INTEGRATED ANTENNA SYSTEMS FOR CONNECTED VEHICLES

TE Automotive Wireless
HIRSCHMANN MOBILITY

"Connectivity" – one of the key words that customers look for when buying a new car. Everything is connected nowadays: Our phones, our watches, our cars. The underlying technology to enable wireless connectivity is Radio Frequency Technology, and the necessary piece of equipment is the antenna. As we see more and more services available in our cars, the more antennas have to be placed into our vehicles.

This has become a challenging task for automotive engineers. For many years, there was only one antenna in every car: A classic rod antenna for the reception of AM and FM radio. In modern cars we are now seeing almost 20 antennas. It is clear that the conventional approach of placing antennas into vehicles is outdated. New ways and possible architectures are discussed in the following.

1. Overview of Antennas in Vehicles

1.1 Evolution of vehicle antennas

Almost immediately after the invention of the automobile, the reception of broadcast radio became a standard feature in any vehicle sold worldwide. A radio connection on-board connected the driver and passengers to the outside world, bringing all sorts of entertainment, e.g. music, while also ensuring the availability of critical information, such as traffic reports, emergency warnings, and breaking news. The novel challenge was to enable RF (radio frequency) reception in a moving system vs. a stationary one. All necessary components for enabling radio reception, i.e. antennas, amplifiers, and electronics, needed to be appropriately packaged into the automobile. That was – and still is – not an easy task in the face of EMC (electromagnetic compatibility) and susceptibility issues in the harsh automotive environment.

Moving into the year 2022, we witness a steady increase of radio standards in our daily life (see figure 1 for the development of RF services). Most of them have also found their way into our vehicles. Today, everything is connected. Especially in cars.

New applications such as V2X (Vehicle to everything), ADAS (Advanced Driver Assistance Systems), FOTA (Firmware Over the Air), diagnostics, realtime maps etc. require a larger dataflow in and out of the vehicle. As a result, amount and variety of antennas have increased tremendously. Different frequency ranges and radiation pattern requirements drive the evolution of more antenna variants. Differing radio standards and higher bandwidth demands require more on-board antennas. Often, the MIMO (Multiple-Input Multiple-Output) principle is applied to enhance data throughput. In MIMO systems, several antennas are used at the same time to ensure maximum signal transmission and reception.

For optimal performance of an antenna system, location and surrounding conditions are critical. With more and more antennas being integrated into vehicles, finding suitable packaging and location solutions is becoming ever more of a challenge.

At TE Connectivity Automotive Wireless (formerly Hirschmann Car Communication), we have been developing automotive antenna systems for over 90 years. We build on a strong expertise on how architectures have evolved and will continue to evolve. In this white paper, we provide an overview of new antenna and architecture concepts to guide engineers as they develop the next generation of vehicle systems.

1.2 State-of-the-art antenna systems

First of all, the commercial antenna systems are shown below:

Broadcast

Antenna systems for terrestrial broadcast enable the reception of both analog/digital radio and TV standards. While TV remains a niche market, radio reception is a standard feature in almost any vehicle. Classical analog standards like AM/FM are being augmented with digital standards, such as DAB, HD Radio and DVB-T/DVB-T2. For many years, broadcast antenna systems were the only antenna type used in automobiles.

There are three basic ways for implementing terrestrial broadcast antennas into a vehicle.

Rod antenna
In this construction, the antenna is a visible element on the outside of the car. In the early times, fairly long rod antennas (~80 cm) were mounted onto the front fender. Today, rod antennas are much shorter (~30 cm) and usually mounted on the roof.

