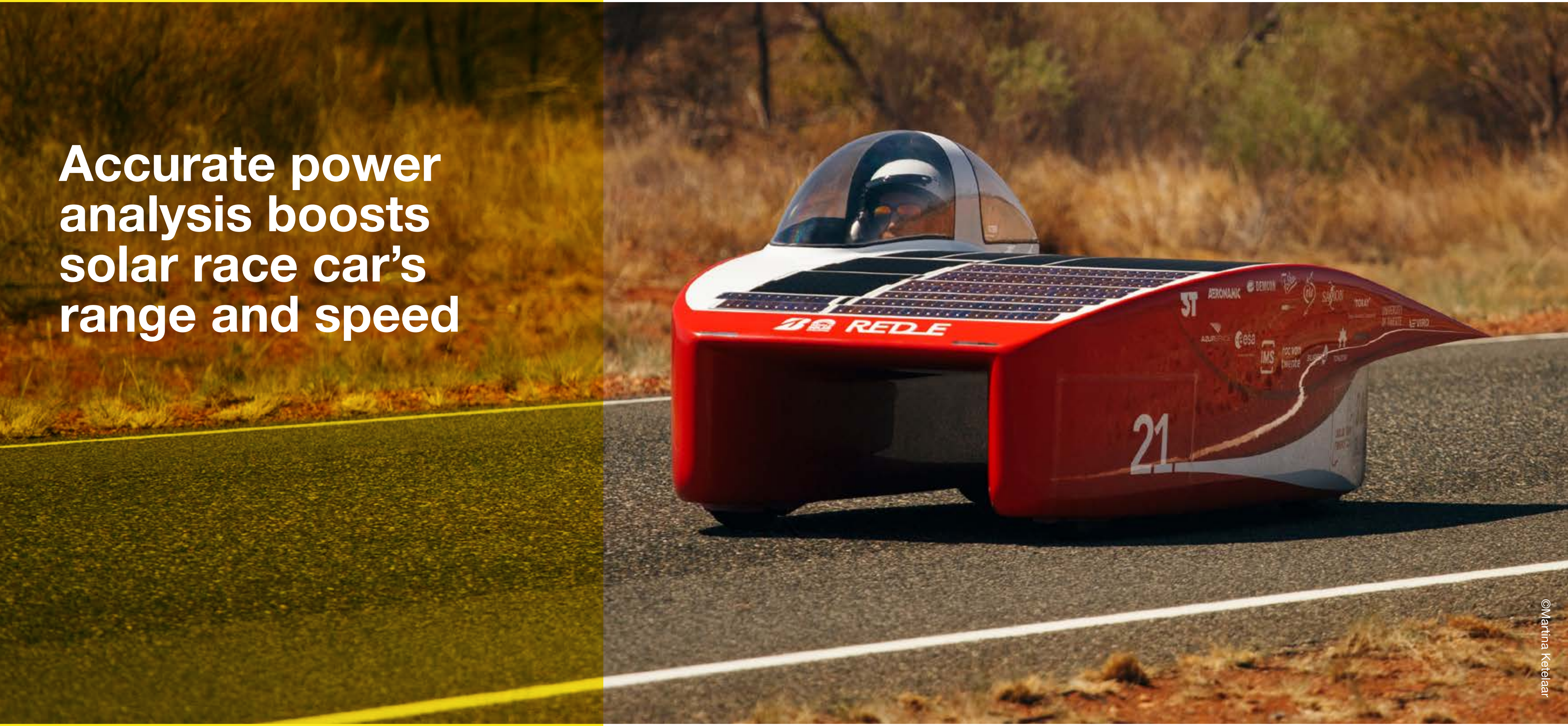
Test&Measurement

YOKOGAWA

Case Study



Accurate power analysis boosts solar race car's range and speed

Precision Making

Solar Team Twente

The ultimate challenge for pure solar-powered race cars is the biennial Bridgestone World Solar Challenge, on a 3,000km route from Darwin in the north of Australia to Adelaide in the south. Teams of engineers and drivers compete to finish the race in the shortest possible time, in specially designed cars which have only one power source: the light of the sun.

