Porsche Engineering
MAGAZINE

CUSTOMERS & MARKETS Future mobility concepts, digitization, and electric driving pleasure
PORSCHE UP CLOSE Greater efficiency and performance with the new Porsche 911 Carrera
ENGINEERING INSIGHTS An intelligent control unit for electric and hybrid vehicles

ISSUE 2/2015

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FRESH WIND

Aerodynamics Development of the Future

Dirk Lappe and Malte Radmann,
Managing Directors of Porsche Engineering

Dear Readers,

_____ Developments and changes in the automotive industry take place at a rapid pace – and that is truer than ever in this age of digitization. The interview "Electric. Efficient. Emotional." lays out how we at Porsche Engineering view the current challenges in the field of mobility and deal with rapid changes in order to create the solutions of tomorrow for you, our customers.

The founding of our new subsidiary in Cluj, Romania, is another important step in further readying ourselves for the future. This strengthens and expands our capabilities in the field of software development and offers you the opportunity to advance the digitization of vehicle development with us as a development partner even further.

The focus theme for this issue takes a detailed look at aerodynamics development and shows how this field will play an even more important role in the future. Learn more about the potential of the early stages of development and Porsche's first-class testing facilities, which are also available for you to use in your projects.

Last but not least, this issue once again provides "Engineering Insights" as well as everything there is to know about the new Porsche 911 Carrera.

We hope you find it interesting and enjoy the read!

Sincerely,
Malte Radmann and Dirk Lappe

About Porsche Engineering

Creating forward-looking solutions was the standard set by Ferdinand Porsche when he started his design office in 1931. In doing so, he laid the foundation for today's engineering services by Porsche. We renew our commitment to that example with each new project that we carry out for our customers.

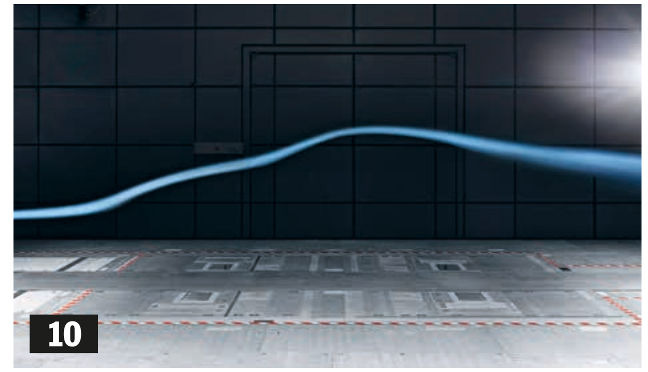
The scope of services provided by Porsche Engineering ranges from the design of individual components to the planning and execution of complete vehicle developments, and is also transferred to other sectors beyond the automotive industry.

911 MODELS (TYPE 991 II)
Fuel consumption (combined):
9.0–7.4 l/100 km;
CO_2 emissions (combined):
208–169 g/km;
Efficiency class: F–D

28

CUSTOMERS & MARKETS
ELECTRIC. EFFICIENT. EMOTIONAL.

In an interview, Dirk Lappe, Technical Director of Porsche Engineering, explains his views on future mobility concepts, digitization, and the pleasure of electric driving.



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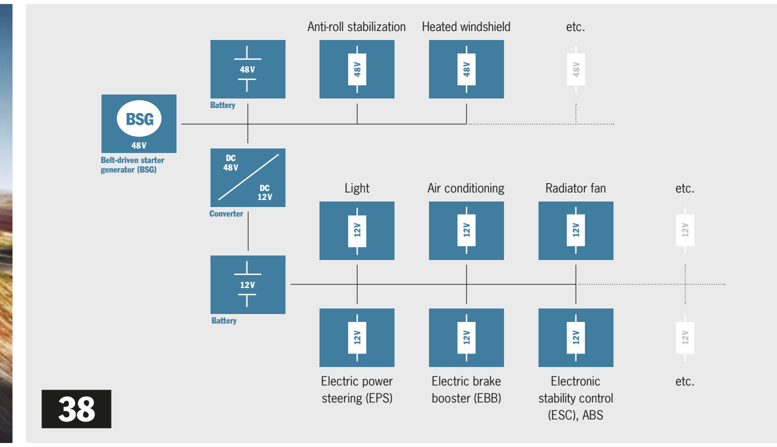

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911 CARRERA MODELS (TYPE 991 II)
Fuel consumption (combined): 9.0 – 7.4 l/100 km;
CO_2 emissions (combined): 208 – 169 g/km;
Efficiency class: F–D

News

NEW SUBSIDIARY: PORSCHE ENGINEERING ROMANIA SRL

___ Porsche Engineering is expanding its capabilities in the field of digitization. The subsidiary Porsche Engineering Romania SRL was founded for this reason in the university city of Cluj-Napoca. Romania, and the university city of Cluj-Napoca in particular, are among the most innovative regions in Europe for software development. A number of IT companies were founded here and the city is home to a lively start-up scene. This environment is fertile ground for Porsche Engineering as it is developing innovative solutions for the automotive sector. “Cluj will play a significant role in helping us advance the digitization of vehicles,” says Malte Radmann, Managing Director of Porsche Engineering. “To do so, we need first-class software engineers, and we can find them in Cluj.” The continuous exchange between engineers at the various locations in Germany and abroad enables the company to augment its complete-vehicle expertise in ideal fashion. ■

News

A SPORTY YEAR

EMPLOYEES MASTER SPORTS CHALLENGES

___ Porsche Engineering employees are not only fit in their job but also physically fit. That is what they demonstrated on numerous occasions in 2015: At the 6th Bietigheimer BZ Corporate Run, which took place in July, the Porsche Engineering team took an impressive third place in the team classification. A few weeks later, the Porsche crew took on the challenge of the “Rad am Ring” 24-hour bicycle race on the Nürburgring in the mountain bike and road bike categories alongside more than 5,000 other cyclists. The Porsche Engineering staff team also participated in the Porsche Leipzig soccer tournament and the “Porsche 6-Hour Run.” The latter two events were dedicated to charitable causes. ■

ROUNDING THINGS OUT

MANY HIGHLIGHTS IN THE NARDÒ ANNIVERSARY YEAR

Nardò Technical Center 40 YEARS 1975 2015

___ Marked by many highlights, Nardò’s anniversary year is coming to an end. Just in time to mark the 40th anniversary of its founding, the revised website of the testing grounds went online with a new Porsche design on July 1, 2015. The website presents a broad range of test tracks and testing services with a new structure and appearance. At the Automotive Testing Expo Europe 2015 in Stuttgart, in addition to record vehicles, the new Nardò image film was presented and visitors had the opportunity to explore the forward-looking testing grounds using an “augmented reality” application. Later, regional and international journalists received background information on the ongoing enhancement measures taking place at the grounds at an on-site press conference in Nardò. ■

www.porsche-nardo.com

NEW WORLD RECORD

SUCCESSFUL SEASON FOR THE STUTTGART GREENTEAM

___ The GreenTeam at the University of Stuttgart, which has been supported by Porsche Engineering since 2011, can be more than pleased with last season’s results: After placing third in the “Formula Student Germany” design competition at the Hockenheimring in August of this year, a few weeks later the students set a new world record in their E0711-5 at the Jade-Race in Mariensiel, Germany: The GreenTeam electric race car accelerated from 0 to 100 km/h in just 1.779 seconds. The achievement earned the formula race car, which has a carbon-fiber monocoque and aluminum and titanium chassis components and whose control units and high-voltage batteries were developed by the students themselves, a place in the Guinness Book of World Records. ■

911 TURBO CABRIOLET
Fuel consumption
city: 13.4 l/100 km
highway: 7.8 l/100 km
combined: 9.9 l/100 km
CO_2 emissions (combined): 231 g/km
Efficiency class: G

FRESH WIND

____ Aerodynamics development is a classical discipline in automotive development that today influences the overall vehicle system more than ever before. In the following pages, find out about the optimization potential that the early stages of aerodynamics development bring to the overall product creation process, what challenges and requirements will most strongly shape aerodynamics development in the future, and how the new aeroacoustic wind tunnel at the Weissach Development Center enables optimal and realistic testing.

EARLY AND EFFICIENT

Optimization potential in the early phase of aerodynamics development

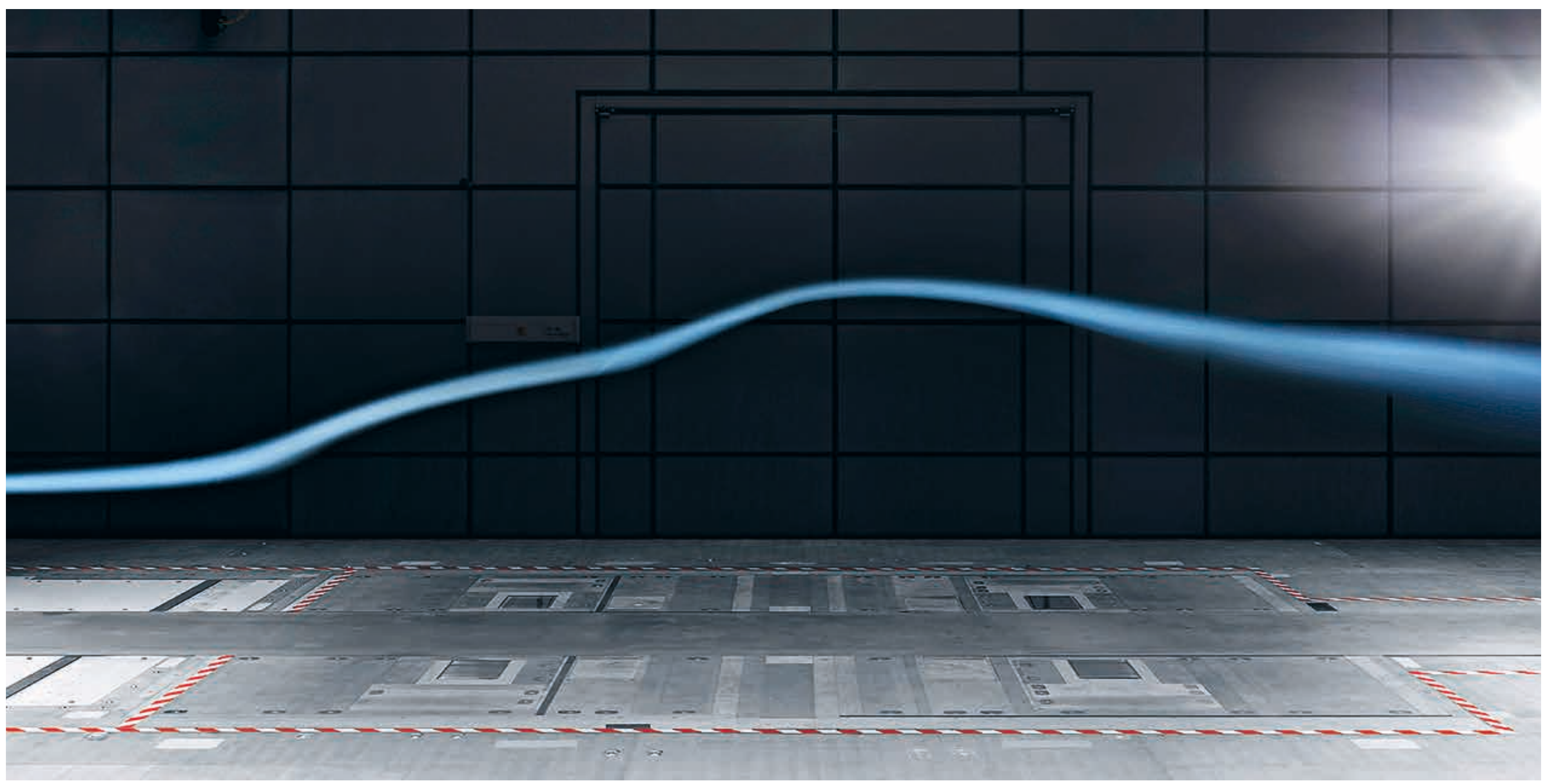
____ Aerodynamic optimization plays a central role in all Porsche sports cars—always have. Even in the very first Porsche vehicles, a great emphasis was placed on good aerodynamics. This contributed to many triumphs on the race track in vehicles presumed to be outmatched by the competition. And the engineers don't just design Porsche models using exceptional aerodynamics—they do the same for other manufacturers and industries as well. In particular the early phase of aerodynamics development offers great potential for efficiency enhancement.

By Thomas Aussem and Marcel Straub

The aerodynamic forces acting on a vehicle are enormous. They rise in relation to the square of the vehicle speed; and at a speed of approximately 250 km/h they reach a level that causes an airplane to lift off. The task of an automobile aerodynamics engineer with performance-oriented vehicles is to utilize these forces to generate downforce to enable higher cornering speeds and driving stability. At the same time, the drag is reduced to the greatest extent possible to enable low consumption, low CO_2 emissions, and high top speeds.

Aerodynamics play a major role in deciding whether the vehicle will meet the desired objectives. New test cycles, new requirements in the field of electromobility and the further tightening of legal requirements will make having low aerodynamic drag an ever more important factor in the future.

Porsche Engineering offers customers in the field of aerodynamics the possibility to transfer knowledge gained in sports car development to their own projects. The range of vehicles that can benefit from this is not restricted to sports cars. From compact sedans to SUVs, all vehicle classes can profit from the engineers' many years of experience. Customers can expect a development process tailored to their specific needs including access to the entire aerodynamics testing facilities at the Development Center in Weissach.



This visualized air flow reveals the form of a familiar silhouette.

The project scopes range from consulting to measurement support to taking on complete responsibility for aerodynamics development.

Aerodynamics is more than just the C_D value

The drag is the central unit in modern automotive aerodynamics development and at speeds over 80 km/h represents the dominant factor in overall driving resistance. As a dimensionless coefficient, the C_D value is a means of quantifying the aerodynamic quality of the shape of a vehicle and enables direct comparison of different vehicle sizes and classes.

Another aerodynamic spec is the lift coefficient C_L, which is distributed among the front and rear axles. This coefficient expresses the lift and downforces generated by the flow around the vehicle contour. But it's not just these absolute values that are critical. One significant factor for driving dynamics is aerodynamic balance, i.e. the distribution of the forces on the front and rear axles, in order to ensure outstanding driving stability, especially at high speeds.

These traditional disciplines have led to the development of new fields of activity in which aerodynamics have a direct influence on the development process (see the illustration on the next page). The close link between aerodynamics and thermodynamics is particularly noteworthy. All of the air flows for the purposes of cooling and ventilation have a direct effect on the overall aerodynamic performance of the vehicle. In most cases, these secondary flows are associated with losses. Thus the principle: as much as necessary, as little as possible.

