PERFORMANCE OF ADI WIRELESS BMS ENSURED USING ROHDE & SCHWARZ RECORD AND PLAYBACK SOLUTION

AT A GLANCE

- **Customer**: Analog Devices (ADI)
- **Task**: Create a realistic test environment for investigating EMI for wireless battery management systems (W-BMS) for electric vehicle
- **Challenge**: Recreation of a real-world RF environment in the lab; drive tests are time, resource and cost intensive and it is also difficult to replicate corner cases on the fly
- **Solution/product**: RF spectrum record and playback solution consisting of R&S®FSW signal and spectrum analyzer, R&S®SMW200A vector signal generator and R&S®IQW wideband I/Q data recorder
- **Key benefits**: Reproducibility when testing corner cases, higher confidence in the product's real-world performance, cost reduction due to fewer drive tests

Case Study | Version 01.00

CURRENT STATUS OF THE AUTOMOTIVE INDUSTRY

The car industry is going through a major transition, from internal combustion engine (ICE) vehicles to plug-in hybrid electric vehicles (PHEV) and electric vehicles (EV). Almost all automotive OEM companies have set out ambitious roadmaps for the next generation of plug-in hybrid and battery-powered electric vehicles. The customer appetite for PHEVs and EVs is also on the rise. However, wide spread adoption of the technology will still take time and there are a few reasons why this is the case. First and foremost, EVs are expensive and secondly the limited drive range you get out of one full charge. They are not yet a mass market technology. Even though the high-end offerings have a good driving range, the mid-range and lower-end budget electric vehicles still have limited range which is heavily dependent on the weather and road conditions as well as the travel speed. In addition to this, the charging time is not comparable with the refueling time of traditional internal combustion engine vehicles and the charging infrastructure is not widely deployed. Not to mention, there are not yet enough EV models to cater for all customer tastes, lifestyles and requirements when directly compared with the corresponding ICE offerings.

ICE vehicle model design has evolved over the years primarily based on user requirements such as space, performance and capabilities. The fuel capacity of a vehicle historically has played a secondary role in the product design phase. With EV, the industry is taking a different, ground-up approach to vehicle design with a different set of priorities. Weight reduction, aerodynamic drag performance, and weight distribution all play a crucial role in achieving higher drive range and thus have a greater influence on the design.

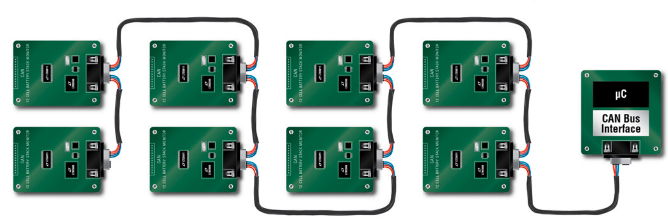
Automakers are racing to bridge the gap in the EV market by setting fixed goals on going fully electric by 2030. Some of the elements that make a good EV are aerodynamic design, high-tech infotainment system, seamless software operation, efficient motors, high energy density battery packs and a reliable battery management system.

Unarguably one of the most vital components of an EV is the battery subsystem. It is bulky in size, heavy in weight and greatly influences the overall design of the vehicle. It is also perhaps the most expensive item on the bill of material (BOM). Therefore, it is critical that its performance and operation, controlled by the battery management system, is optimal.

LATEST BATTERY MANAGEMENT TECHNOLOGY

Automakers want a battery subsystem that is reliable and serviceable, with minimized weight and complexity, full flexibility on how to pack the battery modules and scalability in terms of pack size for different categories and types of EVs. The battery management system (BMS), which monitors and controls the battery cells to optimize their power, range, efficiency and lifetime, holds the answer to many of the points mentioned here. Almost all the EVs on the market today have a wired BMS connecting all the cell monitors to the BMS controller using a daisy chain architecture. Even though these wired BMSs have many upsides, they have some downsides as well. A battery management system measures the voltage and current level in each cell, energy charging and discharging rates, cell/module temperature and the health status of each individual cell. The readings are then used to calculate the state of charge (SoC), prepare the pack for optimal charging and interpret the health status of the overall battery pack. In most cases, it also implements the cell balancing technique to keep all cells on an equal charge level within a cell pack.

