Driving the Future:
Bluetooth® Technology Revolutionizing Automotive Connectivity

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Introduction

Our never-ending appetite for, and ability to process, data from a multitude of sources drives the adoption of Bluetooth® technology into all sorts of markets and applications. This has fuelled the growth of what is now widely known as “the Internet of Things”: a catch-all collective noun for anything and everything that we now interact with over our mobile devices. To date, this has fuelled the boom in consumer electronics, driving new behaviors: whether it is making sure we do our 10k steps a day, using our phone to find our keys, or even checking that our kids brush their teeth properly! All these, and many more besides, are made possible by the easy wireless connectivity provided by Bluetooth. In this paper we will explore how this is now extending beyond the consumer space and into automotive, opening up a host of a new data capture opportunities that will bring new behaviors and benefits in the way we interact with our vehicles.

Automotive Bluetooth

For many of us we first experience Bluetooth almost immediately we acquire a new car: pairing our phone so that we can receive calls and play our favourite music while on the move. And for the vast majority of today’s vehicles that is the one and only Bluetooth application. But this is in the process of changing, driven in the main by the dominant shortcoming of battery powered electric vehicles (EV) when compared to the internal combustion engine: range. A standard diesel car can cover up to 600 miles on a full tank, the EV equivalent barely half that. And to refill? A few minutes for an internal combustion engine versus a few hours for an EV. For sure EV charging technology will make big inroads into the full charge time, but unlikely to ever make it as quick as filling up the tank. One of the factors limiting the range is the weight of the car: EV's are typically 20-30% heavier, due to the weight of the batteries. Battery weight is pretty much proportional to the range, so reducing the weight is only going to do the same to the range. However, there are other factors contributing to the total weight of an EV, one of those is the amount of wiring, which can run into 10's of kgs. Most of that wiring is for essential power and control functions, but also there can be as many as 70 different sensors in an EV, generating all kinds of data to be fed back into the vehicle management systems. And here we reach the entry point for Bluetooth: replacing wiring for wireless sensors can bring savings in kgs to the vehicle weight, and with that weight loss comes an improvement in the range. This is the driving force behind various initiatives the EV makers are pursuing to adopt wireless sensor solutions.

The weight saving argument is a clear justification for wireless sensors, but why does this have to be Bluetooth? The fact is that Bluetooth fits the bill in terms of low power data handling. Plus, Bluetooth is a universal, ubiquitous, proven and still developing protocol. Bluetooth's capabilities are widely known and available in a host of products from vendors all over the world. There are other options, usually sub-GHz, that can get close in terms of functionality, but these are non-standard proprietary protocols and lack the scale and reach that Bluetooth brings.

As well as wireless sensors, another application that Bluetooth is being considered for is vehicle entry. Schemes like Phone-as-a-key (PaaK) and Passive-Entry/Passive-Start (PEPS) have wireless protocols at the heart. However, these use cases are particularly vulnerable to abuse through man-in-the-middle (MitM) attacks, necessitating a heightened focus on security aspects. While Bluetooth technology may play a role in addressing these concerns, it is likely that the stringent security requirements will drive the adoption of multi-protocol solutions, incorporating technologies such as UWB and NFC.

There is one stand out wireless sensor application that is already a perfect fit for Bluetooth adoption: tire pressure monitoring systems (TPMS).

Tire Pressure Monitoring Systems (TPMS)

The TPMS application has become a distinct market with its own characteristics and regulations. First of all, it is important to draw the distinction between the two types of TPMS: direct TPMS (dTPMS) and indirect TPMS (iTPMS). In dTPMS the tire pressure is measured directly by a pressure sensor, whereas in iTPMS the tire pressure is not measured but derived from the wheel speed. As it is dTPMS that is now the dominant scheme we will focus the discussion on this technology.

New vehicles have included factory installed dTPMS solutions for the past years, with a wireless connection from the wheel to a central control unit. The wireless technology used in these solutions will be a sub-GHz proprietary protocol. These solutions give you a warning when the tire pressure drops below a set threshold and can show the pressure for each wheel/tire on the dashboard display screen.

The shift to Bluetooth will give an improved user experience, particularly because it will enable connection to our smart phones.

TPMS Regulatory Requirements

Separate from the user desire for TPMS's with greater interactivity there are also regulations that drive this application: tire pressure features prominently in both the vehicle safety and green agendas.