As the challenges of aerodynamics development have risen continuously, the development tools have kept pace and can handle any task in modern aerodynamics development. Porsche, therefore, has remarkable aerodynamics testing facilities at its disposal. The latest addition is an aerodynamics and acoustics wind tunnel for 1:1-scale vehicles, which also enables road simulation (see the article “Precise and Flexible” from page 16). The new wind tunnel has been in series production use since early 2015 and is helping master the challenges of tomorrow. The Weissach Development Center also has a 1:1-scale vehicle wind tunnel without road simulation capabilities, as well as a wind tunnel for 1:3-scale aerodynamics models. External customers can also make use of these resources through Porsche Engineering. The range of development tools is nicely rounded out by the use of computational fluid dynamics (CFD). This involves creating, calculating, and evaluating digital aerodynamics models with a high degree of detail and millions of cells. Thanks to modern computer clusters, accurate results are available overnight.

Aerodynamics in the early project phase

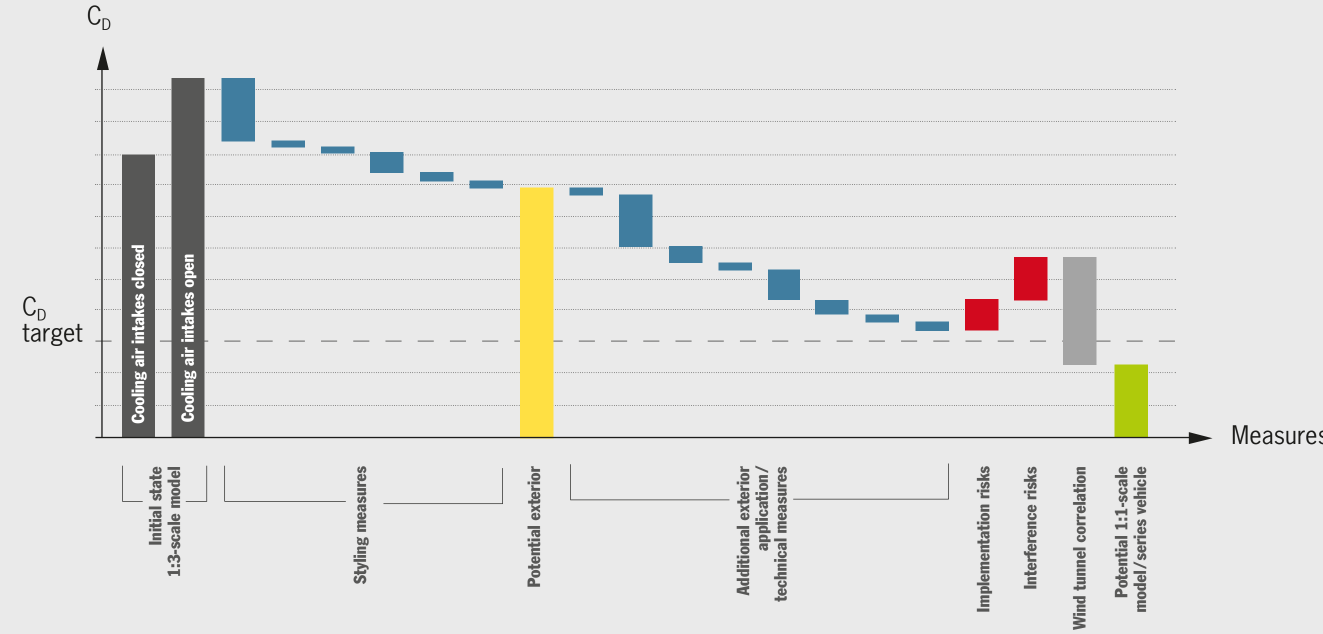
The early phase of a vehicle project is especially relevant for aerodynamics development. At this stage, it is possible to extensively influence the vehicle shape together with the styling department in order to achieve aerodynamics objectives. Within a defined set of limitations, there is still a great degree of freedom in terms of optimizing the basic shape, and changes to the vehicle shell generally remain cost-neutral. To fully exploit the aerodynamic potential of a project and achieve the desired objectives, it is essential to react quickly, flexibly, and cost-effectively to the various changes in the project. Porsche Engineering applies an integrated aerodynamics process comprised of measurements and optimizations in the 1:3-scale model wind tunnel and virtual CFD simulations. This enables the optimal combination of the complementary advantages of both methods.

The 1:3-scale aerodynamics model makes it possible to model optimizing shape modifications and evaluate their effect in the wind tunnel in a very short amount of time. ›

THE DIVERSITY OF AERODYNAMICS: CHALLENGES AND OBJECTIVES

- Drag
- Lift balance
- Engine cooling
- Engine ventilation
- Soiling
- Component forces
- Draft stop
- Aeroacoustics

TARGET VALUE SCALE (SCHEMATIC ILLUSTRATION)



This allows not only for the evaluation of the effect on the aerodynamic coefficients, but above all also the impact on the appearance of the vehicle, together with the stylist. Like this, up to 30 different model configurations can be examined on a single day. The use of a scale model has two advantages: First, it is significantly cheaper both in terms of build costs and wind tunnel costs compared to a 1:1-scale model; and second, the wind tunnel time can be used much more effectively with the 1:3-scale model because changes can be implemented more quickly.

In the early phase of a project, multiple styling variants are usually created in parallel. The creation of a large number of wind tunnel models for each of the designs would be very expensive and the reaction times between the data release and evaluation would be too long—this is where CFD simulation shows its advantages. On the prepared digital platform dataset, the styling designs can be quickly swapped out and thus efficiently evaluated. This makes it possible to assess the aerodynamic potential of the various styling variants at a very early stage in the project.

Optimization with the wind tunnel model

In model design, the primary consideration is the cost-benefit ratio, with the degree of detail of the models being the decisive factor. Porsche model design runs the gamut from simple foam bodies to complex flow-through bodies (DSK) with clay exteriors for modeling shape optimizations, as well as model radiators outfitted with pressure sensors, the mapping of engine compartment flows and a precisely detailed underbody. Based on the customer's objectives, a model mix is developed which achieves the optimal aerodynamic result in view of the specified budget framework.

The greatest advantages of development with scale models are in the flexibility and degree of freedom in the wind tunnel. A shape change can be defined and transferred to the aerodynamics model by an experienced modeler within just a few minutes. Wind-tunnel feedback is immediate. The coefficient changes can be evaluated online and incorporated into the next configuration change. And it's not only possible to achieve optimizations through the addition or removal of clay—the effect of add-on parts such as spoilers or wings can be determined on the spot as well. It is therefore possible to assess the aerodynamic efficiency of different measures and support concept decisions at an early stage.

The results of CFD simulations also support work in the wind tunnel here, too. The virtual development method manifests its huge advantages in terms of flow visualization. Flow separations, vortex structures, and pressure and velocity distributions can be analyzed with great precision from nearly every conceivable viewing position and sectional viewpoint. A morphing tool also enables rapid sensitivity analyses of factors such as rear end lengths, rear end heights, or windshield and rear window angles. The insights thus gained can then be applied to the 1:3-scale wind tunnel model for targeted optimization. The result is an aerodynamically optimized vehicle model. The measures can now be discussed with stylists or development engineers in the presence of the model. Additionally, the model is scanned, for example with a 3D laser scanner, so that it can be made available in a digital format to the styling and technical departments. Based on the diverse potentials for optimization, a forecast of the target for the later series production vehicle is determined (see also the illustration above). Elements such as the underbody covers and radiator grill shutters that will later be developed in detail in the 1:1-scale wind tunnel vehicle are already taken into account at this point.

The target of optimization in the wind tunnel and CFD simulation is to implement enhancements in the project. In many cases, new solutions must be worked out with other technical departments and the styling department. This is also a part of the scope of services offered by Porsche Engineering. Porsche engineers, with many years of experience, support customers on-site with their process knowledge in representing proposals before decision-making bodies as well as in the implementation of the defined measures in order to achieve the best overall package.

Conclusion

The importance of aerodynamics will continue to rise in the future. The objective will be a further reduction of CO_2 emissions and consumption by reducing drag while also generating downforce for optimal driving characteristics and comfort. The aerodynamics engineers at Porsche Engineering approach this challenge with the intelligent combination of computational fluid dynamics and real measurements—and not least, with the experience gained through the development of sports cars. ■

ESSENTIAL AND CHALLENGING

____ In this interview Michael Pfadenhauer, Director Development Aerodynamics/Thermal Management at Porsche AG, talks about the particular challenges facing aerodynamics development in view of new technologies and continuously changing vehicle requirements.

How have the demands on aerodynamics development changed over time?

Michael Pfadenhauer The demands on aerodynamics have become more diverse and complex. While just a few years ago it was enough to present a model outfitted with special measures that had a low C_D value, today the focus has shifted to fleet consumption and thus an overall view of all models, and in particular the highest-selling ones. In addition to this, there are a range of technical questions focusing on performance, comfort and complexity with regard to controllable elements, and, not least, strong cost pressures on solutions that are to be implemented, as well as a pronounced feel for and understanding of the appearance aspects of aerodynamic elements: Nowadays no one accepts solutions that are either beautiful or aerodynamic; the expectation is that premium products will be optimal in both regards. Now more than ever, aerodynamics development is one of the central factors in successful vehicle development, with increasing numbers of involved parties and issues to resolve. That's what makes it so interesting and the challenges in a traditional development discipline so exciting.

What role will simulation play in the future?

Pfadenhauer Even today, without simulations we would not be able to do our work. As such, the capability of using software effectively and interpreting it correctly is a core competence without which aerodynamics development would be unthinkable today. Rapid processes in developing models and in the computing itself, as well as the availability of adequate software and hardware resources, are just as critical as the intelligent interaction with the equally necessary conventional testing methods. It's no accident that Porsche has concluded long-term cooperation agreements both in the computing area with the supercomputer manufacturer Cray and with software suppliers while investing in-house in the construction of our aeroacoustic wind tunnel. That gives us the capability to deliver reliable testing results long before there is any hardware. In early phases, it is now possible to make targeted decisions at a stage in the process when the costs for making changes, both in terms of time and resources, are still at a manageable level. This is the only way of handling hardware-free project phases efficiently. The importance of simulation will continue to rise in the future—but in my estimation, purely virtual development will not be possible.

Michael Pfadenhauer

Michael Pfadenhauer (47) studied aerospace engineering at the Technische Universität München. After completing his post-graduate engineering studies, for ten years he held a managerial position in aerodynamics with Audi in Ingolstadt. He joined Porsche in 2005 and has headed up the aerodynamics/thermal management development area since then.

"Now more than ever, aerodynamics development is one of the central factors in successful vehicle development."

What are the special aerodynamics requirements for Porsche vehicles?

Pfadenhauer We develop vehicles of extraordinary quality for extraordinary customers. The simultaneous achievement of all the typical Porsche juxtapositions of seemingly contrasting values, such as tradition and innovation, performance and everyday usability, exclusiveness and social acceptance, and design and functionality, is the embodiment of these standards. We want to develop products that deliver both low consumption and high performance, i.e. low drag for low consumption and yet high downforce at the same time for high performance on the track. Physics, unfortunately, binds the two in a rather unfavorable manner, such that high downforces are naturally associated with high drag. We could just throw up our hands and accept that that's just how it is. But we don't. At Porsche, the solution for this is known as adaptive aerodynamics, i.e. the targeted adjustment of the aerodynamics to the preferences of the driver or the operating mode. That means low drag when the intention is to drive economically and downforce when performance on the track is called for. Our vehicles can do both—that's what distinguishes us and is a part of the reason for the success of Porsche. The same naturally applies to the design: Both aspects have to fulfill the premium standard to the utmost to be regarded as a premium product on the market and succeed in that environment.

"The importance of simulation will continue to grow in the future."

To what extent do electrified vehicles present new challenges for aerodynamics development?

Pfadenhauer Due to the special characteristics of electric drive systems in automobiles, there is a shift in the loss distribution of the energy required to power the vehicle. The combustion engine is eliminated as a high source of loss, which brings the overall vehicle losses, such as rolling resistance and, in particular for faster electric vehicles, the drag, into the foreground. Moreover, the recuperation options mean that less importance can be given to the vehicle weight. The result is that for such vehicles, aerodynamics plays an even more important role than in conventional vehicles and is therefore an important factor for consumption and range, and thus ultimately for the success of the product. All of the manufacturers are aware of this, and if you look closely, almost all electric vehicles are equipped with special aerodynamic solutions. We pay attention to this issue as well, but when we go forward with it, then naturally with a typical Porsche solution. So you can look forward to finding out what we've come up with. ■

PRECISE AND FLEXIBLE

The new aeroacoustic wind tunnel at the Weissach Development Center

____ The new aeroacoustic wind tunnel at the Development Center in Weissach went into operation in early 2015. Together with the electronics integration center and the design studio with concept design, the three buildings set a new standard for forward-looking vehicle development “engineered and designed in Weissach.” The core objectives of the new wind tunnel are to promote energy-efficient aerodynamics, even greater driving safety and greater comfort in future vehicle generations.

It was already possible to conduct highly precise aerodynamics measurements in the wind tunnel used as yet in Weissach. The new aeroacoustic wind tunnel that went into operation in early 2015 enables even more realistic testing capabilities. The most important reason for this: While the prototypes in the old wind tunnel remained in a fixed position, now they “drive” on a belt system located beneath the vehicle being tested. It simulates the relative motion of the car in relation to the road at speeds of up to 300 km/h. This makes it possible to test the air flow under the vehicle during real driving with even greater precision. But precisely here, in the area around the car’s underbody and wheelhouses, is where there is considerable potential to increase efficiency and stability by enhancing the aerodynamics.

