and above in multiple pin count applications

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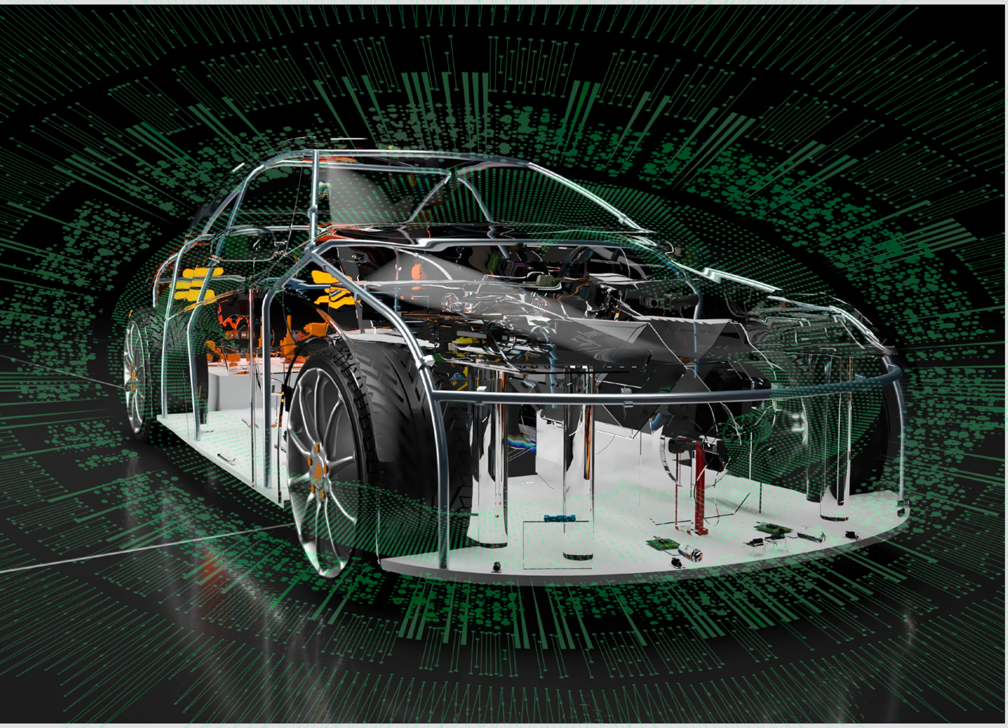

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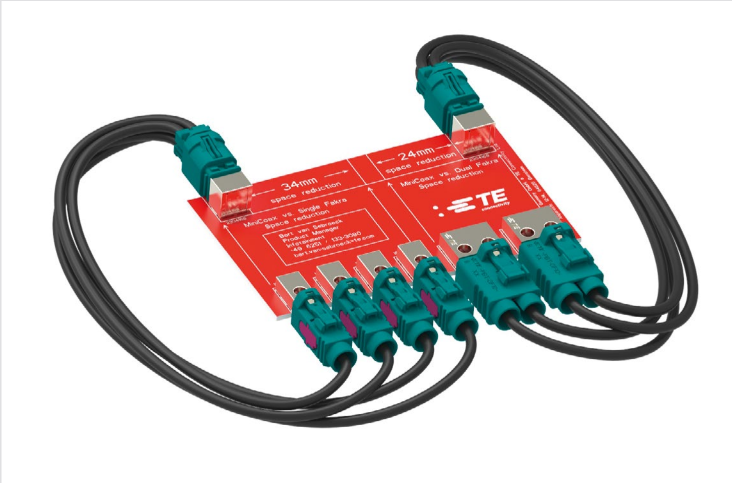
ABSTRACT

As the global automotive industry progresses towards safer, greener and more comfortable driving, connections throughout a vehicle increase and connectivity becomes ever more important. Both the number of interconnections in the car increase, and the volume of transmitted data increases. High radio frequency (RF)/high-bandwidth connections are required.

MATE-AX miniaturized coaxial terminal provides the industry 9 GHz immediate RF performance and capability up to 20 GHz in much smaller, lighter layouts. A 4-terminal-MATE-AX connector is 75 percent smaller and 34 percent lighter than a 4-terminal FAKRA connector.

TE Connectivity's (TE's) new MATE-AX interconnection system is a genuine automotive-grade design offering reliability plus affordability with the manufacturing process advantage of full automation. Because the design is compatible with existing RTK031 and RG174 types, MATE-AX is easy to integrate with existing wiring architectures.