It was the safety aspect that drove the US to implement the Transportation Recall Enhancement, Accountability and Documentation (TREAD) Act in 2000, following a spate of fatalities involving Ford Explorers fitted with Firestone tires. This act mandated that all new passenger vehicles and light trucks sold after 1st September 2007 had to be fitted with a TPMS.

In 2009 the European Union passed regulation that mandated new passenger vehicles sold from 1st November 2014 had to include a TPMS (UN ECE R64). In 2022 this regulation was extended to include commercial vehicles, starting in 2024 (UN ECE R141). This regulation sets out criteria for systems going beyond simple monitoring, more advanced active schemes are laid out:

TPRS = Tyre Pressure Refill Systems

CTIS = Central Tyre Inflation Systems

This might seem like a glimpse into the future but the first CTIS actually dates back to 1942!

Although there are other regulatory schemes around the world, these are the two that really drive the TPMS market.

TPMS Aftermarket

In parallel, and quite independent to anything to do with the new regulations, there has been a strong consumer pull, that has driven a rapid growth in the after-market for Bluetooth TPMS. Today there are hundreds of inexpensive TPMS kits that come with a phone app and can be fitted and running in just a few minutes. These are simple monitoring schemes, another proof point that illustrates our insatiable appetite for connected devices, feeding data to our smart phones. Here it is mostly about the enhanced user experience we get, now that we are so comfortable navigating our way through mobile apps.

The aftermarket TPMS's have a simple sensor that replaces the dust cap on the outside of the tyre/wheel. The sensor unit includes a pressure sensor, battery and Bluetooth SoC. These TPMS solutions are sold as consumer electronics devices, meaning that they are not of automotive quality, the components are not qualified to AEC standards. The beauty of these products is the user experience: once fitted it becomes just another app on our phone, something we are totally familiar with these days, and something the in-vehicle display screens have some catching up to do. As these are monitoring systems only, the ease of access to the data they generate makes it much more likely that the user takes action to adjust their tire pressure at the earliest possible opportunity. After all, it is the action that is needed to maintain the safety and optimise the fuel consumption.

For these sensor units space is at an absolute premium, it is a primary driver for the components used. And, as for all consumer electronics, cost is also critical. What this means is that the component count is reduced to the essential only, no redundant functionality. They are a perfect fit as a consumer gadget but cannot be adopted by vehicle manufacturers for in tire/wheel mounting because of the quality level.

Inside the Wheel

The most obvious difference between aftermarket and automotive TPMS is that the sensor unit is now fixed inside the wheel, rather an external screw-in. With such a fitting the TPMS is supplied as part of the vehicle so automotive quality is paramount. Space is at slightly less of a premium and cost is just as critical as for consumer electronics, albeit with the increase in quality. As such, the sensor unit needs the same functionality with automotive grade components.

For the sensor unit the increase in quality manifests in two basic ways:

1. Failure rate (zero ppm)
2. Battery life

The determination towards zero ppm has been embedded in the automotive industry for many years now, TPMS is no different in this regard. All the components used will have to satisfy the appropriate Automotive Electronics Council (AEC) quality requirements, as will the complete sensor unit itself. These exacting requirements ensure “quality by design”, necessary for any product striving for a zero-ppm failure rate.

Advances in component technologies mean that AEC quality sensor units with Bluetooth are now coming to the market: entry-level AEC-Q100 qualified Bluetooth SoC’s and AEC-Q200 qualified crystals make this possible.

This leaves the battery as the weakest point in a TPMS sensor unit: with the sensor fixed inside the wheel we can pretty much forget about battery replacement; the sensor will have to work for the many years of life expected for the wheel/vehicle. In turn, this brings attention to the power profile of the Bluetooth use-case: low power when actively transmitting data and ultra-low power when inactive (in sleep or hibernation mode). Indeed, it is the inactive mode that tends to dominate the system power consumption, and thus the battery life.