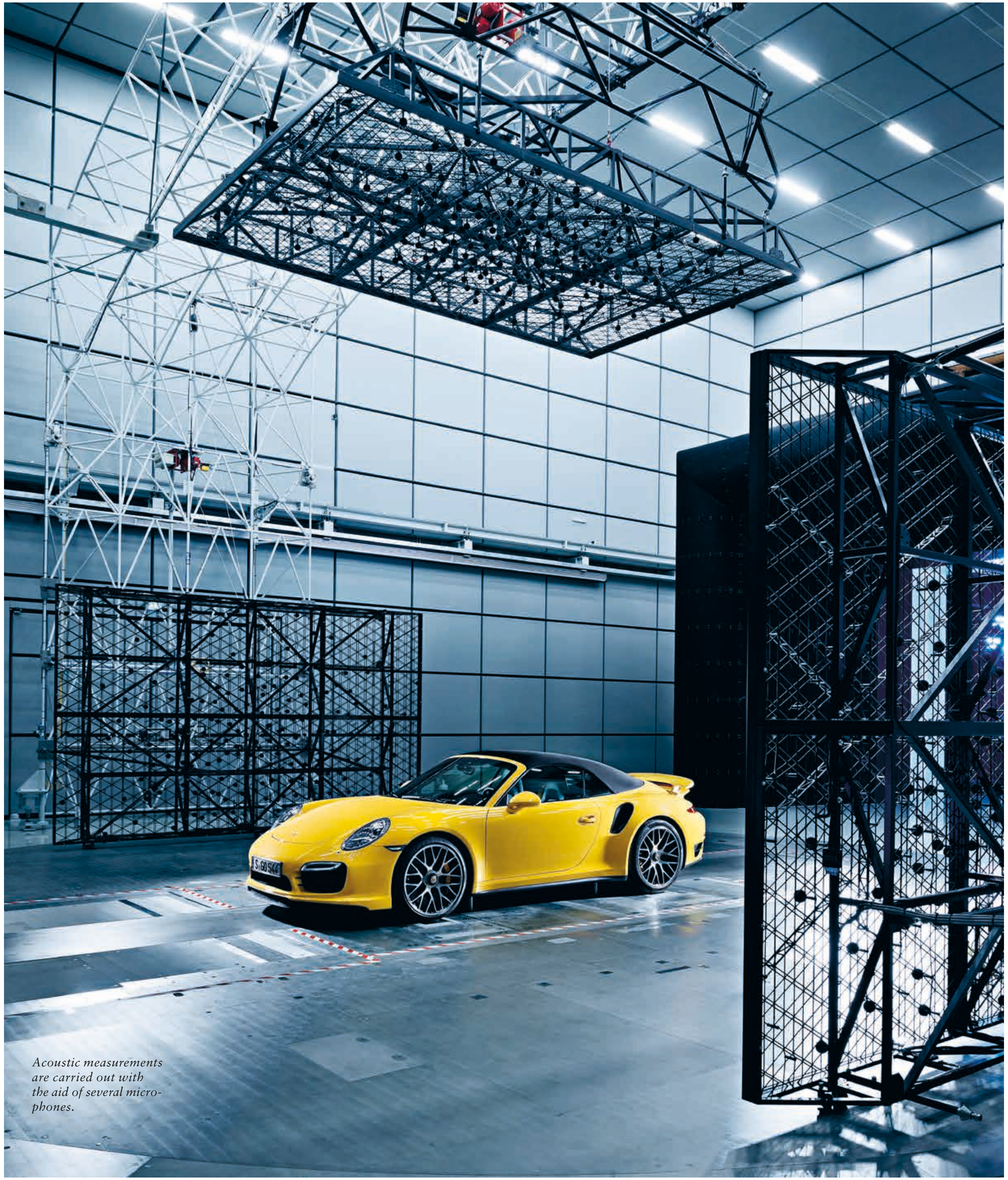
Combined belt systems

The heart of the new wind tunnel is its belt system and scale. A special feature of the Weissach tunnel is that it offers test engineers a choice between two different belt systems. One system has five steel belts: one runs below each of the four wheels and a larger one down the middle below the vehicle floor, enabling even more precise measurements. The other is the one-belt system, which, as its name suggests, consists of a single steel belt that runs below the test object. It reflects real conditions more closely, which has great advantages in many testing scenarios, but yields measurements that are somewhat less precise. Porsche followed the motto “Take two!” in its decision to incorporate both measurement systems in one facility. With the use of an industrial freight crane, it takes just a few hours to switch the systems, which weigh more than 20 tons.

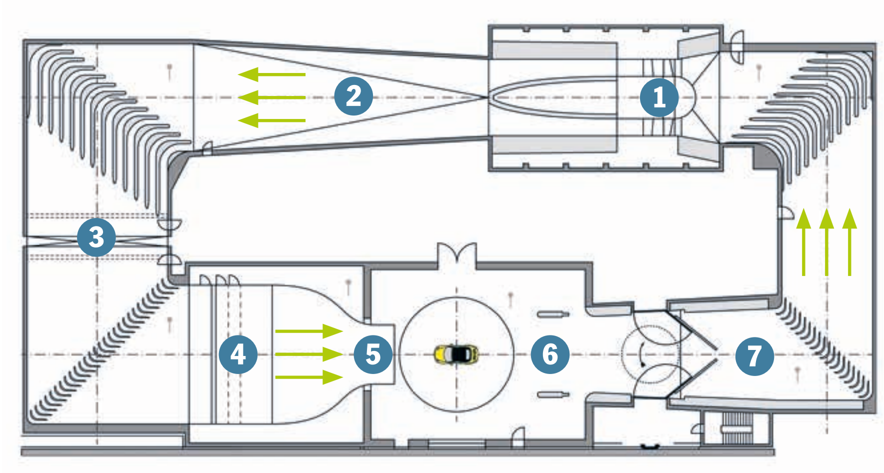
Another crucial benefit of the belt systems is that they allow the engineers to measure the forces that the wind exerts on the car. Linked with a precision scale that stands on its own foundation, the belt system can measure minimal changes in the wind forces on the car or their distribution among the wheels. This measurement in turn enables the engineers to calculate the drag and the up- or downforces on the front and rear axles. ›

911 TURBO CABRIOLET
Fuel consumption
city: 13.4 l/100 km
highway: 7.8 l/100 km
combined: 9.9 l/100 km
CO_2 emissions (combined): 231 g/km
Efficiency class: G

A 911 Turbo Cabriolet in the plenary on a five-belt system.



Acoustic measurements are carried out with the aid of several microphones.



Structure of the new aeroacoustic wind tunnel

1 Fan 2 Main diffuser 3 Heat exchanger 4 Antechamber 5 Jet 6 Plenary 7 Diffuser

Closed air circuit

The wind tunnel has what is known as a Göttingen design (see above). A powerful turbine generates an air flow in a closed circuit, which means that less energy is required. A jet upstream from the actual test section accelerates the wind by a factor of six, and a diffuser downstream of the test section decelerates it again. A powerful heat exchanger removes the heat generated by air friction. The wind is generated by a huge fan with carbon vanes and a diameter of about eight meters. It has a peak output of around seven megawatts, or 9,300 horsepower, generated by an electric motor the size of a small bus. Many of the measurements, such as those to determine drag, continue to be done at the usual European speed on freeways of 140 km/h. However, it is important to be able to generate considerably higher wind speeds, in order to test the structural strength, for example, or to contribute to developments in racing.

Acoustic measurement detective work

The wind tunnel is not terribly loud, however, and at 200 km/h is far quieter than its predecessor. Consequently, certain acoustic measurements can now be done in Weissach which used to be sent to external service providers. Of interest here is not so much the absolute noise level, but some detailed detective work. For example, how does a certain mirror shape or a new door seal affect the sound pattern? Several hundred microphones are set up on the car in the test section, allowing a computer to generate a three-dimensional representation of the sound propagation from the car. ■

FUTURE-ORIENTED AND UNIQUE

____ Dr. Hauke Stumpf, Director Test Facilities at Porsche AG, explains the features of the new wind tunnel.

What are the characteristics that make the new wind tunnel so special and distinguish it from the previous wind tunnel?

Dr. Hauke Stumpf Thanks to the ground simulation with the moving belt, we've come a lot closer to the reality of driving on the road. In doing so, we can use either the five-belt system or the single-belt system. That enables us to address different requirements flexibly and yet still stay focused on our primary objective: precision. We need to be able to detect force changes on the order of one Newton—and the new wind tunnel gives us that capability. Moreover, there are not very many automotive wind tunnels that enable a wind velocity of 300 km/h with such a large flow cross-section and such a high flow quality. For us as a sports car manufacturer, that's especially important, because our vehicles reach those speeds, including on the track.

Before a wind tunnel can be put into operation, it first has to be prepared for its task. What's important in that process?

Stumpf Nearly all of the components are custom-built parts that only a few suppliers worldwide are capable of producing. And just as musical instruments have to be tuned before a concert, a wind tunnel also has to be precisely checked and configured before it can be used. For example, a team of experts tested the distribution of the air flow in the test section for weeks. For the results to be viable, the air flow parameters in the room may only fluctuate by less than one percent. We are very pleased to come in well below that.

In what way is the new wind tunnel equipped for the requirements of automotive development of the future?

Stumpf A variable belt system of the type we have is the first of its kind worldwide. This not only makes it possible to measure and compare the results for a vehicle with different ground simulations in the same wind tunnel, but it also makes us better prepared for the future: If substantial advances in ground simulation methods were to be developed over the next few years or decades, we would have the ability to respond with an additional or modified system configuration. In a conventional wind tunnel like the one we have had since 1986, the construction would not allow that. If you want to make a modification there, you have to take the facility out of operation for a lengthy period of time. That would be very problematic for vehicle development, with its continual need for measurement. With our variable belt system, we are much more flexible.

> *"Just as musical instruments have to be tuned before a concert, a wind tunnel has to be precisely checked and configured before it can be used."*

What advantages emerge from the cluster of buildings that encompass workshops, design and aerodynamics development?

Stumpf The close proximity of the facilities enables aerodynamics developers to test design studies very quickly with the highest degree of confidentiality. The wind tunnel is used again and again throughout the process, from the early development stages of design studies to the testing of vehicles that are ready for production. Moreover, the closeness promotes cooperation between different technical disciplines not only from a technical standpoint, but also from a human one. ■

Dr. Hauke Stumpf

Dr. Stumpf (48) studied mechanical engineering with specializations in lightweight construction and fluid mechanics at Technische Universität Darmstadt and Cornell University in New York. He earned his doctorate in connection with his research on composite materials in Hamburg and Paris. After many years in leading positions with a large aviation company, Dr. Stumpf joined Porsche in 2006 and is the Director Test Facilities at the Development Center in Weissach today.

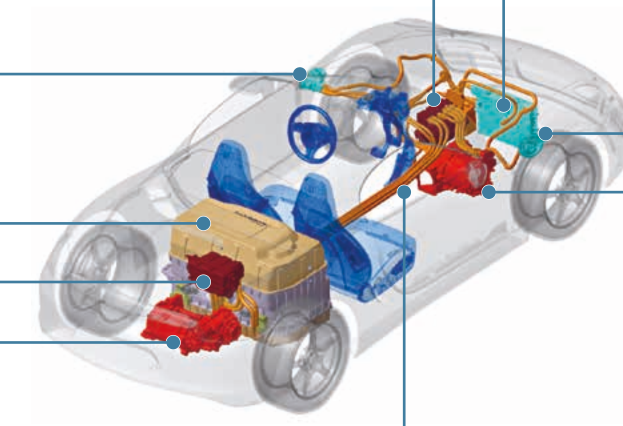
e-generation

Research project with a positive balance

____Under the leadership of Porsche, a research consortium developed new components for electric vehicles and tested them in three electric sports cars based on the Porsche Boxster. In early 2015 the *e-generation* project sponsored by the German federal government and in which Porsche Engineering played a major role came to an end. Significant gains were achieved in terms of the range, cost reductions and day-to-day usability of electric vehicles.

By Stefan Bender, Dr. Hartmut Chodura, Manuel Groß, Thorsten Kühn, and Volker Watteroth

Research vehicle of the project e-generation



Overview of high-voltage components in the vehicle

Back in 2010, three electric-powered Porsche Boxster research vehicles were created under the aegis of Porsche Engineering. The cars were driven over 70,000 kilometers and evaluated in several hundred life-like test drives. The vehicle concept was a success. The driving behavior and reliability were rated positively, while limitations were noted—as expected—particularly with regard to range and vehicle weight.

After that, the three-year *e-generation* project was started in April of 2012 with 13 partners from the fields of research and industry. The project was supported by the Federal Ministry of Education and Research (BMBF) and ended on schedule in early 2015. The primary objectives were the following:

> reduced electrical energy demand (focus: drive unit and air conditioning),
> reduced vehicle weight,
> reduced costs for drive components,
> comfort and day-to-day usability like that of a series Porsche.

The test vehicles were three newly built prototypes from the Development Center in Weissach. The vehicles received the necessary approvals in late 2013 and have been tested on public roads since that time.

Drive concept with two electric motors and all-wheel drive

In the concept phase, numerous drive models were examined and evaluated through simulations. The primary premise was to find a configuration that would meet the project objectives and yet enable the driving characteristics expected of a Porsche sports car. Moreover, the existing construction space and the configuration of the chassis had to be taken into account. Given these circumstances, a drive concept emerged in which a transversely mounted electric motor on each of the front and rear axle would power the vehicle.

Two new electric motors designed for greater efficiency were developed under the aegis of Robert Bosch GmbH. As part of that process, RWTH Aachen University designed a permanently excited synchronous motor (PSM) and an asynchronous motor (ASM) was created in collaboration with the Braunschweig University of Technology. For both motors, Bosch subsequently handled the design and manufacturing for operational use. ›

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The PSM powers the front axle and the ASM is located under the rear luggage compartment. Two power electronics units from Bosch control the motors. The drive management system is based on Bosch software, while Porsche provided the application and parameterization. The front axle has up to 120 kW at its disposal, while the rear axle has a maximum output of 140 kW. Together they can accelerate the vehicle from 0 to 100 km/h in 5.2 seconds. The driver can also switch between the driving programs Normal, Sport and Range. In Range mode, mainly the more efficient PSM on the front axle powers the car. In Sport mode, both axles are always supplied with power, which enables typical Porsche driving characteristics.

The high-voltage battery for the research project was designed and developed by Porsche Engineering.

Energy supply through newly developed high-voltage battery

The high-voltage battery (HV battery) in the 400 volt range was designed and developed by Porsche Engineering. Thanks to rigorous lightweight construction and modern cell technology, approximately 35 kWh of energy are available, or 20% more than in the 2010 prototype. The usable electric power tops out at around 270 kW.