A four terminal MATE-AX connector is one quarter the size of a four terminal FAKRA connector.

1 | CAR CONNECTIVITY AND ADAS

The evolutionary and revolutionary progress of automobile technology can be summarized by three global mega trends: connectivity, autonomous driving and electrification. However, connectivity is an essential part of all three trends 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.

Following "add-on" smartphone integration, the next step – which is sweeping through the automotive industry already – is to use smartphone apps to provide useful functions to the driver. For instance, to find a parking space 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 a highly networked mobile device (Fig. 1). The rationale behind this trend goes far beyond entertainment. In a car which is capable of autonomous driving, connectivity is necessary to extend the vehicle horizon. In order to increase the level of driving safety an autonomous car needs the best possible information database for predictive planning. The autonomous driving control unit factors in current traffic and road conditions, adverse weather, temperature, temporary speed limits and more. Based on real-time data collected from within the vehicle, and, via antennas, outside the vehicle, it can plan an optimum route, speed, trajectory and energy use.

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 are progressively developing into autonomous driving functions, base their support of the driver or vehicle activity on an increasingly detailed environmental model of the traffic situation ahead. This kind of model is the result of sensor fusion (camera, radar, LiDAR) delivering a list of objects, applicable rules and limitations and accessible trajectories. The entry point for external data is the antenna module, acting as a gateway to the network that distributes data in the vehicle.

Because the data that is relevant for this comes from a growing list of sources, former boundaries between domains and functional levels (e.g. safety, infotainment and comfort systems) begin to blur. Everything in the vehicle and beyond it is becoming connected.

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]

RF performance requirements are growing and the number of coax lines will increase to meet this demand.

Fig. 1: Levels of automotive data connectivity

This is particularly true in situations where OEMs begin to concentrate the vehicle computing power in fewer but more capable computers with higher speed I/O, and those computers need to interpret raw sensor data including that coming from mono and stereo cameras.

ADAS development and autonomous driving clearly will require a higher number of RF-capable data lines but at the same time the space for the interface is no larger, and may even be smaller. In the near future, smaller, lighter and even higher performing coax interconnection systems will be needed. Currently, the coax cable defines the possible bandwidth with a frequency range specification of up to 6 GHz. A future-proof coax interconnection system solution would offer even higher RF performance, to avoid needing to adapt once higher performing cables come into use. Once the applications are there, higher performing cables for automotive use can certainly be developed more quickly.

The McKinsey figures illustrate the fact that the car already is probably one of the most underrated computing systems of our time. And it is becoming more complex. Networking and connectivity are moving to the center of attention because consumers want, and OEMs want to provide the raft of possible new functions and services. 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. Every modern car is already a rolling network of computers, so the bottom line is the car has entered into the new age of software and connectivity. There is a whole new value chain forming around this fact for the global automotive industry.

2 | MEETING EVOLVING RF REQUIREMENTS

– Bandwidth –

At the very core of in-vehicle networking and connectivity is the physical layer of networking – the inter- connection system. Existing vehicle bus standards such as CAN, LIN, FlexRay, and MOST were the response to specific requirements and the need to find a balance between cost and performance for each networking application. Once GHz frequencies are required, coax lines provide a cost-efficient solution for truly high-performing RF-transmission. Applications like high-resolution serial data transmission using a Serializer/Deserializer (SerDes) and emerging standards and protocols like GMSL2, FPD-Link III and IV, APIX3, V2X, 5G are key examples of higher bandwidth drivers.

– Scalability -

Coax cables with their inner conductor and outer tubular conducting shield (sharing one geometric axis) are a well-proven backbone for automotive RF-transmission. Used with automotive-grade interconnection solutions such as FAKRA connectors (developed from the underlying SMB connectors), coax cables provide an economic and easy to handle physical layer for RF-signal transmission. To be future-proof, cables and connectors need to move forward in sync. Existing coax automotive connectors may not offer enough RF-performance for the future, and they require too much space. Any future solutions need to eliminate current RF-limitations, and reduce the connector size and weight without making handling more difficult. For that reason, the complete end-to-end solution should have connector, coax cable, and coax wire-to-board header components that can scale up to higher performance. If even one part of the system, for instance the connector, is not able to accommodate future performance standards, the whole system is less usable, and thus, less valuable.