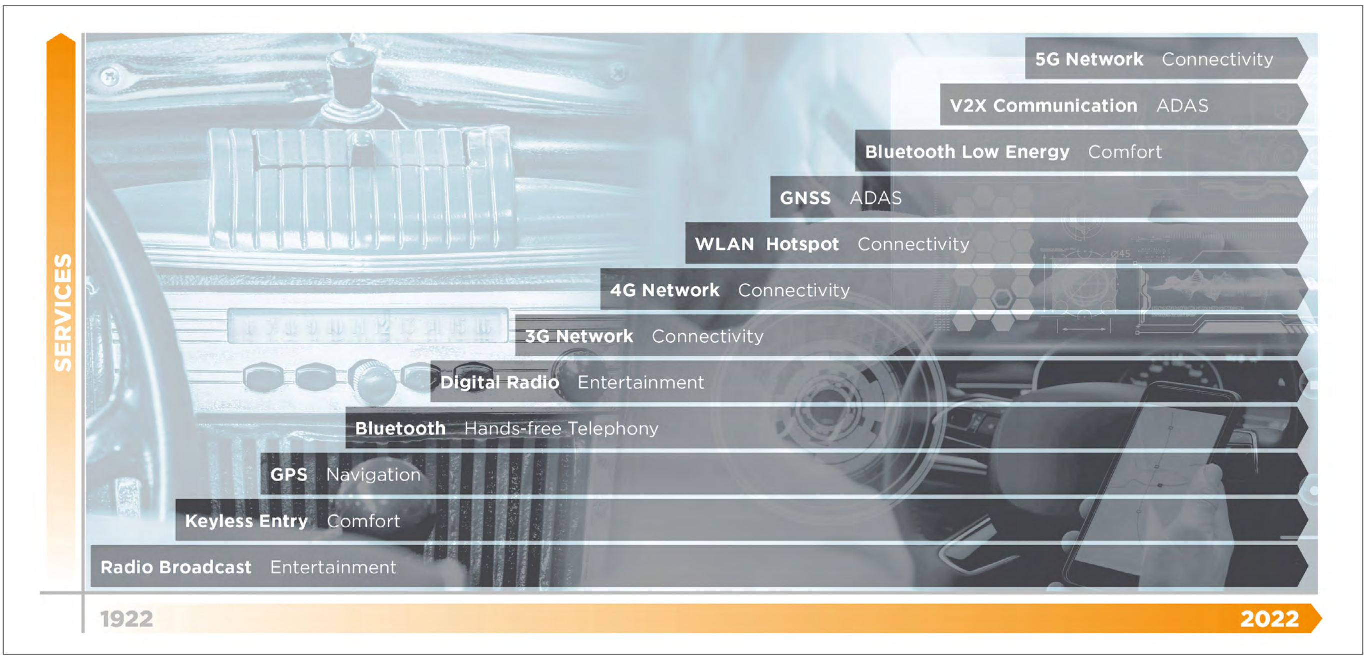

Figure 1: Increase of RF-services within vehicles

Screen antenna
Screen antennas are metallic structures integrated into the surface of the rear screen. In some cases, the heating grid is used as part of the antenna. This makes screen antennas "invisible", which is why they are sometimes called integrated systems.

Film antenna
In film antennas, the antenna structure is part of a plastic film, which is attached to non-conductive parts of the car. Film antennas can be found in side mirrors or on fenders.

For broadcasting via satellites, a specific type of antenna is required:

Patch antenna
Patch antennas are exclusively used for Satellite Digital Audio Radio Services (SDARS) in a broadcast context. SDARS is a satellite-based system, therefore patch antennas must be placed so that they have an unobstructed view of the sky, typically on the car roof.

Communication

This field covers everything outside of broadcast, with a variety of services: Telematics via cell network, WIFI®, Bluetooth®, RKE (Remote Keyless Entry), UWB (Ultra-Wide Band) and V2X (Vehicle to Everything). The differentiation is: Any bi-directional data flow is communication, any one-way, reception-only data flow is broadcast. Of course, there is no rule without exception. Although GNSS (Global Navigation Satellite System) is a reception-only service, it is usually considered part of communication.

In the early 2000s, when cellular communication became a worldwide mass phenomenon, cellular technology (2G to 5G) and other communication technologies also found their way into automobiles. The strong variety of antennas and services in this field makes it challenging to generalize the mounting environment.

One popular concept adopted by many car manufacturers, especially for cellular and satellite antennas, is the roof top antenna. The roof constitutes the highest point in any vehicle and is therefore the obvious preferred location for antennas. Roof top antennas are available with and without short rod. Antennas without short rod are called "shark fin" antennas, since they resemble the fin of a shark cutting through the water surface.