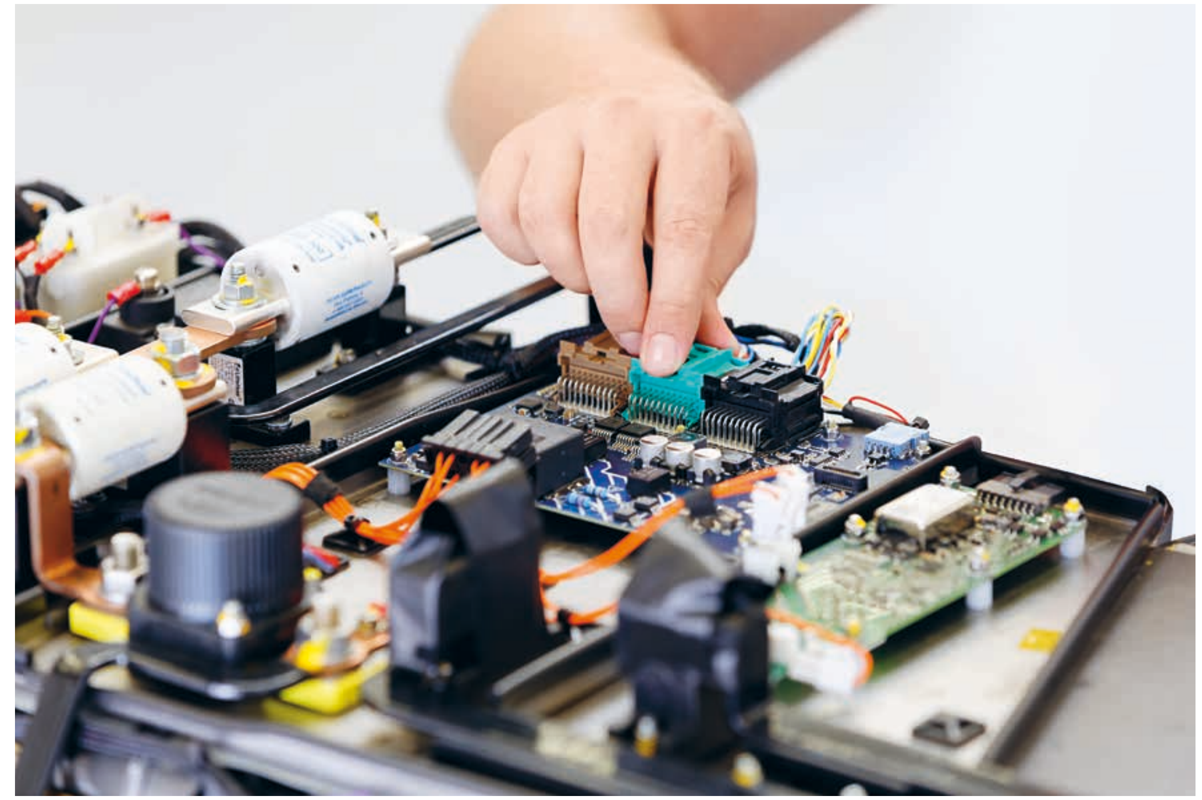
The battery is liquid-cooled and can be heated up via PTC heating foils. A new cooling concept was developed that dispenses with the previously common, relatively heavy metal plates. Instead, cooling elements were developed that are directly attached to the cell poles. This resulted in weight savings and improved heat dissipation.

The prototypes have several connections for charging the battery. Depending on the energy source, the integrated charger delivers up to 22 kW of electric power. This makes it possible to charge an empty battery in roughly one-and-a-half hours. At rapid charging stations, the battery can be charged to 80% of its capacity in less than 20 minutes.

The battery development in the research project is a further development of the components used in the previous vehicle in 2010. The principle is based on the following design:

> two cell module layers with five cell modules each,
> circular support frame as the central structural element,
> two housing covers in a fiber-reinforced lightweight design,
> division of traction paths within the battery into one connection each in front and back.

The fundamental difference to the concept of 2010 is the in-house development of the cell modules using pouch cells from the LG Chemicals company. The module development features numerous innovations: The independent modules with integrated cooling/heating, the Battery Management System (BMS) and the modular structure within a minimal construction space create a compact package. The connection of the cell terminal and surface cooling results in a highly efficient module cooling for performance-oriented applications. The developers also broke new ground with the first-time use of a PTC heating foil for efficient heating directly on the cell. Finally, the battery management system is a completely in-house development by Porsche Engineering for voltage ranges up to 800 volts and can be applied optimally in various drive systems.



The battery management system (BMS) for voltages of up to 800 volts can be applied optimally to various drive systems.

Over the three years of the project, the engineers developed a complete high-voltage energy storage unit and built three prototype batteries. Every battery module has a cell controller developed by Porsche Engineering. It monitors all cell voltages and temperatures of the module. The data is transmitted to the central control unit of the battery. That is where the evaluation and monitoring of electric insulation takes place. Via the CAN bus, other components can also receive this data.

Distribution of the cooling medium in the battery is done using a parallel connection of the module coolers with one coolant distributor per module layer. The coolant connections on the module cooling system and the coolant distributors are comprised of standard parts from the Norma Group. This guarantees tight seals and high quality. The battery also has two non-spill quick release connectors from the Stäubli company that enable the fast and easy installation and removal of the traction battery including frame.

A glass fiber-reinforced cover protects the battery against spray from above, while a Gore membrane ensures pressure regulation. The complete electrical shielding for good electromagnetic compatibility (EMC) is done using a coating of metalized paint on the two plastic covers on the top and bottom. The technical specifications and specific operating data of the battery are summarized on the following page.

Crash-safe mounting of the battery in the vehicle rear

The battery package is mounted in a crash-safe location in the rear of the vehicle. Safety is assured above all by the ring-shaped support frame made of high-strength aluminum. Its structure-optimized design enables it to withstand all normal loads as well as crash loads for accelerations of up to 60*g*. The support frame essentially transfers the rear crash concept from the series Boxster with a combustion engine to the electric vehicle. The two cell module layers are permanently attached to the support frame—the upper one directly, and the lower one indirectly through a glass fiber-reinforced plastic cover.

To accommodate the 360-kilogram battery in the vehicle, a few changes to the body-in-white were necessary. The changes affected both the rear of the vehicle, to which the battery is fastened, and the front end in order to create space for the front-axle drive unit. On production lines designed for series production, special parts such as a hybrid ›

Technical data

Cell manufacturer	LG Chem
Cell type	Pouch P2.6 (PHEV)
Cell chemistry	NMC
Capacity	25.9 Ah
Rated voltage	3.7 V
Circuitry	100S4P, 10 cell modules
Energy content	38.3 kWh nominal, 35.8 kWh usable
Output	270 kW (420 V, 650 A)
Current	370 V nominal, 410 V maximal
Range	> 200 km
Battery cooling	Terminal and area cooling with water / glycol

HV battery specifications

Cell share of total volume	31% (84 l of 271 l)
Module share of total volume	61% (166 l of 271 l)
Cell share of total mass	64% (230 kg of 362 kg)
Module share of total mass	81% (295 kg of 362 kg)
Structure share of total mass	15% (54 kg of 362 kg)
Power density per kilogram	754 W/kg
Electric energy per kilogram	106 Wh/kg

cross member developed by Porsche Engineering and made of fiber-reinforced plastic were built (see *Porsche Engineering Magazine* 1/2015).

Thermal management reduces energy consumption

Batteries function best in climatic conditions that are also agreeable to humans. If temperatures are too low or too high, the lifetime of the energy storage unit is affected and the power available is also lower at low temperatures. For that reason, batteries need to be cooled and heated depending on ambient conditions. The energy required for that is drawn from the battery itself, which, however, reduces the range.

In case of low exterior temperatures, the battery is heated during the charging process with a portion of the applied electricity. That saves energy from the battery and ensures that the drive system has access to the maximum performance power capacity as soon as the drive begins. As the efficiency of the battery is roughly 95%, the self-heating process, at roughly five kilowatts, is relatively minimal when the vehicle is operating at high energy levels. Only when exterior temperatures exceed 30 degrees Celsius is a cooling cycle required that cools the battery to below the ambient temperature through a cooling process.

Since electric motors and HV batteries are highly efficient, they produce relatively little residual heat compared to a combustion-powered vehicle. But if it is necessary to heat the passenger compartment, energy from the HV battery must be used. This naturally reduces the range of the vehicle.

As part of the *e-generation* project, the Mahle Behr company led the development of a thermoelectric heat pump with which low residual heat can be warmed to a temperature that is suitable for heating the passenger compartment. This heat pump works most efficiently at ambient temperatures between 10 and 15 degrees Celsius, as are common in Central Europe. The coefficient of performance is an impressive two. This means that the energy requirements of the high-voltage battery can be reduced to 50 percent.

Testing confirms day-to-day usability

In the first testing phase, the prototype covered several thousand test kilometers while being continuously enhanced and optimized. To be approved for road traffic, the vehicle was tested for functionality and robustness at the testing grounds in Weissach. The optimization of the drive system and chassis was primarily conducted at the Porsche testing grounds at Nardò in southern Italy. The prototypes held their own in the wintry Alps as well: the fully electrical Boxster was ready to go even after a night of negative 25 Celsius outdoor temperatures.

Various assistance systems were developed over the course of the project to improve the day-to-day usability. Together with the Karlsruhe Institute for Technology (KIT), a linear guide system was developed that uses predictive route data to calculate the most efficient speed plan for the route ahead. The system not only enables the vehicle to operate optimally in traffic, but also makes it possible to navigate corners safely and dynamically when driving on open rural roads. Together with RWTH and KIT, a coasting assistant was developed that advises the driver when it is the optimal time to take the foot off the accelerator before corners or speed zone changes.

Outlook

The *e-generation* project will be followed by *e-volution*: Together with partners from the fields of industry and research, Porsche is now pushing the ongoing development of electric vehicles in the third successive project. *e-volution* is aimed at further increasing the range, day-to-day usability and performance of electric vehicles. ■

Two Porsche Boxsters from the e-generation *research project on a wintry test drive in the Alps.*

Electric. Efficient. Emotional.

____Dirk Lappe, Technical Director at Porsche Engineering, on future mobility concepts, digitization and electric driving pleasure.

Interview: Frederic Damköhler; Photos by Jörg Eberl

Mr. Lappe, what do you think the car of the future will look like?

Dirk Lappe Many people immediately think of autonomous driving when they think of the car of the future. So I would like to begin by pointing out that the car of the future will always be strongly influenced by environmental concerns and the imperative to reduce CO_2 emissions, and will require massive investments and substantial efforts on the part of us engineers. Future vehicles will have energy consumption values that would have been unimaginable just a few years ago and comprise smart concepts that utilize renewable energies in appropriate ways for individual mobility. It is also important to bear in mind that mobility cannot be separated from deliberations on the environment and energy in general, but must be an integral part of the overall global strategy for decarbonization. From this point of view, autonomous driving is, to my mind, more of an application in the context of smart mobility concepts that contributes to CO_2 reduction, but not an end in itself.

What environmental and energy issues will have the greatest impact on the car of the future?

Lappe By 2020, greenhouse gas emissions are to be reduced by 40 percent compared to 1990 figures and plans are in place to scrap nuclear power as a bridging technology by 2022. And by 2050, at least 80% of gross energy consumption is to be covered by renewable energy sources. Targets are also in place for a 50% reduction in primary energy consumption and a 25% reduction in electricity consumption compared to 2008 figures. By 2050, energy consumption for traffic is set to be reduced by 40% over 2005 figures. The EU has also taken up the issue of exhaust emissions and defined targets that will go into effect in 2020 according to which the entire EU new vehicle fleet of a manufacturer can emit only 95 grams of CO_2 per kilometer according to the specifications of the European consumption cycle NEDC.

How will we get there?

Lappe To achieve these objectives, it is necessary to exploit the potential for greater efficiency in the industrial sector and expand the power grid in a manner that is as efficient and environmentally sound as possible. Digitization is likewise not an end in itself, but should rather primarily be a means of directing traffic and energy flows in an intelligent way. In short, it will require major investments and effort on the part of many actors involved in the process. It's not enough for us simply to build electric vehicles; the overriding framework has to be in place for those cars to actually be bought by consumers. The new mobility services being announced in Silicon Valley that will allegedly flow from the advent of autonomous vehicles, or potentially changing business models due to new players emerging as competition to the conventional automotive industry, are, for now, either of secondary importance, or indeed counter-productive, in resolving the CO_2 problem.

Do you believe that electric vehicles will be successful?

Lappe Of course! Electric drive systems offer, first of all, the possibility of CO_2-neutral and zero-emission mobility. Another bit of good news: electric motors also offer an outstanding driving experience. Being CO_2-neutral and fun to drive are not mutually exclusive. An electric vehicle is a highly emotional product. Due to the characteristics of electric motors, they develop very high torque from the outset, which is reflected in extremely dynamic acceleration from a standstill. Electric vehicles are also highly efficient and exceptionally maintenance-friendly. An electric drive unit requires only a small construction space and enables new, attractive interior concepts. ›

Dirk Lappe, Technical Director of Porsche Engineering since 2009

What do you see as the biggest hurdles for electric vehicles?

Lappe The biggest challenge, now as in the past, is storing the electric energy in the vehicle. The battery system in an electric vehicle is heavy and expensive and still far inferior to conventional vehicles in terms of the available amount of energy that can be transported. In small electric vehicles, the battery accounts for more than half of the sale price.

As battery systems increase in size, another problem comes into play: the subject of charging times. With a battery size of 80 kilowatt hours and a typical charging capacity of 30 kilowatts, a full fill-up at the charging station takes two-and-a-half hours. Of course the situation will arise that you didn't charge the car overnight at home and now have to take a lengthy unplanned drive. And the idea that the "tank" is constantly empty without having the capability of re-charging quickly is tough to swallow for the consumer. One solution to the problem is raising the charging capacity to 300 kilowatts. This reduces the charging time to just over 10 minutes. To achieve such high charging capacities, we need to find new ways of moving forward, such as raising the charging voltage from 400 to 800 volts.

"We are developing a sustainable, highly appealing future that I am very excited about."

How will the problem of energy storage be resolved in the future?

Lappe The storage capacity of lithium-ion batteries today is around 100 watt hours per kilogram. In the Boxster E research vehicle with a consumption of roughly 140 watt hours per kilometer, ideally this is enough for a range of 270 kilometers, but the high battery weight of some 360 kilograms also contributes to a significantly higher overall weight as compared to a gasoline-powered model. The limit for lithium-ion cells is currently estimated at roughly 200 to 250 watt hours per kilogram; the ranges possible within those limits are expected to double in the next five years. The general assumption is that between 2020 and 2030 we can expect a technological leap to more than 500 watt hours per kilogram, for example in the direction of lithium-sulfur. This technology could revolutionize electric vehicles in terms of range and weight. For lithium-air batteries, between 400 and 2,200 watt hours per kilogram are being talked about, though I don't believe that this technology will be used in the foreseeable future.

Are fuel cells still an alternative?

Lappe The subject of a "hydrogen transformation" is indeed back in the press. While the technology is already mature enough for market launch, the associated costs are still too high. The high platinum content in the catalysts and the expensive insulating material for the hydrogen tanks ensure that the material costs will remain significantly above those for batteries for a long time. Although many components would actually be ready for series production from a design standpoint, there is a lack of suppliers that would have the capability to produce high unit numbers. Moreover, to date there is no established network of fueling stations and it looks likely to stay that way in the near future. Thus, in my view, a sensible battery or plug-in hybrid concept will continue to be far superior to a fuel cell concept both in terms of application and the cost-benefit ratio for a long time to come, while achieving similar sustainability performance through the use of liquid or gaseous fuels from renewable sources.