A higher performing connector is an important element of a coax interconnection solution that supports higher performance levels throughout all components. By shifting to higher performing 9 GHz connectors now, existing 6 GHz cables can still be used and the transition to future cables greater than 6 GHz will be very smooth. This requirement poses quite some challenges to connector and terminal design and manufacturing, because higher RF-performance regularly means greater precision and smaller tolerances.

– Automotive-grade Robustness –

Unlike high RF applications in consumer electronics, genuine automotive-grade interconnection is not a "normal" environment for coax networking and data traffic: vibration, impact, heat, cold, dampness, aggressive fluids, and voltage fluctuations in the on-board electrical infrastructure pose tough challenges to managing data flows. Automotive component designers and engineers must include features like scope-proof Kushiri, anti-stubbing, protected contact beams, mechanical stability of terminals, and terminals fully protected by their housing.

Section 7 provides some important insights into another vital automotive application challenge: robust connector handling during assembly.

Despite the robustness requirements, the cabling harness must be easily installed in a volume manufacturing environment. In other words, connectivity is the key to the future of mobility, but vehicle networks require very specific solutions to get there.

3 | DATA AND CONNECTIVITY IN THE VALUE CHAIN

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. Much of this data will originate within the vehicle, for instance from ADAS sensors and ECUs. This growing data traffic will require high bandwidth RF-transmission via coax cables.

To handle this present and future scale of data, in-vehicle networks need to be fast and high bandwidth. And, they need to be reliable, robust, affordable, and easy to install. Considering the importance of data flows in the car, an interconnection technology that meets this list of requirements is a true enabler and will be integral to new value chain.

4 | MATE-AX: MINIATURIZED AUTOMOTIVE TERMINAL FOR COAX

When TE Connectivity started designing the MATE-AX interconnection system in early 2015, the development challenge was to quadruple the number of coax cables that can be terminated as compared to a FAKRA connector, and to double the amount of lines in comparison to a HSD (High Speed Data differential signaling) connector.

ADAS control units may have as many as 24 coax inputs coming from a multitude of environment sensors required to detect objects and free spaces around the vehicle. Given the high level of ECU miniaturization and functional integration, existing RF-coax interconnection technology could have led to a situation where the electrical interface dictated the level of ECU compactness. Clearly, this was unacceptable.

To overcome this evolving challenge the new miniaturized MATE-AX interconnection system offers a high number of coax positions at an increased level of frequency range performance. To make the system future-proof, the first generation of products was successfully tested with up to 9 GHz of frequency.

Considering that coax applications, includingRTK031 and RG174 cables are currently specified for up to 6 GHz, MATE-AX technology provides a true long-term solution that has the potential for future upgrading without changing the interface (Fig. 2).

Continuing development and design work will further increase the MATE-AX RF-performance with an ultimate target of reaching 20 GHz in individual applications through detail optimization and even higher precision and smaller tolerances. The initial product offering will consist of an unsealed 4-position 90 degree header, and 4-position 180 degree inline connectors. However, the product portfolio will be developed in accordance with customer and application needs. Sealed connector versions and connector position assurance (CPA) features figure prominently.

The list of natural vehicle applications includes antenna con nections, ADAS cameras, cluster instrument connections, digital tuner video/audio connections, display connections, rear seat entertainment, telematics control units, and head-up displays.

Fig. 2: MATE-AX initial product offering: 90° header, 180° inline connector, and 180° plug connector (from left to right)

Acceptance criteria met by 180° MATE-AX connections

Mechanical data	
Mating force Single port Multiport (4 pos.)	 Max. 30 N Max. 75 N
Mating cycles	Min. 10
Retention force connector lock	Min. 120 N
Retention force Primary lock Primary & secondary lock	 Min. 50 N Min. 110 N
Cable retention force Inner conductor	Min. 50 N
Coding efficiency	Min. 130 N

Electrical data	
Resistance of a mated contact pair (180°) Outer conductor Center conductor	(before / after exposure) Max. 7.5 mΩ / max. 40 mΩ Max. 15 mΩ / max. 40 mΩ
Isolation resistance	Min. 100 MΩ
Operating voltage	Max. 60 VDC
Current capability @ 80° C	Max. 3 A (N.909.934)