Other types of antennas can be installed in several locations in the vehicle: dashboard (IP), center console, bumper area,

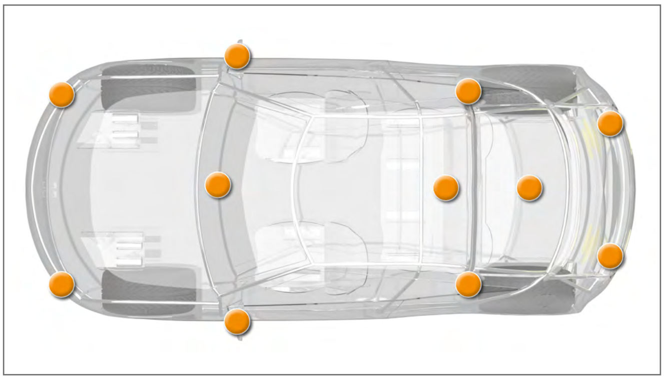

Figure 2: Typical antenna locations in a state-of-the-art antenna system

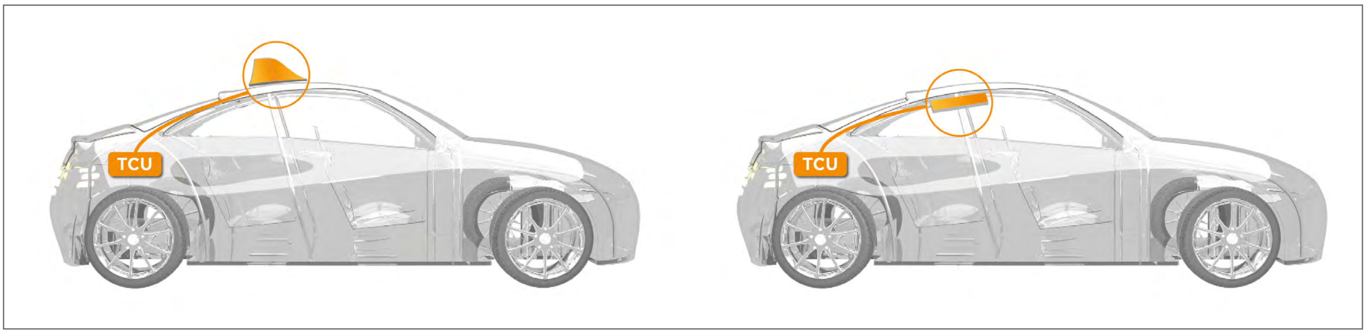

Figure 3: Mounting of shark fin antenna and antenna farm

or side mirror (see figure 2). Usually, these antennas are not visible from the outside.

The roof top antenna is a central element in today's antenna landscape. From a technical point of view the roof is the ideal antenna location. However, economic and technical constraints involved in combining a wide variety of services into one antenna system may call for finding other locations and construction solutions:

- Design – A roof top antenna is very visible; therefore, its design is important. For esthetic purposes and fuel efficiency purposes, roof top antennas should be kept as small as possible. However, as more and more antennas must be packaged into the vehicle, antenna size can become a conflicting issue in the design of new automobiles.
- Damage – Due to their exposed position, roof top antennas may be easily damaged or vandalized.

2. Integrated antenna systems – a new approach to antennas

Today, there is a broad mix of single-function and multi-function antennas (mostly shark-fin and rooftop) distributed across the vehicle. The increasing number of antennas, plus the corresponding coax wiring, pose new challenges. As a consequence, car manufacturers are rethinking the way how to implement antenna systems into vehicles.

Their objectives are:

- reduced design impact – i.e. the antenna should not be visible from the outside
- better signal quality – by reducing the distances between antennas and TCU (Telematic Control Unit)
- reduced wiring effort and less cost – by combining several antennas into one housing

Among the many options how to design integrated antenna systems to meet all these requirements, two design types are prevalent:

The first design approach separates the antennas from the telematics control unit (TCU) by an analog RF interface (coaxial lines). The second design approach integrates the TCU with the antennas and features a digital interface to the vehicle's wiring harness.

2.1 Separating antennas and TCU

A classic example for a separated system is a shark fin antenna, connected by coaxial cables to a TCU located in the trunk area. This arrangement is used in vehicles featuring several connectivity functions. It offers a high degree of flexibility, good performance, and is relatively easy to implement cross carline.