What will these cars' interiors be like?

Lappe The interior of the car of the future will look different. The interior will be designed to enable both autonomous and non-autonomous driving. The operating concept will change radically. Even steering wheels will look different than they do today and will fulfill additional functions. New types of user interfaces are just around the corner. We're prepared for this and are massively expanding our software capabilities.

What role does Porsche Engineering play in all of these developments?

Lappe Porsche Engineering is committed to playing an active role in shaping the world of tomorrow – particularly with regard to mobility questions, of course. Entire vehicles, or individual components and modules, are continuously optimized to meet the demands of the future. Beyond innovation and efficiency, environmental issues and sustainability are focal points in these developments. As an integral part of Porsche development, we are active in all areas of future vehicle development, including in the fields of electric drive systems and smart mobility. Porsche Engineering is the strategic partner for many customers in the design of complete electric drive systems, a field in which we can boast across-the-board expertise, from the idea on a blank sheet of paper to testing of the final product at the Nardò Technical Center.

What will the overall mobility scenario of the future look like?

Lappe By the year 2030, there will be massive changes and challenges in the field of mobility. Worldwide, more and more people are living in large cities. Particularly in less-developed countries, the living conditions in cities are more attractive for many. Currently some 100 million Chinese migrant workers are flowing into the cities from rural areas. In 2008, for the first time, more people lived in cities than in rural areas; meanwhile nine percent of the urban population worldwide lives in megacities. This situation of having such a large number of people living in tight quarters inevitably leads to new urban problems and challenges. The vehicle manufacturers have to adjust to that, and that is already happening in many areas.

The relatively short distances within megacities will, within the foreseeable future, increasingly be driven in electric-powered vehicles. So plug-in hybrids and electric vehicles will be an integral part of the urban scenery. In the field of two-wheeled vehicles, electromobility has long since begun its march to dominance in China. Existing roads for cars can be expanded to include additional lanes for motorcycle-like vehicles. While stationary, these single-track vehicles can be stabilized by a rotary drive that returns its energy while the vehicle is in motion.

To what extent will these vehicles be connected?

Lappe My hypothesis is that drivers in the year 2030 will no longer sit in traffic jams because intelligent traffic control systems will direct traffic flows in a way that ensures that traffic jams do not form in the first place. If a traffic jam did occur under exceptional circumstances, this will not bother the driver of the future overly because it will be possible to pursue normal activities in the car as if one were at home or in the office. So one vision for the future would be a large city in the year 2030 in which completely connected cars of all classes are directed on multiple levels. Local and long-distance traffic are perfectly integrated in an intermodal concept. People's need for individual mobility would still exist, however, with one's own personal vehicle representing a part of one's individual lifestyle.

So mobile self-determination will not end with autonomous vehicles?

Lappe The desire for mobility is as old as humanity itself. In 30 years there will still be people who want to explore their surroundings or drive to the countryside with their families. We at Porsche Engineering want to play our part in making the future better and more sustainable. Everyone will be moving around significantly more efficiently than today. That applies both to the consumption and emissions of the vehicles, but also to a more pleasant travel experience thanks to the connectivity of the vehicles. There will continue to be areas in which autonomous driving makes little sense or the human simply does not want to have the "external control" element.

Ferry Porsche once said that the last car ever built will be a sports car. What that means to me in a more general sense is that even in future vehicles, driving pleasure and the appreciation of having one's own, personal mobility will continue to be the focus. So we're not satisfied with simply furthering the development of the here and now. Together with our customers, we are developing a sustainable, highly appealing future that I am very excited about—and in which I can still get behind the wheel and drive if I so desire. ■

Dirk Lappe

Dirk Lappe (52) studied electrical engineering with a specialization in communications engineering at Braunschweig University of Technology. After his studies, he joined the research department at Robert Bosch GmbH in Hildesheim, Germany, and worked there from 1989 to 1996. There he worked on various projects in the field of image processing and transmission and was involved in the development of the MPEG-4 and UMTS standards. As the head of the European projects Mobile Audio Visual Terminal (MAVT) and Mobile Multimedia Systems (MoMuSys), between 1992 and 1996 he represented the European platform for MPEG-4 and the multimedia services of UMTS in the Mobile Project Line Assembly (MPLA) in Brussels. From 1996 to 1998, Dirk Lappe headed up UMTS development at Bosch Telecom GmbH. In 1998 he joined Harman Becker in Karlsbad, Germany, as General Manager for Strategic Programs and established the telematics development department. In 2002, Dirk Lappe joined Porsche Engineering and initially took over as director of the Electrics/Electronics department. He has been the Technical Director of the company since 2009. Dirk Lappe holds more than 70 invention disclosures and patents.

911 CARRERA MODELS (TYPE 991 II)
Fuel consumption (combined):
9.0–7.4 l/100 km;
CO_2 emissions (combined):
208–169 g/km;
Efficiency class: F–D

The New Porsche 911 Carrera

Greater efficiency and performance

No model embodies the Porsche brand so much as the 911. For over five decades, it has brought design, performance, everyday usability and efficiency together in unparalleled harmony—as does the new generation of that model line. With innovative turbo flat engines, an enhanced chassis with an even more impressive combination of performance and comfort, and a new infotainment system, it is perfectly suited to carrying on an unparalleled tradition. And the optional rear-axle steering being offered for the first time in the Carrera models extends the driving-dynamics spectrum in an impressive fashion. The new 911 Carrera also boasts a bevy of exterior refinements: They range from new headlights with four-point daytime driving lights and door handles without recess covers to a redesigned rear lid with vertical flaps and new rear lights—including, among other features, the characteristic four-point brake lights. In the interior, the new, standard Porsche Communication Management (PCM) with a multi-touch screen, offers a significantly expanded range of functions and simplified operation.

The engine in the 911 Carrera S: 3.0-liter, biturbo, flat-six engine with 309 kW (420 hp)

Increased power, torque and efficiency: the new biturbo flat engines

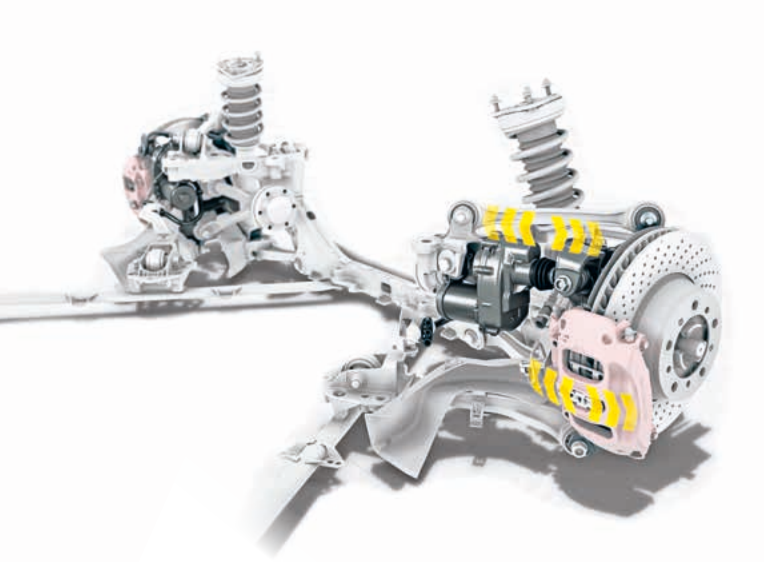
Thanks to over four decades of experience with turbo engines—both in the racing milieu and series sports cars—the newly developed engines of the 911 Carrera achieve top marks in terms of performance, driving pleasure and efficiency. The completely new generation of biturbo engines and the central location of the injector in the combustion chamber increases driving pleasure to create an even more intense experience: commanding power even at low rpms, spontaneous unleashing of power up to the highest engine speeds, and yet significantly lower consumption. 272 kW (370 hp) in the rear of the 911 Carrera are just waiting to be converted into vigorous propulsion, while the engine of the 911 Carrera S boasts an even more impressive 309 kW (420 hp). In both cases an additional 15 kW (20 hp) over their respective predecessors. The boost in torque is even more striking: With 450 Nm in the 911 Carrera and 500 Nm in the 911 Carrera S, both engines add an imposing 60 Nm. The driver benefits not only from this boost in the bottom line; it also means that the full torque can be converted into sprinting power from 1,700 rpm. Maximum torque is available across the entire range from there to 5,000 rpm. At the same time, the new engine generation is considerably more economical, with consumption dropping by up to a liter per 100 kilometers depending on the version. According to the New European Driving Cycle (NEDC), the 911 Carrera with the Porsche double-clutch transmission (PDK) now uses just 7.4 liters of fuel per 100 kilometers (0.8 l/100 km less than before), and the 911 Carrera S with PDK comes in at 7.7 l/100 km (1.0 l/100 km less).

There are many opportunities for the new 911 to show the benefits of its turbo engine.

0 to 100 km/h in 3.9 seconds

The driving performance of the new 911 is no less impressive: The 911 Carrera Coupé with PDK and the optional Sport Chrono package sprints from 0 to 100 km/h in 4.2 seconds—two-tenths of a second faster than its predecessor. The 911 Carrera S with PDK and Sport Chrono package performs the same feat in just 3.9 seconds (also a 0.2-second improvement). It is thus the first 911 in the Carrera family to beat the magical 4-second barrier. The top speeds of both models have also soared to new heights: The maximum speed of the 911 Carrera is now 295 km/h (an increase of 6 km/h), and the 911 Carrera S now reaches 308 km/h (an increase of 4 km/h).

In combination with the Sport Chrono package, the 911 Carrera has for the first time a mode switch in the steering wheel derived from the hybrid mode switch in the 918 Spyder. The mode switch consists of a revolving ring with four positions for the driving programs “Normal,” “Sport,” “Sport Plus,” and “Individual.” The last setting enables the driver, depending on equipment, to configure an individual vehicle set-up, for example Porsche Active Suspension Management (PASM), active engine operating cycles, the PDK shift strategy and sport exhaust system. In conjunction with the PDK transmission, the mode switch features an additional button—the “Sport Response Button.” When this button is pressed, the drivetrain is preconditioned for optimal acceleration for 20 seconds, for example for planned overtaking maneuvers. The system shifts into the optimal gear and the engine control is temporarily primed for greater responsiveness. ›



The optional active rear-axle steering in the 911 Carrera S

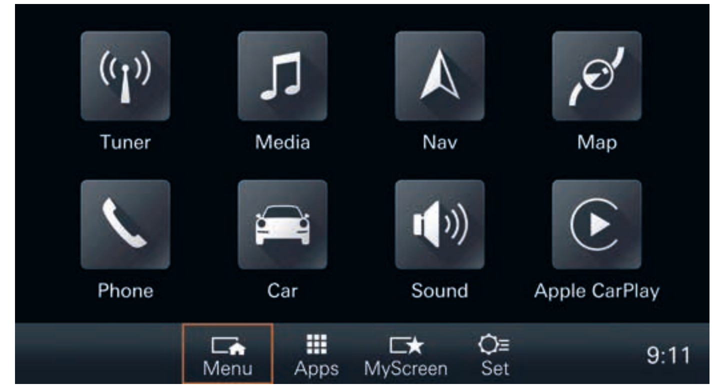
New configuration of the PASM suspension

The 911 Carrera is the benchmark for driving dynamics in an all-around sports car. Generation after generation, Porsche has been honing the combination of everyday comfort and track performance. The newly configured, 10-millimeter lower PASM suspension is now standard on all Carrera models for the first time. This further increases stability during fast cornering. At the same time, the new generation of dampers with their further enhanced control maps both ensure greater comfort through their more finely-tuned responsiveness and yet also improves car body control during dynamic driving. New standard wheels with five slim double spokes are outfitted with tires with lower rolling resistance and improved performance. In all variants, the width of the rear rims increases by 0.5 inches to 11.5 inches, and the rear tires of the 911 Carrera S now measure 305 millimeters across instead of 295 millimeters.

With the optional active rear-axle steering in the 911 Carrera S, the suspension technology from the 911 Turbo and the 911 GT3 is used. This gives the 911 considerably greater agility while cornering. It is also characterized by great stability when changing lanes at high speeds. At the same time, it handles urban traffic thanks to a half-meter shorter turning circle superbly. The improved handling is transmitted to the driver through the new steering wheel generation, whose design is based on the steering wheel from the 918 Spyder. The standard steering wheel has a diameter of 375 millimeters, while the optional GT sports steering wheel is 360 millimeters in diameter. And for unlimited day-to-day usability, Porsche offers a hydraulic lift system with integrated lift cylinders in the front axle spring struts. At the press of a button, the ground clearance of the spoiler lip rises by 40 millimeters within 5 seconds to prevent scraping the ground with steep garage entrances and the like.

More comfortable PCM system

The new 911 Carrera models also come standard with the newly developed PCM (Porsche Communication Management) system, including an online navigation module and voice control. Similar to a smartphone, the PCM system can be operated using multi-touch gestures on a seven-inch screen. It also allows handwritten command entry. Cell and smartphones can also now connect via WiFi. The smartphone storage area, integrated for the first time in the center armrest, enables battery-conserving charging and optimized signal reception. Also new is the option



Porsche Communication Management 4.0

of connecting an iPhone with PCM system to use Apple CarPlay. Real-time traffic information is available for significantly improved navigation that gives the driver a quick overview of the traffic situation and guarantees dynamic route modification based on traffic conditions. Also improving orientation is the new integration of the Google Earth and Google Street View services. Other elements in the PCM system include Porsche Car Connect and the Porsche Connect app, which enable remote control of vehicle functions, transmission of destinations to the PCM system for navigation purposes as well as the use of music streaming services from third-party providers through the PCM system.

New and improved assistance systems for a greater degree of personalization

With additional new and improved assistance systems, the 911 Carrera can be personalized to a greater degree than ever before: The optional cruise control can now also brake moderately if the defined speed has been exceeded, for example due to a descent. The also optional ACC (Adaptive Cruise Control), in conjunction with the PDK transmission, now also features a coasting function that decouples the engine from the transmission and allows the car to coast when appropriate, which saves fuel. The optional Lane Change Assist feature uses radar to monitor traffic behind the vehicle and uses LED lamps in the left and right of the mirror triangle to warn the driver of approaching vehicles in the blind spot. In addition, Porsche has enhanced the active safety of the sports car with the standard multi-collision brake.