Environmental data	
Mechanical shock unsealed	VW 75174 severity level 1
Vibration unsealed	VW 75174 severity level 1 DIN
Thermal shock passed DIN IEC 60068-2-14	-40° C – +105° C
Temperature resistance	VW 75174

Signal propagation	
Impedance of mated a connector	50 ± 10 Ω (trise = 35 ps)
Insertion loss of a mated 180° connection 0.03 GHz < f ≤ 1 GHz 1 GHz < f ≤ 2.5 GHz 2.5 GHz < f ≤ 4 GHz 4 GHz < f ≤ 5.5 GHz 5.5 GHz < f ≤ 7 GHz 7 GHz < f ≤ 8.5 GHz 8.5 GHz < f ≤ 9 GHz	 ≤ 0.15 dB ≤ 0.25 dB ≤ 0.35 dB ≤ 0.45 dB ≤ 0.55 dB ≤ 0.65 dB ≤ 0.75 dB
Return loss of a mated 180° connection 0.08 GHz < f ≤ 6 GHz 6 GHz < f ≤ 9 GHz	 ≥ 20 dB ≥ 15 dB

Materials	
Outer contact plating	SNSn
Center contact plating	Ag
Housings	PBT-GF20

Table 1 (left) lists selected acceptance criteria which are met by 180° MATE-AX connections.

5 RECEPTACLE AND PIN TERMINAL SUB COMPONENTS

The MATE-AX connector system is the result of detailed optimization work that includes manifold precision tuning plus design changes compared to FAKRA connector technology. The new MATE-AX receptacle terminal (socket/female) and pin terminal

Fig. 3: MATE-AX terminal design

(male) fit on existing RTK031 and RG174 coaxial cables. Fig. 3 shows the new terminals in the on-reel delivery state.

Both the receptacle and pin terminal subassembly consist of a center contact (Ag-plated in the contact area) with five serrations on the crimp sleeves, crimped onto the inner conductor of the coax cable.

The terminated center contact gets inserted into the Sn-plated outer terminal and the ferrule which are then crimped onto the outer tubular conducting shield and the dielectric (= round