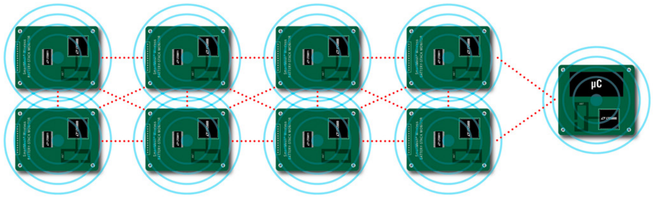
Figure 1: Battery monitoring interconnections with CAN bus [1]



Up until now, the state-of-the-art BMSs have been wired systems. The wired systems with their extremely long cable harnesses need to be supported by an additional redundant capacity in case of failure. The cable harness wiring is also complex and, of course, increases the weight of the entire EV significantly. It is very expensive to run maintenance and, in some cases, it is cheaper just to replace the entire battery pack even if one individual cell fails. The complex wiring and daisy chain based connection make it difficult to realize flexible module packaging strategies and thus scaling up in terms of overall energy capacity is not possible on the fly. It requires a great deal of complex engineering and planning to make it happen.

REFERENCE
[1] Wireless battery management systems highlight industry's drive for higher reliability, Greg Zimmer, Linear Technology Corporation

Figure 2: Battery monitoring interconnections with ADI W-BMS [1]



The latest trend in the battery management system is to go wireless. Each individual module transmits the cell/module status information over a radio frequency (RF) link using the 2.4 GHz ISM band. The central BMS control unit has a redundant receiver and transmitter setup in order to receive the status information from all the deployed modules within a given battery pack setup. It can also send messages to individual modules if required. The benefit of such a system includes a significant reduction in weight because the entire cable harness and the redundancies are no longer required. Going wireless also means the complexity of wiring is no longer there and thus many possibilities open up in terms of cost reduction, flexibility, scalability and design freedom. Not to forget the servicing aspects. Each individual module acts as a plug and play subsystem. The modules can be packed flexibly and, unlike wired systems, do not have to be laid flat on the floor. This removes a huge bottleneck in EV design. The number of modules can be scaled up or down depending on the type of vehicle. Wireless BMS (W-BMS) also makes post-sale maintenance cheaper because if a cell in a module fails, the affected module can be easily swapped out instead of having to replace the entire battery pack. Even multiple subsystems or complete battery packs stored in a warehouse can be monitored in this way and treated according to their needs.

CHALLENGE

In September 2020, Analog Devices Inc. (ADI), a leading global high-performance analog technology company, introduced the industry's first wireless BMS for production EVs. ADI's W-BMS is a single system-level product that includes all the necessary integrated circuits, hardware and software for power, battery management, RF communications, and system functions.

ADI's W-BMS retains most of the traditional BMS technology whilst replacing the traditional wired harness with a modern wireless 2.4 GHz RF link, saving up to 90% of the wiring and up to 15% of the volume in the battery pack, as well as improving design flexibility and manufacturability, without compromising range and accuracy over the life of the battery.

The introduction of the 2.4 GHz wireless communications modules gives rise to a handful of new challenges in maintaining uninterrupted communications. The bulk of the problems arise from RF interference signals at around the same operating frequency as the communications system. Most connected consumer gadgets (such as smartphones, wireless headsets, smart wearables, tablets and laptop computers) carried by the car users support Bluetooth® Low Energy, Wi-Fi, LTE technology which operates in overlapping or adjacent frequency bands centered on the 2.4 GHz spectrum. In addition to these interference sources that the users bring into the car, the W-BMS system has to deal with the hostile RF environment on the road as the car drives into areas of varying RF spectrum activity as can be found in big metropolitan cities that have high population densities. The vehicle's wireless systems have to maintain and ensure seamless operation even in areas with high RF spectral complexities which are part of its everyday operating environment. Some causes of these demanding environments are telecommunications base stations and a high number of public Wi-Fi hotspots or at highway toll collection lanes that offer free-flow drive-by payment. The RF environment changes over time. It varies considerably depending on the time of day, location (urban, rural, city center) and the number of RF transmitting devices in the vicinity. This is not a case of the more the merrier. In fact, it is the contrary. The quantity of transmitters located close to the receiver antenna of the W-BMS increases the load and desensitizes the receiver of the battery management system. The antennas in W-BMS systems are typically omni-directional antennas that pick up all RF signals. Since the number of unwanted signals at this frequency band from all nearby wireless systems is, as explained here, quite high, the noise floor of the RF receiver of the W-BMS is increased. As a result, it is difficult for the W-BMS to successfully decode the information from the wanted sources. The situation can be further exacerbated at locations where high-powered transmitters (such as LTE base stations, TV towers, intentional jammers located close to prisons and police stations, etc.) are located.