The 911 Carrera has been the best-selling sports car in the world for decades. The new generation has now arrived to build on that lead. With innovative turbo flat engines, an enhanced chassis with an even more impressive combination of performance and comfort and a new infotainment system, it is perfectly suited to carrying on an unparalleled tradition. ■

Dynamic Vehicle Electrical System Simulation

The degree of electrification in vehicles is rising constantly: New driving dynamics and assistance systems work together with actuators that draw their power from the vehicle electrical system. However, such high-current consumers, with their peak currents, can place enormous demands of a completely new magnitude on the vehicle electrical system. The result: It is no longer possible to ensure the safe functioning of the vehicle without dynamic simulation of the vehicle electrical system.

By Niklas Guder

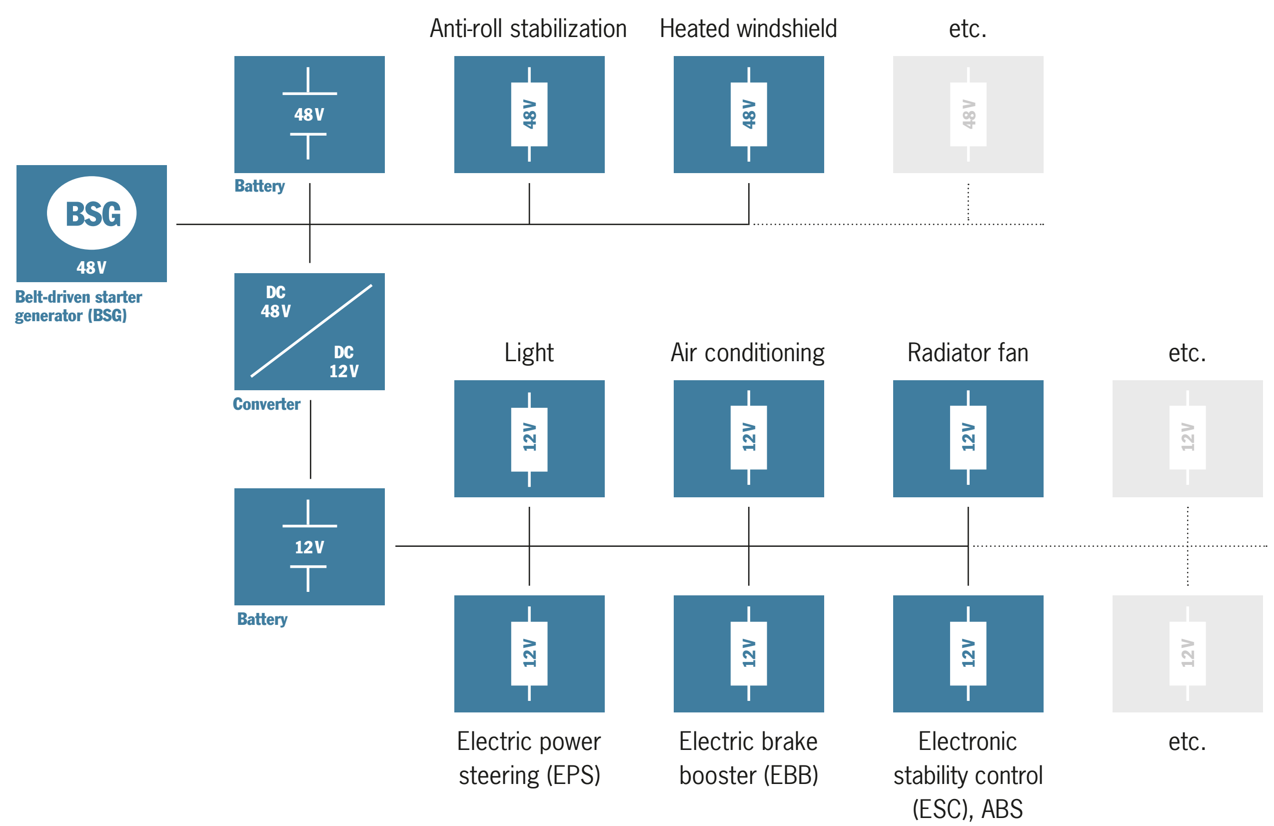


Figure 1: Vehicle electrical system with two different voltage levels

The low-voltage vehicle electrical system: central nervous system of the vehicle

Developments of recent years have clearly demonstrated that the low-voltage vehicle electrical system (12-volt vehicle electrical system) is becoming increasingly important. With increasing electrification, the demand for energy and performance rises steadily. The days in which the generator had to power just a few components, such as the main energy consumer—light—are long gone. (The colloquial name for an alternator in German—“light machine”– highlights this history.) Vehicles today include ever more driver assistance systems and chassis systems designed to enhance comfort, driving dynamics and safety. This includes functions such as the stability program, automatic anti-roll stabilization, and electrically-powered front and rear-axle steering.

Some of these functions, or rather their components, require huge amounts of power in short bursts because they need to respond quickly. These components are also referred to as high-current consumers. The electricity of these interacting chassis components can quickly lead to peak loads of over 200 A.

Ideally, the generator supplies more power than is needed to cover the base load for the air conditioning, heated windshield and lights. This excess energy is fed into the battery. This ensures that after the drive, the battery has enough power for the next time the car is started. This is referred to as a positive energy balance.

If the demand for energy in the vehicle electrical system rises faster than the generator can adjust for (the control rate for generators is a few hundred ampere-seconds, while chassis components require a current of several thousand ampere-seconds), a power shortage occurs and the voltage in the vehicle electrical system sinks. The battery now supplies the extra power required, provided that it is able to do so. In some circumstances, such as low temperatures, it can happen that it is no longer sufficient to meet the dynamic requirements. Its ability to supply power diminishes and the internal resistance rises, which also results in higher internal losses. The vehicle electrical system voltage thus sinks below the permissible limit. Depending on the voltage value, the vehicle control system reacts with various measures; the limits can vary by vehicle class. Figure 2 provides an example of the distribution of the voltage limit values. Below 13 V, unpleasant effects such as fan noise and flickering lights may be noticeable for the driver.

Multi-voltage vehicle electrical systems increase the power, but also the complexity

With the introduction of hybrid drive systems, new voltage networks with two voltage levels were developed. For vehicles with high-voltage batteries for the drive power, a DC-to-DC converter takes over the task of supplying power for the low-voltage side rather than the generator. It transforms the higher voltage in the vehicle electrical system to the desired voltage of the low-voltage side. In contrast to the generator, a DC-to-DC converter can control a current with tens of thousands of ampere-seconds and thus handle the power requirements of the high-current components. ›

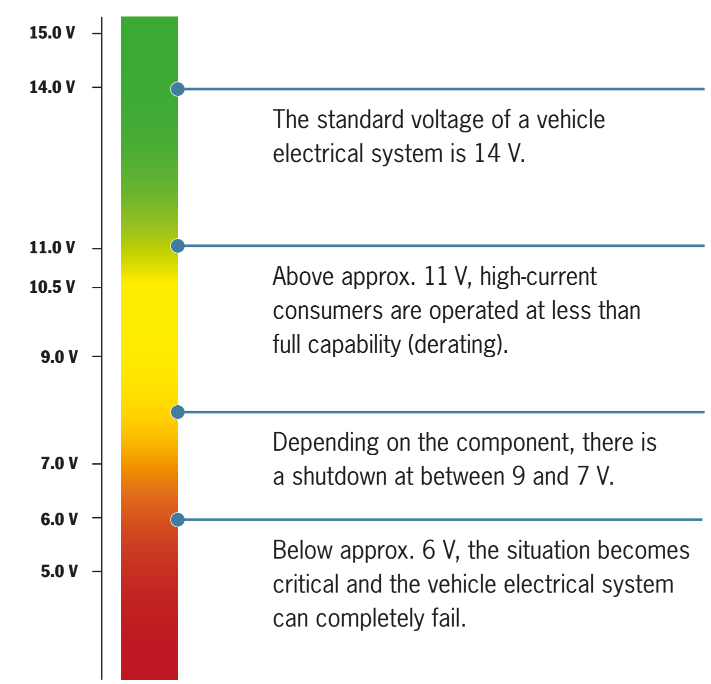


Figure 2: Voltage limits for high-current consumers

Rising energy demands in the vehicle electrical system also result in higher fuel consumption. Major efforts are undertaken to reduce this to the greatest extent possible. In this context, the conventional storage technologies used in the high-voltage realm, such as lithium-ion batteries or electric double-layer capacitors, are increasingly interesting for the low-voltage context due to their high efficiency and thus lower losses. These storage technologies can also recuperate, for example, braking energy in the low-voltage area.

The efficiency of components can also be improved through the variation of the electrical quantities. For a required amount of power, a higher voltage can allow a lower current (since current, in contrast to voltage, goes into the loss calculation squared, a doubling of the current means a quadrupling of the losses). Another advantage is that cables with smaller diameters can be used, which in turn results in weight savings. This has a positive effect on fuel consumption. The power loss that has to be dissipated in the form of heat, which often causes problems, would also be somewhat lower.

This is why efforts are under way to switch from a 12 V vehicle electrical system to a 48 V vehicle electrical system. As this transition needs to be carried over to the series production process and there are currently few components with a sufficiently long history of experience to draw on, this is associated with significant development work and costs. Thus initially, the transition to a 48 V vehicle electrical system will proceed step by step. It makes sense to start by integrating high-current consumers such as the power steering into the 48 V vehicle electrical system since they generally benefit from higher efficiency and less waste heat. The vehicle electrical systems of different voltage levels then need to be connected, however.

The variety of different functions, components and voltage levels has significantly increased the degree of freedom in designing vehicle electrical systems. To identify all critical paths in functions, components and environmental conditions at an early stage of development, it is essential to analyze the respective target system in advance. In view of the ever-increasing complexity of such systems, it is no longer possible to do so without simulating the components, the environment and the impact of the interactions of the components with each other. The high temporal resolution required for the analysis of voltage behavior in the vehicle electrical system with active driver assistance systems requires transient models (physical modeling). With the results of this analysis in hand, development times and costs can be reduced.

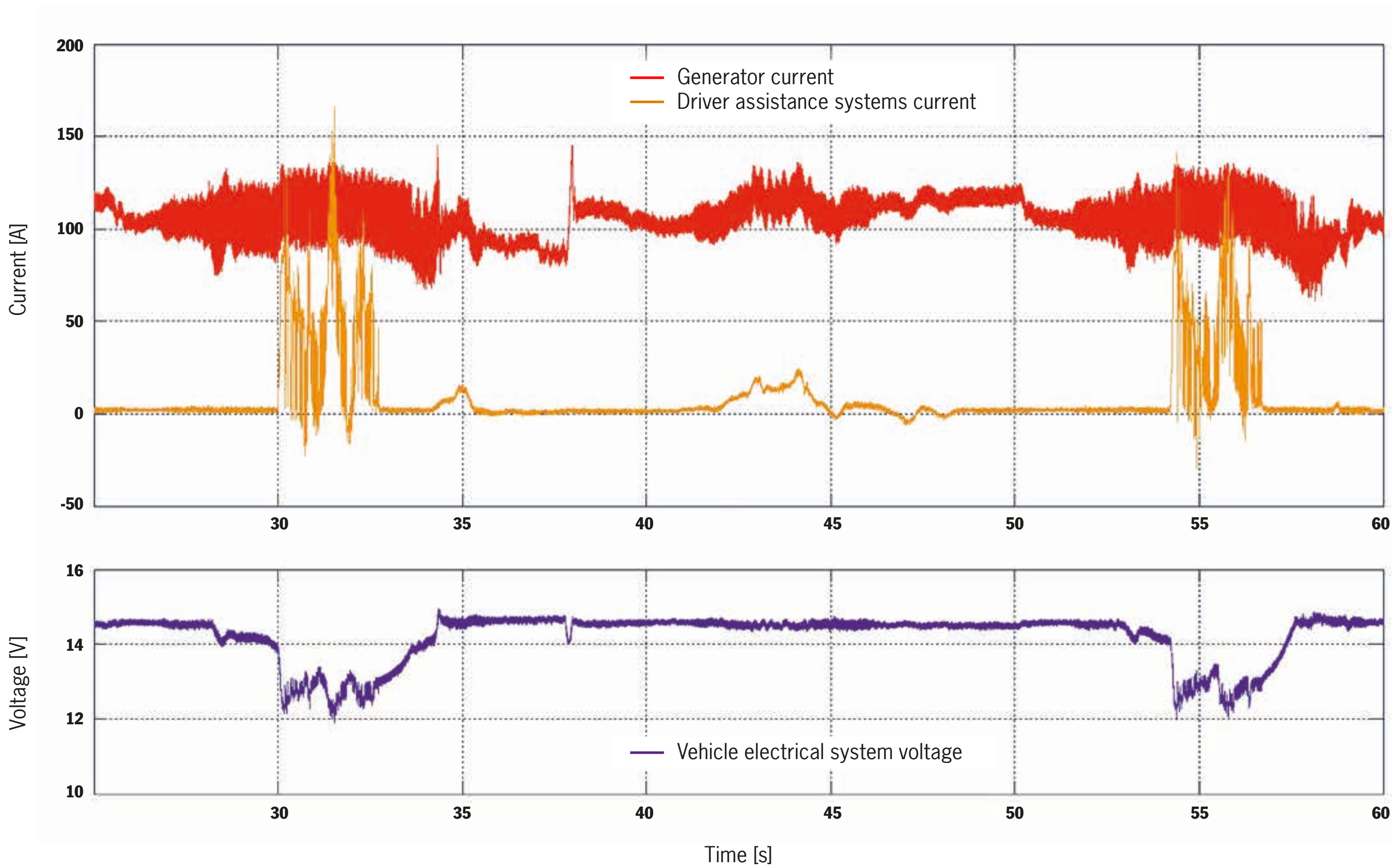


Figure 3: Example of the superimposed power demand of high-current consumers (ESC, EPS, etc.) in the maneuver "braked double lane change"

The types of vehicle electrical system simulation

If the "vehicle electrical system" is to be analyzed through simulation, the type and complexity of the models depends on the issues to be examined. Models can be of a static nature. That means that the respective components are represented in their static operating states such as the map of a generator. On the other hand, models can be of a physical nature if they represent the dynamics, i.e. the transition from a static state into other states, of the elements. The difference is not only in the precision, the effort required and the necessary parameters, but also in the execution of the simulation. In some cases, combining the two types of modeling is appropriate. Whether a simulation with the vehicle electrical system environment or an isolated vehicle electrical system simulation is preferable, and which components should be calculated at which respective temporal resolutions, always depends on the particular task at hand. Porsche Engineering analyzes vehicle electrical systems in accordance with customer requirements and has the expertise to generate the appropriate model for every stage of vehicle development.