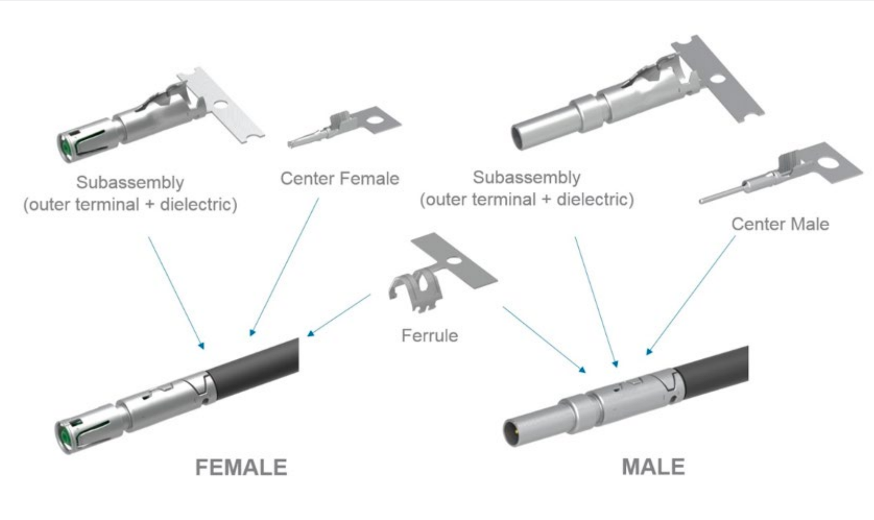


Fig. 4: MATE-AX terminal subassemblies

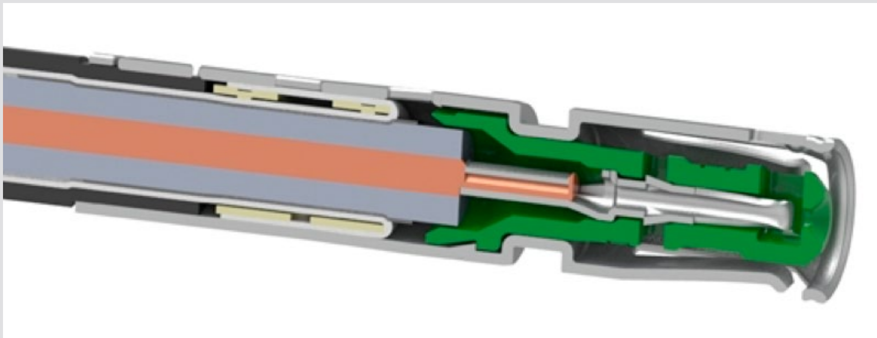


Fig. 5: Cut-away of the MATE-AX RTK031 crimped receptacle terminal and cable

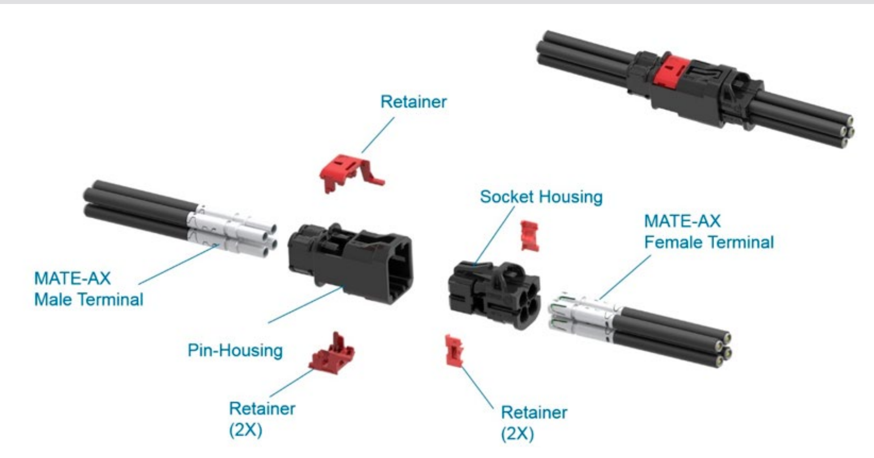


Fig. 6: Exploded view of a 4-position unsealed MATE-AX connector and its sub components

O-crimp) (Fig. 4). The 180° terminals are the same for the unsealed and sealed connector versions. The 180° terminal design is the same for the 90° terminals, to support customer design integration.

Among the main quality features of the receptacle terminal is the welded contact box which provides high robustness, the reduced stubbing potential that is owed to carefully designed chamfers to lead in the pin contact into the female terminal, and a design with the dielectric covering the conductor crimp of the inner terminal to provide short circuit protection (Fig. 5).

During the assembly of the connector, the terminal is fully inserted into the housing cavity which adds to the overstress protection level as lateral forces that could cause deflection are better absorbed by the cavity walls. Side pull of over 75 N (applied to the cable in all directions) has been successfully tested. Together with cavity lead- ins the terminal design supports smooth insertion during connector mating.

The terminal box diameter (female and male) is the same for the RTK 031 and RG 174 versions (3.6 mm ±0.03 mm). However, the crimp diameter of the RG 174 version is reduced in accordance with the RG174 cable. The backend diameter of the RG 174 version is the same as that of the RTK031 version to confirm the optimum fit in the connector cavity.

6 | HOUSINGS AND HEADER

The new MATE-AX terminals are either inserted into the newly developed and miniaturized conductor or they get inserted into the new wire-to-board 90° header made from zinc die-cast with an attached PBT-GF20 plastic housing.

Fig. 6 shows an example of an unsealed 4-position 180° inline interconnection. The pin housing that envelopes the socket housing measures 26 x 11.9 x 14.4 mm (L x W x H). The fully engaged complete connection measures 35.4 x 12 x 14.5 mm, as shown in Fig. 7.

To confirm correct connector mating during harness/vehicle assembly the housings offer 6 polarization codings plus 1 neutral key and two of the coding ribs are always corresponding. A high force of at least 130 N makes this keying very effective.

Coaxial wire-to-board connections are established with the MATE-AX 90° header. Fig. 8 shows the 4-position header version. Its four pins are inserted in the PCB and connected by reflow soldering or selective soldering. Each channel of the header is fully shielded.