Therefore, from the W-BMS perspective, the principal challenge to be overcome is to successfully receive and decode the wanted cell monitoring information with a very high degree of accuracy at all times and under all RF spectral conditions.

IMPROVEMENTS INTRODUCED AFTER THE JOINT COLLABORATION PROJECT

At present, interference testing is first done at module/component/pack level and then after the battery pack with the W-BMS has been integrated in the vehicle. Conducted as well as radiated test methodologies are employed. One key item of test equipment used in this setup is the vector signal generator. It is used to generate multiple "realistic" simulated interference test profiles. This is vital in making the tests repeatable and ensures high performance for all W-BMS systems.

This test approach already ensures an extremely high confidence level in the BMS's on-road performance but testing in real-world drive conditions is what differentiates the best from the good products on the market. Modern vector signal generators are capable of generating wideband complex modulated interference signals but it is complicated and expensive to completely reproduce real-world RF conditions with hundreds of transmitters. The next best alternative is to perform actual drive tests for hundreds of hours and over millions of test miles. This is where all the problems begin to emerge from a test and measurement viewpoint. Firstly, drive tests are extremely expensive. Secondly, the repeatability of test scenarios in the "uncontrolled" real world from an RF perspective is a matter of huge concern. And, last but not least, it is a huge time sink without the guarantee that all corner cases have been captured. This is important because in order to ensure highly consistent performance across all W-BMS products, the battery pack systems need to be tested using the same test scenarios in a reproducible manner. Each W-BMS system incorporates an antenna system which can greatly affect the overall performance.

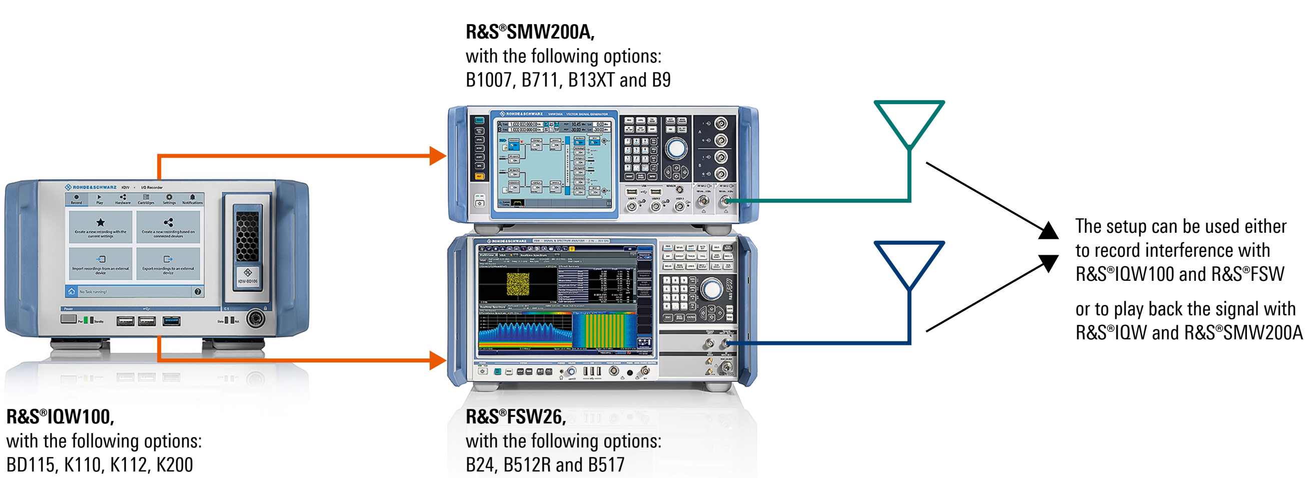
This is where Rohde & Schwarz and ADI joined forces to find the perfect record and playback solution to solve these challenges and improve the current test strategy. The goal of the project was firstly to have a working proof of concept that the real-world RF environment can be recorded and repeatedly played back during testing in a lab setting using off-the-shelf test and measurement equipment. Secondly, improve and update the existing interference signal test library used for ensuring EMI immunity of ADI's W-BMS.

We are happy to announce the successful completion of the project with all the goals fulfilled to a high degree of satisfaction. The next generation of BMS technology will benefit from the updated state-of-the-art test methods developed as a result of this project and will play a vital role in ensuring the reliability of the W-BMS products in real-world operation.