Different ways of creating models

Depending on the stage of development of the vehicle, the available information about the components and systems varies and so, consequently, do the simulation models. Nevertheless, even before beginning the construction of the first prototypes, substantial decisions regarding the voltage behavior of the vehicle electrical system must be made as changes later in the process can result in major costs. There are various ways of dealing with a lack of important data. For previously used components, there may already be existing models that can be used instead. If this is not the case, models can be created on the basis of existing or calculated component parameters derived through measurements.

If it is a new component and the potential suppliers are known, preliminary data can be requested from them. The supplier may even provide an encapsulated model of its component. If, for example, the power requirements of an electric brake booster (EBB) at different voltage levels is known, the simulation processes these parameters in the calculation of the vehicle electrical system model. If the suppliers are not known, comparable components and their models can be applied with appropriate adjustments. The respective component experts are involved in the process at every stage. With their expertise, it is also possible to develop the right test cycle to determine the maximum current load, for instance during a braked lane change.

Energy balance as the basis for vehicle electrical system assurance

The first step is establishing energy balance. This involves a simulation with the target components in a particular cycle, for example urban traffic under conditions as they would occur in a real vehicle. Multiple minutes are simulated with models that generally have a temporal resolution of a few milliseconds to seconds. The results show whether the energy in the battery after the drive is still sufficient to start the vehicle again. If that is not the case, the components are modified in their performance and another simulation is carried out.

This type of observation, however, is not sufficient to ensure the proper functioning of the vehicle electrical system. The high-current consumers among the driver assistance systems require a low current on average, but often manifest extremely high dynamic peaks when in action. In dynamic analysis, the overall time period examined is in the second range and the models have a temporal resolution of a few microseconds. An example of the manifestation of the superimposed currents of various high-current consumers is shown in figure 3.

Dynamic analysis using the example of a DC-to-DC converter

New safety regulations demand that the vehicle remains functional until it comes to a standstill even if it is only being powered by a generator, DC-to-DC converter or battery. Therefore one simulation case is to assume that the battery is defective and only the DC-to-DC converter is supplying energy. In the first step, the simulation is conducted with the target components (see figure 4 on page 42). A braked lane change ("evasive maneuver for animal") is used as a test cycle. The characteristic units that describe a DC-to-DC converter include its rated power (in the example 2 kW), its supply and output voltage range, the temperature range in which it may be operated, and its behavior above the rated current. ›

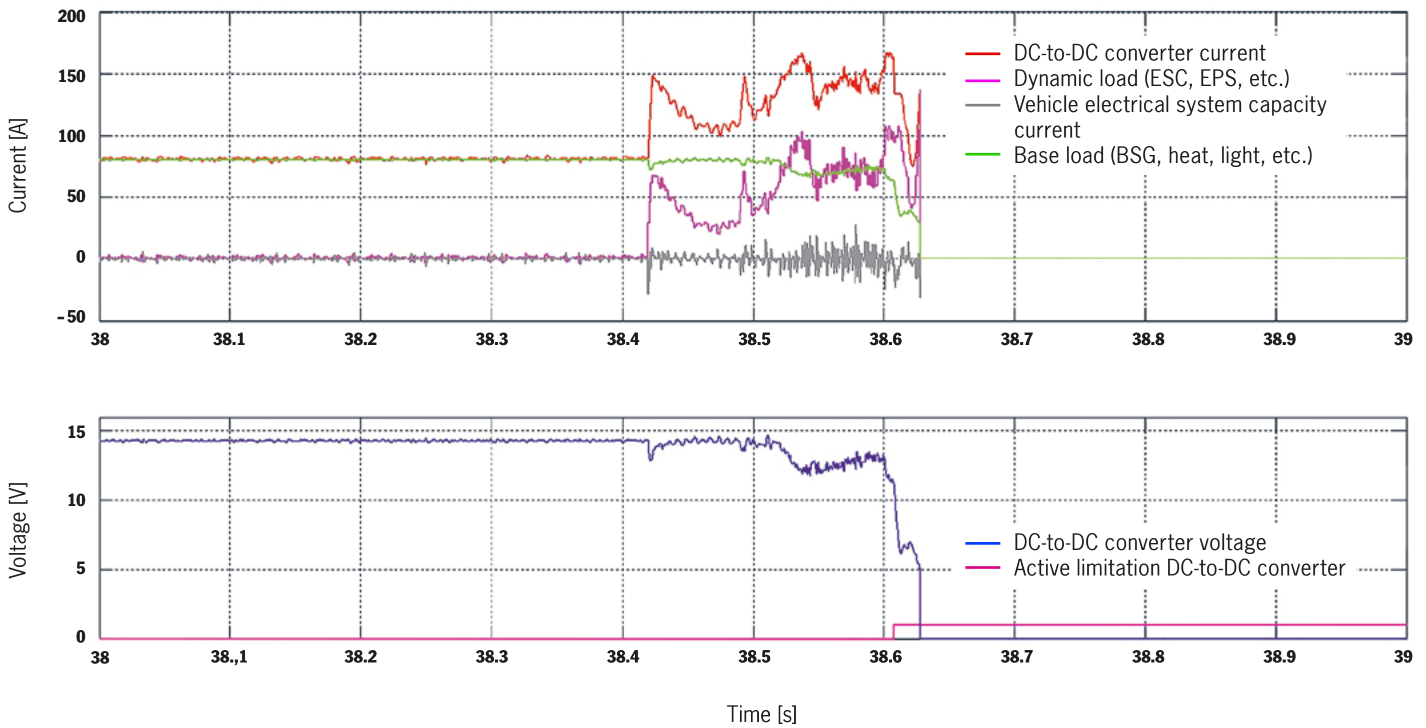


Figure 4: Current profile in the vehicle electrical system with a 2-kW DC-to-DC converter in case of total failure during braked lane change ("evasive maneuver for animal")

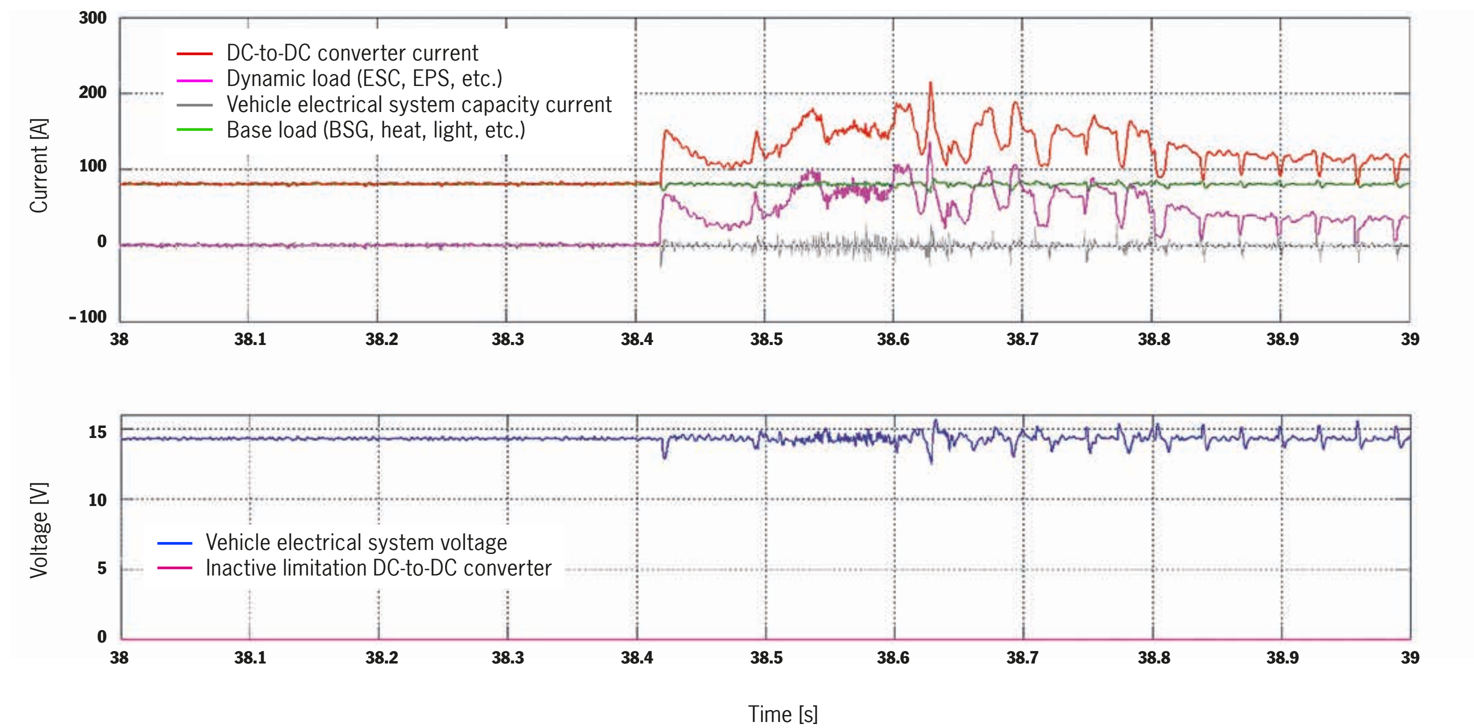


Figure 5: Current profile in the vehicle electrical system with a 3-kW DC-to-DC converter

The task of the converter is to keep the voltage constant at a target value (in the example 14.3 V). If the actual voltage (blue in the example) in the vehicle electrical system deviates from the target voltage, the converter adjusts its output current so that the required voltage is restored. It has the capacity to go into overload temporarily in moments of high power demand, but that means that it is supplying more than its rated current. However, operation above the rated current results in the DC-to-DC converter heating up beyond its permissible range. To prevent thermal damage occurring, after a defined time or above a certain temperature, the current is restricted to the rated value until it dips back below the threshold temperature.

The DC-to-DC converter usually has a capacitor in the form of a condenser in order to stabilize the output current. Together with the wire harness and the internal storage of the control units, there is also a very small storage unit that can serve as a "load buffer." But the voltage in the vehicle electrical system is also influenced by parasitic factors such as cable resistance and inductance, so they need to be taken into account.

The current profile in the simulation is shown in gray. The base load (green), which is comprised of the supply to the control units, switched-on lights and other consumers, amounts to 80 A. Due to the additional dynamic energy demands of the high-current consumers (magenta), a power deficit in the vehicle electrical system is produced. The DC-to-DC converter attempts to compensate the deficit by increasing the current even into the overload range, but cannot supply enough current to raise the voltage to the desired target value. If the voltage now falls below the minimum voltage of the control units, the vehicle electrical system as a whole will shut down. The result: The DC-to-DC converter with an output of two kilowatts is not suitable for this load as the sole supply.

In the next step, the simulation is run with a 3-kW DC-to-DC converter (fig. 5). This fulfills the current requirements and the vehicle electrical system voltage remains at an acceptable level. If supplied by a generator, the result would be different as its control rate is much lower. There the problem is not resolved by increasing the output of the component. The power behavior when consumers are discarded, or stabilization through additional energy stores such as double-layer capacitors, would be potential further lines of examination.

In analyzing the results of this, or indeed any, simulation, it is important to bear the following in mind: It is not only important to devise the model with sufficient model depth and precision for the particular task, but also to know the limits of the model so that it is possible to distinguish the physical and model-specific factors in the analysis.

Conclusion: The rapid development of complex vehicle electrical systems requires simulations

The demand for power is rising constantly due to increasing electrification. Securing the proper functioning of the vehicle electrical system by increasing the output of components such as generators and batteries is no longer possible due to the highly dynamic loads produced by the high-current consumers. At the same time, components from the high-voltage side, such as lithium-ion cells, are increasingly moving into low-voltage vehicle electrical systems. Multi-voltage vehicle electrical systems significantly increase the complexity level yet again. Dynamic analysis and assurance through simulation are therefore an indispensable part of ensuring the reliable design of future vehicle electrical systems. ■

Intelligently Controlled

Evolution of a powertrain manager for electric and hybrid-electric vehicles

____ The emergence of alternative powertrains has created new challenges for automotive engineers. The entire propulsion concept for modern cars needs to be re-engineered in order to achieve satisfying levels of efficiency and performance. Porsche Engineering considers the creation of a universal device suitable for use in any type of electric and hybrid-electric vehicles, called the Electric Vehicle Manager, and enables flexible and fast development of software architectures and functions for the powertrain of the future.

By Dr. Ondrej Spinka, Dr. Martin Rezac, and Dr. Jan Rathousky

EV manager and its architecture

The Electric Vehicle Manager (EV manager) is a highly configurable electronic control unit (ECU) that is able to form a cornerstone for any type of electric and hybrid-electric vehicles. It interacts with the driver by means of the pedals, shift lever, and ignition switch, and it controls the powertrain. It is a standard automotive ECU that typically acts on the powertrain and hybrid CAN buses, and carries out direct operation of several other sensors and actuators on its own (see illustration on page 45).

Apart from powertrain control and torque calculation, which are its main functions, the EV manager is capable of much more. Its most important functions include:

> high-voltage (HV) battery charging management,
> energy flow management,
> driving range calculation,
> cruise control,
> HMI including dashboard messages and indicators,
> brake booster control and brake blending,
> thermal management (control of the cooling systems),
> passenger compartment heating and air conditioning.

All these functions, as well as a number of others, can be added or implemented as customers wish. This high level of configurability is made possible by the unique modular structure, which allows fast customization of the EV manager for a specific powertrain and vehicle configuration by using a library of software modules. These modules can be configured and connected in Simulink, much like Lego bricks. A structure like this is used to generate the C code and automatically compile it for the specific ECU.

The modular structure of a general EV manager is shown in the illustration on page 46. The software is structured into several layers that define the level of abstraction from the vehicle hardware—these being the *core algorithms layer, vehicle mapping layer,* and *ECU mapping layer*.

The *core algorithms layer* covers functions such as torque calculation, the state machine for the powertrain, or the driving range calculation. This is the uppermost layer of the software and is largely vehicle-independent, and easy to reuse.