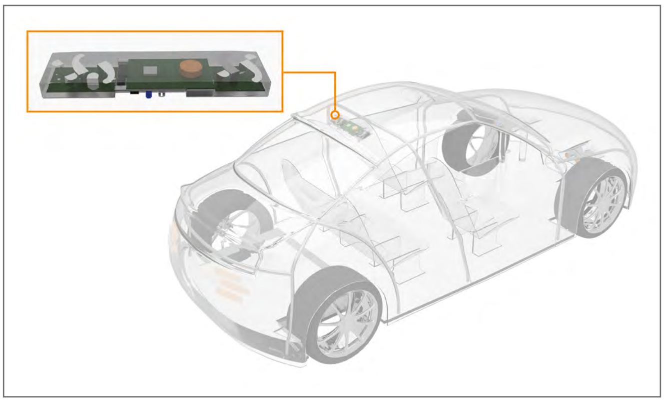

Figure 4: Antenna farm with TCU in roof

However, with an ever-increasing demand for telematic services the fin's outer dimensions may become the limiting factor. Height is limited to max. 70 mm by legal regulations. In addition, length and width cannot be increased beyond certain technical limits without looking awkward.

To mitigate this problem, some OEMs have abandoned the shark fin concept in favor of relocating the antennas in a "box" underneath the roof, called antenna farm. The major

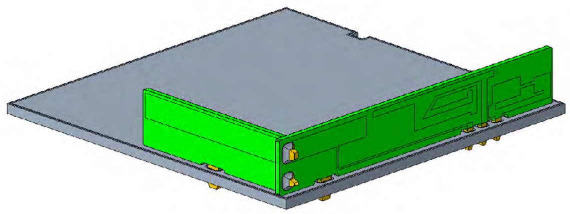

Figure 5: TCU box design with antenna elements

drawback of this construction is a reduction of head clearance for rear seat passengers due to the required antenna farm space. To enable rollout of the antenna farm concept across different carlines, detailed mechanical evaluation and planning is necessary. Even though an antenna farm usually is considerably larger than a shark fin (at least in length and width), it is usually less expensive, as complex mechanical waterproofing and expensive painting processes are eliminated.

Service	**Shark fin antenna** (above roof)	**Antenna farm** (below roof)
Cellular	good	fair
WiFi/Bluetooth external	good	fair
WiFi/Bluetooth internal	NA	good
GNSS	good	good
SDARS	good	good
V2X front	fair	poor
V2X rear	good	fair

Table 1: Technical comparison of shark fin and antenna farm

Cost efficiency is even higher when additional antennas must be integrated. However, certain antennas may exhibit performance degradation due to being "buried" inside the roof where they cannot achieve optimum radiation characteristics. This effect can be mitigated by allowing for more antenna space. Ultimately, optimum design will always be a tradeoff between desired performance and size.

A technical comparison between shark fin and antenna farm is shown in table 1. In both designs, the antenna part is clearly separated from the TCU part (see figure 3). This gives OEMs the freedom to independently source both components. The harness must be able to accommodate several coaxial lines.

2.2 Combining antennas and TCU

A way to counteract some of the performance degradation of an antenna farm mounted underneath the roof is the integration of the TCU directly into the antenna farm. This approach eliminates RF cable losses, especially at higher frequencies, where cable attenuation becomes significant. This approach also reduces cost by eliminating the need for coax cabling and connectors. Even though this combined approach may seem advantageous compared to the separated approach described in 2.1, there are also certain disadvantages.

An antenna farm with integrated TCU will require extra space underneath the roof, as TCUs must carry a lot of functionalities and therefore are not small. With active electronic components right under the roof, thermal management becomes an issue. Internal tests have confirmed ambient temperatures of up to 105° C underneath the roof when the car is parked in the sun. Keeping the TCU within its temperature limits may quickly become a challenge, requiring additional cooling features, e.g. thermoelectric elements, fans, air ducts from the B or C-pillar or even air condition access, further increasing complexity and cost.

In cases where performance requirements are not paramount, other mounting locations for the combination of antennas and TCU may be considered, for example inside the dashboard. The performance of a TCU box inside the dashboard may not be as good as in the roof environment, however this effect can be counteracted, if the housing of the TCU acts as the main carrier and is augmented with antenna elements from an RF-transparent material. Metal structures of the car body in close vicinity of the TCU must be carefully evaluated in order to avoid performance losses in this demanding environment.