SOLUTION

The newest addition to the existing interference testing solution is the RF record and playback component. The existing RF coexistence setup includes the R&S®SMW200A vector signal generator and the R&S®FSW signal and spectrum analyzer for monitoring the RF spectrum. To record the spectrum, the R&S®IQW wideband I/Q data recorder is connected to the R&S®FSW, which is then connected to an antenna in order to record the RF spectrum during test drive sessions. The recorded spectrum profiles can be played back at a later time in the lab by connecting the R&S®IQW to the R&S®SMW200A, which is connected to an antenna as shown in Figure 3.

Figure 3: Record and playback solution for capturing real-world RF spectrum



This makes the test approach more realistic, since all W-BMSs can be repeatedly tested using the same real-world RF environment. It helps enormously with the troubleshooting and problem debugging process. And in the long run, the cost of gathering RF data from areas where W-BMSs face constant problems in the field decreases quite significantly.

The RF environment changes constantly as more and more connected devices are introduced, because newer telecommunications base stations and high-powered transmitters are deployed to support the ever-increasing demand for high-speed data connectivity. The recorded test spectrum profiles need to be updated regularly at quarterly, half-yearly or yearly intervals depending on the location. In case of recurring field challenges, recordings could be made and then shared with the R&D team for investigation. The classic drive test can be replaced by this field-to-lab approach, thereby also reducing costs.

KEY FINDINGS

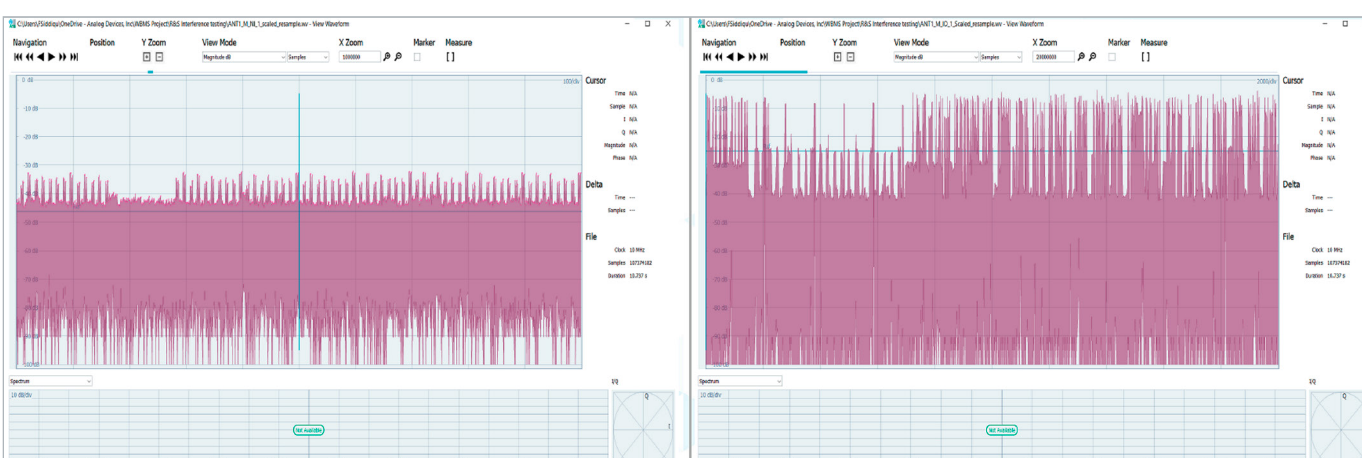
The team from ADI went out with the Rohde & Schwarz spectrum recording setup on a few test drives at different locations in the city of Limerick in Ireland. The team recorded 11-second sections of spectrum at different bandwidths centered on the 2.4 GHz band as well as the same routes with and without interferers inside the test car. The in-car interferers included two smartphones streaming 4K video, an LTE based Wi-Fi hotspot modem and two Bluetooth® audio players. In the following figures, no interference points to the fact that none of the in-car interferers were switched on. With interference means that the above-mentioned interferers were all switched on and operational.

Figure 4 shows the routes that the drive test car took during the test drives while recording the spectrum, and also indicates the traffic congestion at those locations.