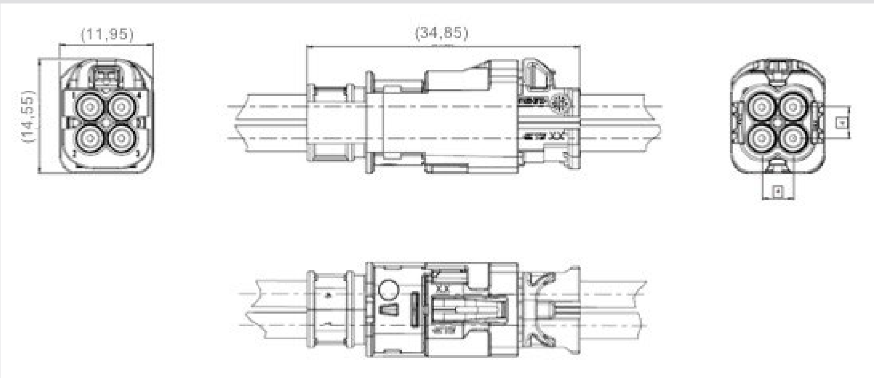


Fig 7: 4-position 180° inline interconnection pin housing and dimensions

Fig. 8: MATE-AX 4-position 90° header

7 | PRECISION DESIGN AND MANUFACTURING: WORST-CASE COVERED

RF range interconnection optimization always includes precision tuning and adding design details which provide the required RF-range even under worst case conditions in the field.

The level of detail of the MATE-AX engineering becomes clearer when going through a worst case of mating two connector components with offset terminals. In contrast to FAKRA connectors, MATE-AX connector alignment is confirmed first by the housing design and then with staggered terminals – and not via the terminal alone.

Precisely dimensioned lead-in chamfers on all relevant mating components confirm that even under worst case assumptions the mating process is a defined sequence of individual adjustment and lead-in steps that fits the required mechanical tolerances and guiding for each step. This precision-tuned design is complemented by precision manufacturing based on decades of metal stamping, injection molding and die-cast manufacturing know-how with the highest levels of process control.

8 | SUMMARY AND OUTLOOK

One can hardly overemphasize how important precision engineering and design optimization is for high RF-performance. The new MATE-AX coaxial interconnection system follows this maxim to the smallest level of detail to achieve a comprehensive RF-performance of 9 GHz throughout each system component and the whole system.

With this performance, the interconnection is ready for the expected increase in cable performance beyond the 6 GHz level of today (2017). The initial product portfolio of 180° components will be expanded and further options, such as CPA, 90° versions, and sealed versions, will be added in line with market demand.

MATE-AX provides an EMI resistant and miniaturized interconnection solution for existing and future coax lines. The excellent signal integrity and the long-term potential for up to 20 GHz gives the industry a solid digital signaling roadmap.

The MATE-AX connector system takes automotive coaxial technology to the next level of performance and facilitates transmission of large uncompressed data between signal sources and ECU "servers." By offering a higher packaging density (4 coax cables in the space of 1 FAKRA connectors; 2 coax cables in the space of 1 HSD connection), MATE-AX terminals support significant size and weight reductions, which in turn contributes to higher fuel efficiency.

GLOSSARY OF TERMS

ADAS	=	Advanced Driver Assistant Systems
BEV	=	Battery Electric Vehicle
CPA	=	Connector Position Assurance
ECU	=	Electronic Control Unit
EMI	=	ElectroMagnetic Interference
FAKRA	=	Fachkreis Automobil (German supplier group) GF
20	=	(Short) Filled with 20% of short glass fibers
IoE	=	Internet of Everything
LiDAR	=	Light Detection and Ranging (Laser)
OEM	=	Original Equipment Manufacturer (= car maker)
PBT	=	Polybutylene Terephthalate
RF	=	Radio Frequency

REFERENCES

[1] McKinsey & Company: Connected car, automotive value chain unbound. September 2014, page 11 retrieved from: https://www.mckinsey.de/files/mck_connected_car_report.pdf

[2] Bennett, Jeff; Spector, Mike. (2016, January 5).
The Wall Street Journal. US Car Sales Sets Record High

ABOUT TE CONNECTIVITY

TE Connectivity (TE) Ltd. (NYSE: TEL) is a $13 billion global technology and manufacturing leader creating a safer, sustainable, productive, and connected future.

For more than 75 years, our connectivity and sensor solutions, proven in the harshest environments, have enabled advancements in transportation, industrial applications, medical technology, energy, data communications, and the home.

With 78,000 employees, including more than 7,000 engineers, working alongside customers in nearly 150 countries, TE ensures that EVERY CONNECTION COUNTS. Learn more at www.te.com and on LinkedIn, Facebook, WeChat and Twitter.

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