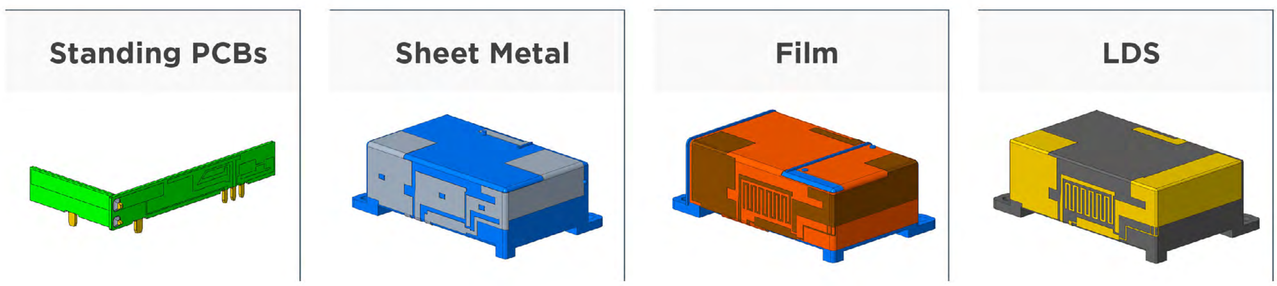

Figure 6: Overview possible antenna technologies for TCU integration

	Shark fin antenna without TCU	**Antenna farm** without TCU	**Antenna farm** with TCU	**TCU box with integrated antennas**	**Antenna farm** with slim TCU
Location	above roof	under roof	under roof	dashboard	under roof
Coax interface	yes	yes	no	no	no
Cable loss	yes	yes	no	no	no
Size requirements	very low	high	higher	highest	higher
Antenna performance	good	fair to good	good	poor	good
Supplier sourcing for TCU and antenna	separate	separate	combined	combined	combined

Table 2: Performance comparison of different antenna architectures

There are different methods for integrating the antenna elements into the TCU:

- 2D standing PCBs: The metallic antenna structure is contained in a PCB, which is then populated and soldered onto the main PCB.
- 3D sheet metal: The antenna is designed as a simple stamped and bent piece of sheet metal. It can also be populated and soldered onto the main PCB.
- 3D film antenna: The metallic antenna structure is added onto a flexible film (foil). The film then is mounted onto a carrier and integrated to the TCU.
- 3D LDS antenna: Using laser direct structuring (LDS), conductive patterns can be added directly onto injection molded parts. Plastic TCU housing parts may be used for this method.

2.3 Integrating antenna farm and slim TCU

If space and/or thermal requirements do not allow for full TCU integration, just a part of the TCU may be integrated, mainly RF-related frontends like the cellular network access device (NAD), Bluetooth®/WiFi® and V2X transceivers. With this approach, called slim TCU antenna farm, the main TCU can be placed in a more favorable mounting environment and connected to the slim TCU antenna farm via digital bus (e.g. Ethernet).

Table 2 presents a comparison of the architectures described in this white paper:

2.4 Floating-ground and fix-ground concepts

When implementing an antenna farm approach, the influence of different RF grounding concepts and their huge impact on antenna characteristics must be addressed.

A) Fix-ground concept
In a fix-ground concept, the communication module is galvanically connected to the roof, forming one big ground plane for the antennas. This enables better radiation characteristics, but requires more height to achieve the necessary cellular antenna bandwidth. Typical module height for ensuring a good performance is 30 mm. With this concept, the car body can be used as thermal sink, facilitating thermal management. In the vehicle, the A or C crossbar is modified to form a trough to accommodate the communication module, creating a bar-shaped design.

B) Floating-ground concept
In this concept, the module ground "floats" in the car roof, thanks to a gap of over 40 mm between module and roof. The module height can be reduced, usually down to around 20mm. Smaller height automatically will result in degradation of radiation characteristics, with the central problem being the loss of radiated energy towards the zenith for cell antennas. In addition, a part of the RF energy is radiated into the vehicle instead of towards the outside, where it is subsequently absorbed. In this concept, there is also the danger of electromagnetic interference (EMI) from within the vehicle. Thermal management will also be a challenge, requiring additional cooling action.

2.5 Broadcast Antenna Integration

It is also possible to integrate broadcast services into an antenna farm. This antenna farm could be placed as a second one into the roof. However, this concept is more expensive than traditional screen antenna systems and does not improve reception performance.

Due to the large wavelength of radio signals, the roof cutout needs to be very spacious to accommodate such a system. Usually around 800x200 mm is considered minimum for decent functionality, which makes integration a challenge. Therefore, this approach is hardly adopted within the Automotive industry.