Wheel Locationing

A shortcoming of all current TPMS solutions is that they cannot automatically identify individual wheels on the vehicle – you have to tell them. If, for any reason, two wheels are swapped, the central control unit will not know unless you manually reset the system. This is a fundamental limitation of the positional resolution of wireless protocols, they can get you to the meter resolution level, but not the cm level needed to reliably detect wheel position on a vehicle. This is an aspect that has been addressed in a variety of ways in Bluetooth technology, striving towards true cm resolution. Previously, these techniques were described under the High Accuracy Distance Measurement (HADM) category, this morphed into Angle-of-arrival (AoA) and Angle-of-departure (AoD) in Bluetooth 5, and now we have Channel Sounding (CS) in Bluetooth 6. A whole bunch of acronyms all leading to one thing: reliable cm resolution distance measurements.

These advancements in Bluetooth serve a plethora of use-cases, certainly not limited to TPMS, but they do perfectly fit the requirements for dependable wheel locationing. In turn this will likely lead to an increase in processing capability in the Bluetooth SoC, with consequences for power consumption and cost – nothing comes for free! The enhanced user experience provided with automatic wheel locationing is expected to outweigh any negative impact of such solutions.

At Renesas, locationing is at the heart of our innovations for data management use-cases. This goes broader than following the Bluetooth standard, requiring complex algorithms and specialist antenna design – all of which are needed to produce a reliable system solution.

Commercial Vehicle Fleet Management

We started this discussion with an illustration about the appetite for data on a personal level, but this also applies for organisations in the business sector, and for TPMS we see this in the context of the heightened attention given to fleet vehicle management. Here the primary need is data gathering in order to plan for preventive maintenance and thus maximise vehicle availability and performance. Credible tire pressure data translates directly into operational costs through fuel consumption, and security of supply in preventing breakdowns. As mentioned earlier, vehicles have many sensors, all generating data streams that can be used to optimize vehicle utilization – there are already companies using AI/ML algorithms to convert this data into practical decision-making tools for commercial vehicle fleet management.

Introducing the DA14533

All this paints a compelling picture for Bluetooth in automotive, specifically for the TPMS application. What is missing is a Bluetooth product that does the job.

The DA14533 extends Renesas' leadership in Bluetooth LE connectivity, delivering a compact, highly efficient solution for automotive applications, TPMSs in particular. Designed as part of the SmartBond™ Tiny family, this automotive-grade SoC features an integrated DC-DC buck converter, enabling optimized power consumption to extend battery life in low-power systems. With an active transmission current of just 3.1mA and a reception current of 2.5mA, the DA14533 offers one of the lowest power profiles in the industry. Additionally, its hibernation mode operates at a mere 500nA, making it particularly well-suited for TPMS, where power efficiency is paramount.

Beyond its low power consumption, the DA14533 is AEC-Q100 Grade 2 qualified, ensuring robust operation in demanding environments with an extended temperature range of -40°C to +105°C. It is qualified against Bluetooth Core 5.3, incorporating the latest security enhancements to safeguard against emerging threats in connected automotive and industrial ecosystems.

To simplify system design and lower total costs, the DA14533 minimizes external component requirements, requiring only six external components for operation. Its ultra-compact 3.5mm x 3.5mm WFFCQFN package makes it the smallest automotive Bluetooth LE SoC available, enabling seamless integration into space-constrained applications. A single external crystal oscillator serves both active and sleep modes, eliminating the need for additional components and further optimizing the bill of materials (BOM).

Key Features

- Ultra-low power operation: 3.1mA TX, 2.5mA RX, 500nA hibernation mode
- Qualified against Bluetooth Core 5.3 with enhanced security features
- AEC-Q100 Grade 2 qualification (-40°C to +105°C)
- Arm® Cortex®-M0+ processor for flexible system integration
- Integrated low IQ buck DC-DC converter for optimized power management

- Compact 3.5mm x 3.5mm WFFCQFN 22-pin package

By integrating the DA14533, automotive developers gain access to a best-in-class Bluetooth LE solution that balances efficiency, security, and cost-effectiveness—powering the next generation of TPMS applications.

The DA14533 is fully released with a full set of Hardware & Software development tools to accelerate your designs.

Summary

In this paper we have taken a brief tour to illustrate how Bluetooth technology fits into the automotive market, with a particular focus on the TPMS application. There are multiple forces at play here that will drive change: for organizations there are regulations to ensure safety & reduce fuel consumption, plus the need for maximizing commercial vehicle utilization and, not least, at a personal level, our insatiable appetite for data. And all this becomes possible with the DA14533, Renesas' first automotive qualified Bluetooth SoC.

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