Figure 4: Two test drive routes while recording the spectrum in the city of Limerick, Ireland

Screen grabs courtesy of Google Maps

Figure 5: 11-second RF I/Q data plot in 2D along the main street of Limerick, Ireland



Driving along the main street of Limerick it can be seen that the 10 MHz RF spectrum looks quite crowded over the 11 seconds even without the interferers inside the car switched on (Figure 5). This results in an elevated noise floor and would result in receiver desensitization. When the in-car interferers are switched on, the RF spectrum crowding increases even more and this is what the W-BMS receiver will have to deal with.

Figure 6 shows the recorded spectrum plot at the Ennis Tunnel in Limerick, Ireland. This route has significantly less congestion than the main street through Limerick and the cars drive faster. The I/Q data plot looks very different while driving through the tunnel compared with the RF spectrum while driving through the city center. The recorded spectrum view in this figure is 90 MHz in bandwidth.

It is also observed that, even without interference inside the car, the recording antenna picked up an elevated noise floor at certain parts of the spectrum as well as some high-powered narrow bandwidth transmitters at that location during the drive-by. The high-power narrow bandwidth signal was captured because a Bluetooth® pairing signal search was taking place inside the car infotainment system. So the captured signal didn't actually originate from outside the car, but instead was coming from the car's own infotainment system which was not completely powered off, despite the Bluetooth® connections having been disconnected. With the interferers switched on, the spectrum looks different to the spectrum in the city center.

Figure 6: 11-second RF I/Q data plot in 2D through Ennis Tunnel of Limerick, Ireland

"The Rohde & Schwarz capability was very useful in capturing the typical RF environment in a driving vehicle. ADI have now added this capability to our extensive suite of bench, pack and vehicle level testing which we have been using to prove the robustness of the system to the most extreme interference, jamming and EMI levels."

David Bourke, Systems Application Engineer Lead at ADI

USE CASE SUMMARY

Rohde & Schwarz and ADI joined forces to improve the receiver EMI immunity testing method in order to increase the reliability of wireless battery management systems in various different RF environments. In order to reduce the cost of expensive drive tests, which typically face repeatability issues, a real-world drive using the spectrum recording and playback solution in combination with COTS T&M equipment was trialled.

The goal of the project was firstly to have a working proof of concept that the real-world RF environment can be recorded and repeatedly played back during testing in a lab setting using off-the-shelf T&M equipment. Secondly, improve and update the existing interference signal test library used for ensuring EMI immunity of ADI's W-BMS.

We are happy to announce the successful completion of the project with all the goals fulfilled to a high degree of satisfaction. As a result of this project, the next generation of BMS technology will benefit from the updated state-of-the-art test methods and recorded RF environment test profiles and will play a vital role in ensuring the reliability of the W-BMS products in real-world operation.

These recorded test profiles can now be used to test the next generation of ADI's best-in-class W-BMS from the comfort of the lab. This will eliminate the planning, scheduling and cost associated with a test drive for the city of Limerick in Ireland, but only for the time being because the RF spectrum is constantly changing. Over time the load on the W-BMS receiver is continuously increasing. Similar drive-by recordings need to be made at different locations and at different times of the day and then repeated at regular pre-defined time intervals in order to keep the test profiles up-to-date. However, the cost associated with regular drive tests has been significantly reduced by the introduction of data collection drives on demand.

The Rohde & Schwarz record and playback solution ensures flexibility, reproducibility and high performance and is a future-proof investment.

Service that adds value
- ► Worldwide
- ► Local and personalized
- ► Customized and flexible
- ► Uncompromising quality
- ► Long-term dependability

Rohde & Schwarz

The Rohde & Schwarz technology group is among the trailblazers when it comes to paving the way for a safer and connected world with its leading solutions in test & measurement, technology systems and networks & cybersecurity. Founded more than 85 years ago, the group is a reliable partner for industry and government customers around the globe. The independent company is headquartered in Munich, Germany and has an extensive sales and service network with locations in more than 70 countries.

www.rohde-schwarz.com

Sustainable product design
- ► Environmental compatibility and eco-footprint
- ► Energy efficiency and low emissions
- ► Longevity and optimized total cost of ownership

Certified Quality Management
ISO 9001

Certified Environmental Management
ISO 14001

Rohde & Schwarz training

www.training.rohde-schwarz.com

Rohde & Schwarz customer support

www.rohde-schwarz.com/support

PD 3683.5216.32 | Version 01.00 | January 2022 (ch)
Performance of ADI wireless BMS ensured using Rohde & Schwarz record and playback solution
Data without tolerance limits is not binding | Subject to change

3683521632
3683.5216.32 01.00 PDP/PDW 1 en