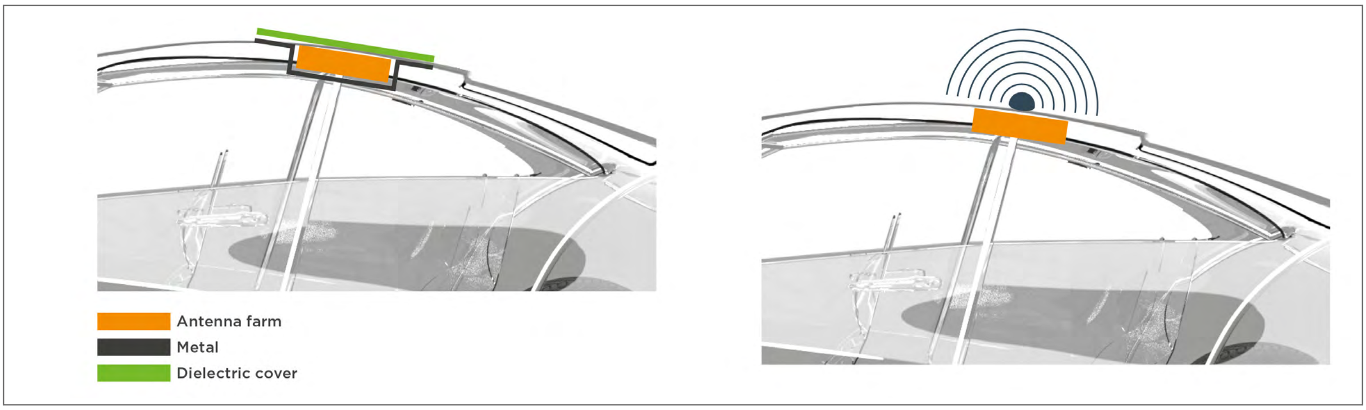

Figure 7: Fix-ground concept

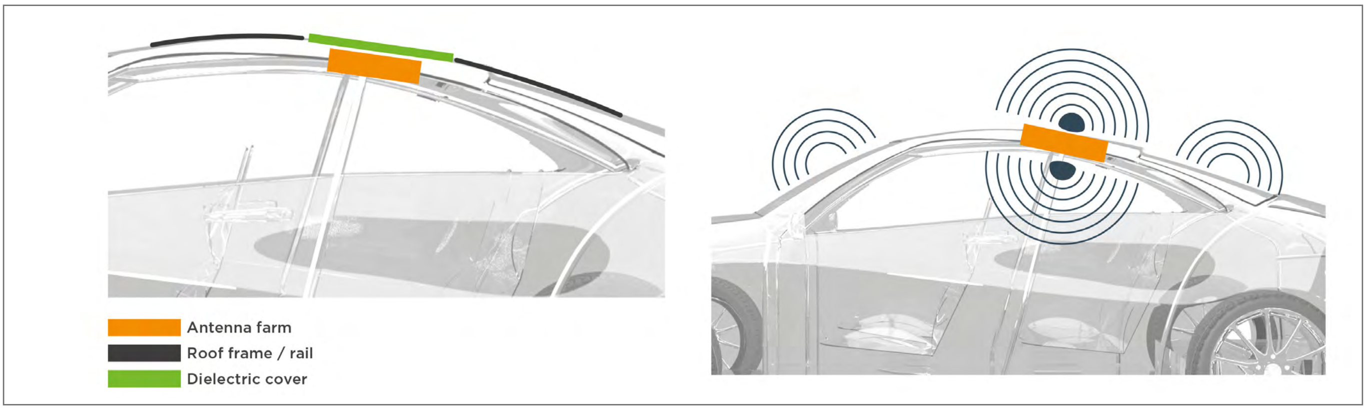

Figure 8: Floating-ground concept

3. Conclusion

This white paper clearly shows that there is no one-size-fits-all antenna solution for modern vehicle architectures. Every solution has its own advantages and disadvantages, which must be weighed to find the best design for the respective cost, performance and space requirements. In the end, there will always be a tradeoff between those three. However, currently we observe a trend within the industry to combine TCU and antennas.

While this approach brings new technical challenges with regard to thermal management and packaging, its technical benefits seem to outweigh the disadvantages.

TE Automotive Wireless is a longtime Tier1 supplier and has extensive experience in the design and implementation of high-performance antenna architectures in today's and next-generation vehicles. We support concept development, RF simulation, measurement, and seamless electronic integration. Our global supply chain ensures very cost-effective solutions for OEM customers and we support various Tier1 TCU manufacturers with tailored antenna solutions.

We are always happy to help you find the optimum solution for your antenna architecture challenges. Please do not hesitate to contact us for more information.

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