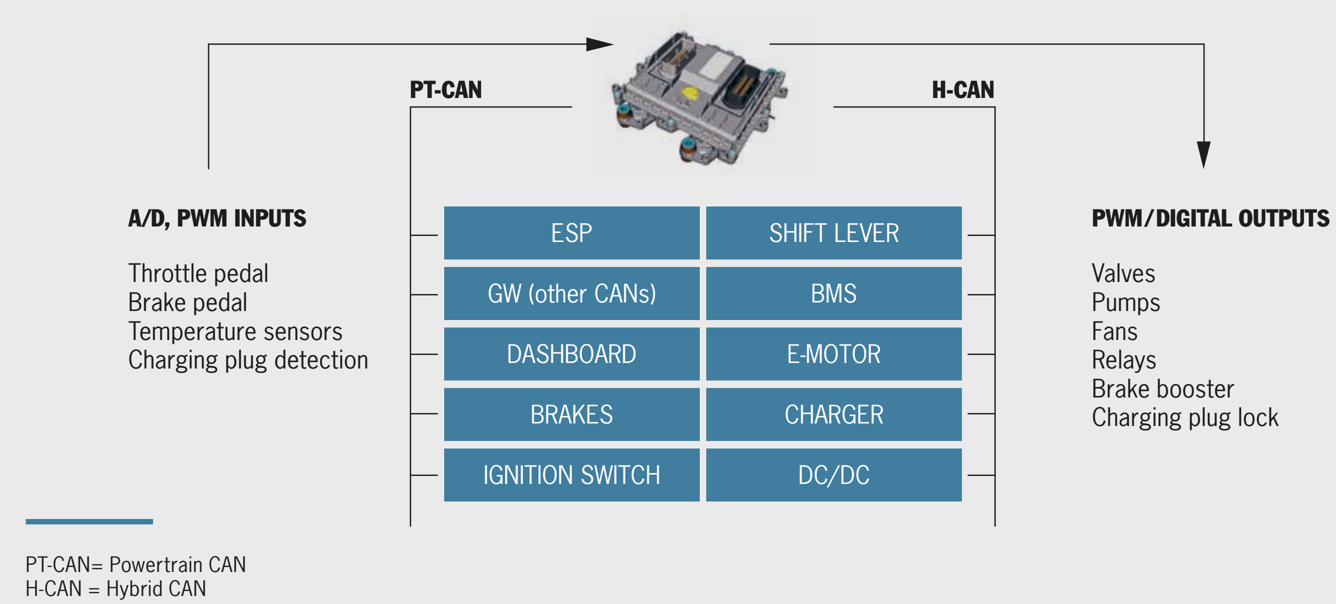
The *vehicle mapping layer* functions as an interface between the core functions and a specific vehicle platform, allowing the customer-specific functions such as thermal control, dashboard interface, HV battery charging management, or passenger compartment heating to be added. Upon replacing the battery management system (BMS) or the e-motor, for example, only a single component in this layer needs to be changed, without any changes to the rest of the software being necessary.

The *ECU mapping layer* provides an interface between the EV manager software and the lower level software used for the target ECU. This layer allows the rest of the software to be operated independently of the specific ECU. CAN messages must be parsed and converted into signals with physical units in this layer, which are processed by the higher layers of the EV manager. If a CAN matrix is available in the form of a dbc file, then this layer may be generated automatically. The EV manager can be delivered with the ECU mapping layer linked to the low level software (delivered by the ECU supplier), or alternately in the form of an AUTOSAR component with a clearly defined AUTOSAR RTE (real time interface).

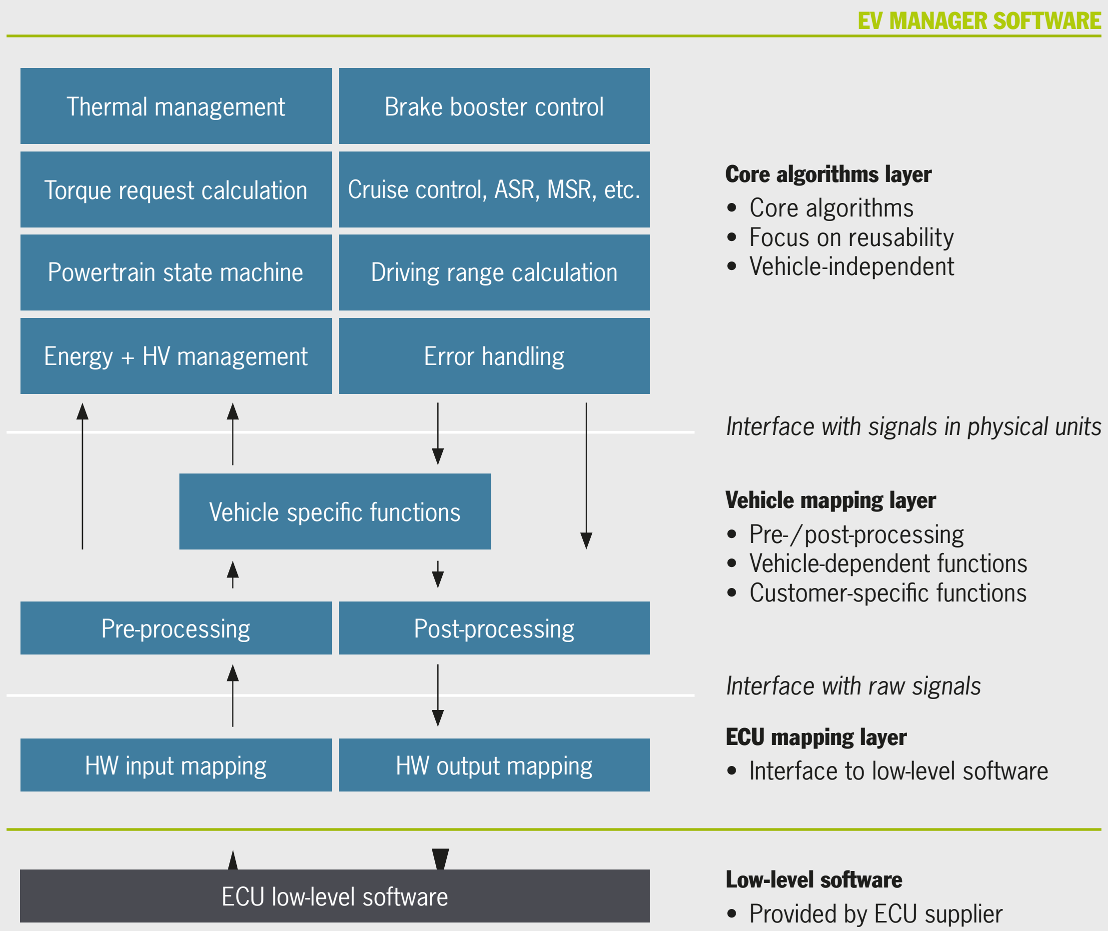
A key factor enabling fast software development is the method used to define the entire architecture. All interfaces between components are stored in IBM DOORS in the form of a list of signals. This list allows standardized interface definition and is used for automatic creation of component interfaces directly in Matlab/Simulink, for automatic software documentation, and for the generation of MIL (model in the loop) test templates. All changes to the architecture are implemented exclusively in DOORS, and the rest of the process ensures their correct implementation.

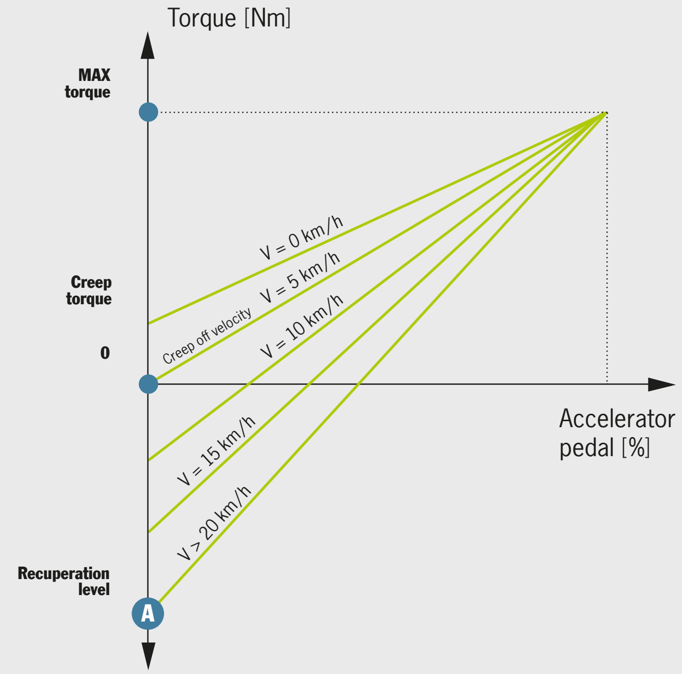
Core functions of the EV manager

One of the most important functions of the EV manager is the calculation of the torque to be applied by the e-motor(s). To do this, the torque request calculation reads the actual position of the accelerator pedal and, depending on the current speed and other driver settings, calculates the torque it needs to apply. The torque may be positive when acceleration is required, or it may be negative, meaning that recuperation is required. ›



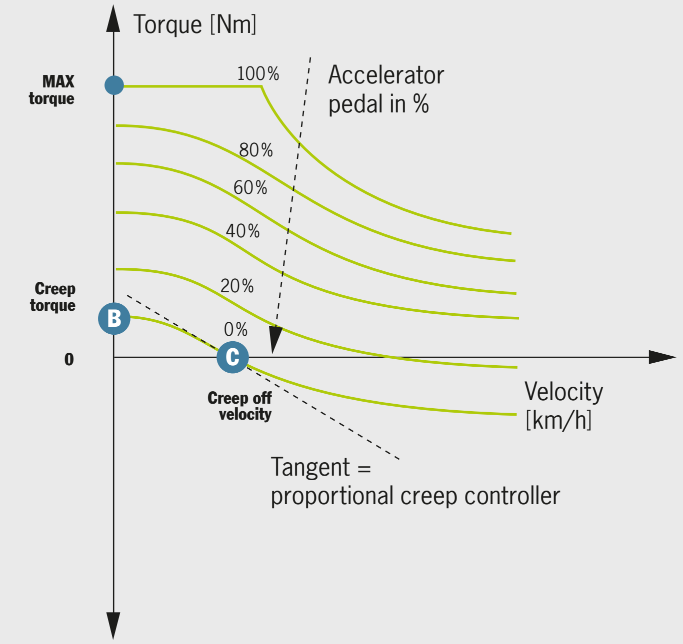
Typical hardware interface of the EV manager in a vehicle—two CAN buses and several analog or digital inputs and outputs





Torque curves (accelerator pedal view)

A "recuperation level" point changes its value according to the selected recuperation level (this is usually realized using the shift lever in manual mode).
B "Creep torque" is the maximum torque value for the creep function—this torque is applied at zero velocity with the accelerator pedal released.
C "Creep off" is implemented at a specific velocity (in this setting, 5 km/h).



Torque curves (vehicle velocity view)

The tangent between the "Creep torque" and "Creep off" points explains the way the proportional creep controller functions (at lower velocities, some creep torque is required, while at higher velocities, zero torque or even recuperation is required—negative torque means recuperation).

The conditions governing the application of torque are quite complex and the customer is largely free to define the dynamic vehicle response according to requirements. For example, the complete accelerator pedal/speed/torque curves can be changed. These curves have been simplified for their depiction in the figure on page 47.

Using these curves, the customer can also define the creep controller, as it is known. The creep response, as is used in vehicles with automatic transmission, is often requested by customers. Other functions that may be calibrated and activated include the driving profiles (ECO/SPORT/SPORT+ modes), or the brake blending function. Of course, functions such as low-pass torque filtering and torque rate limiting, which help to improve the vehicle drivability, are included as well and can be calibrated in full.

Brake blending allows the driver to control the recuperation torque using the brake pedal. This function ensures that the response by the brake pedal (the braking torque) remains the same, regardless of whether it is defined by means of mechanical braking or recuperation. The braking torque is therefore blended between the e-motor and hydraulic brakes, and their respective ratio changes constantly. This function requires an electronic and an external means of controlling the brake cylinder pressure. If, for example, the brake pedal is depressed slowly, a significant share of the braking force will ultimately be generated by means of recuperation. If, on the other hand, the brake pedal is depressed suddenly and with force, recuperation is switched off and the full braking effect is generated by means of standard hydraulic braking.

Main state machine for the electric powertrain, energy and HV management

This function assumes responsibility for the overall electric powertrain state machine. The EV manager transitions between its different states, such as "ignition on/off," "drive ready," "creeping," "driving," or "charging." The state machine that is implemented in Simulink/Stateflow then ensures that the respective transition is only executed when all prerequisites are met. For example, if the charging cable is plugged in after start-up, then a transition from "ignition on" to "drive ready" will be prevented.

The energy management function ensures energy is correctly distributed among the high-voltage (HV) components (e-motor[s], battery, heating and air conditioning, DC/DC converter). The energy manager must allow for the demands from all of these subsystems, and prioritizes or reduces them respectively in the event that they cannot be fully served.

The HV manager is responsible for switching the traction battery voltage ON and OFF. The switching conditions are relatively complex and a number of safety issues must be taken into consideration. For example, the HV manager evaluates the status of the BMS, the e-motor and the driving state to prevent the HV being switched off while driving. On the other hand, it prevents the HV from being switched on in the event of problems with the e-motor or other HV equipment. ›

Driving range calculation as essential driver information

The driving range calculation encompasses a set of functions that estimate the current and average energy consumption of the vehicle (in kWh/100 km) and the driving range (in km). The algorithm is based on a moving average, while previous values are factored in with a lower priority. The time constant used for the analysis may be calibrated according to the customer's requirements. The main advantage of this method of implementation is the fact that the algorithm does not need to be reset after the vehicle has been driven a long distance.

Android-based human machine interface

Usually, the on-board computer display installed in the vehicle's instrument panel is only able to plot vehicle information on a small screen to a limited extent. An additional, high performance human machine interface (HMI) for the center console was developed to demonstrate the capabilities of the EV manager. An HMI like this allows a variety of user-defined and configurable vehicle information to be displayed on several tabs in a large, high-resolution screen. It is easy to switch between the tabs, which are fully configurable.

The Android operating system is known for its robustness and flexibility, with these advantages being the reason that this platform was chosen for the HMI. The HMI runs on a large tablet that is connected via Bluetooth to a CAN-to-Bluetooth gateway called an interface controller (referred to as IC). The IC was developed by Porsche Engineering in 2012 (see Porsche Engineering Magazine 2/2012). It is plugged directly into one of the vehicle CAN networks. The HMI is used intensively to evaluate, test and support the EV manager, as well as to increase the driver's comfort during the journey.

Commissioning and calibration

The EV manager has been successfully employed in a number of customer projects, as well as in in-house Porsche Engineering projects. The vehicle during the measurement procedure on the roller test bench can be seen on the picture below. The vehicle was commissioned and calibrated using this bench before the actual driving tests were performed.

Conclusion

The EV manager developed by Porsche Engineering constitutes a flexible and efficient solution for any kind of electric vehicle. Its modularity enables fast development of software architecture and functionalities individually tailored to the customer. ■

Measurement procedure on the roller test bench

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