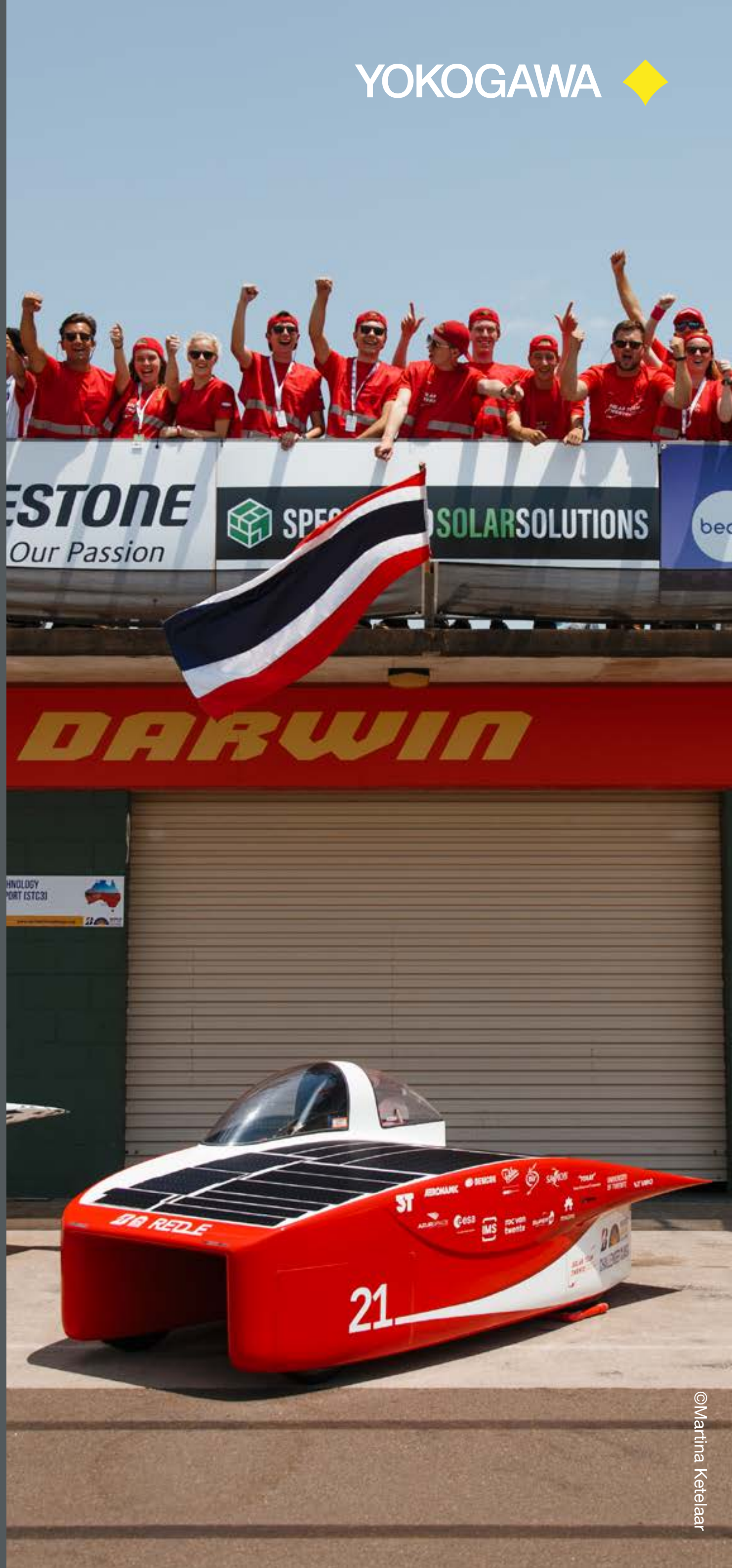
The basic design of all cars in the race is similar: an aerodynamic wing shape covered in arrays of photovoltaic panels to convert the sun's light into electric power, which is fed directly to a motor driving the wheels, with any excess stored in a small on-board battery.

The most highly placed teams are those which can best optimize the various elements of the car's design – the aerodynamics, the power generation system, the motor and the traction system. Race strategy also plays an important part: the driver must move as fast as possible, but not so fast that the car's battery runs out of power when the car is not in bright sunlight.

One of the most experienced teams to take part in the 2019 running of the race was Solar Team Twente. It first took part in 2005 with its car 'SolUtra', finishing in ninth place overall, and the highest-placed new entrant. It has taken part in every World Solar Challenge since then. In 2019, it raced 'RED E', its most technologically advanced solar vehicle yet.

Solar Team Twente's technical accomplishments are impressive given that the team does not benefit from the know-how and resources of an established manufacturing company: in fact, it is led and run by 19 students. This young team of aerodynamic, electrical, mechanical and structural engineers is drawn from the University of Twente and the Saxion University of Applied Sciences in The Netherlands.

One of its most important engineering challenges is to optimize the efficiency of the motor and battery-management systems. In doing so, it benefits from measurements made by a power analyzer donated by Yokogawa. This is the story of the way the power measurements made by the RED E designers helped the team to achieve in the 2019 race the team's highest ever average speed.



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The Challenge

Background

To win the World Solar Challenge, a race car must generate as much solar energy as possible, and convert the electricity it generates as efficiently as possible into mechanical power delivered to the wheels. At the same time, it must keep energy losses to a minimum: race teams pay minute attention to aerodynamic design to keep wind resistance to a minimum. In the case of RED E, total wind resistance is the equivalent of a conventional car's wing mirror.

The cars' designers also aim for better than 99% efficiency in the various electrical power conversion circuits. There are four important electrical systems in a solar race car:

- The array of solar panel generators
- The battery and its battery management system
- The inverter (motor drive), which converts the solar panels' direct current output to a three-phase alternating current drawn by the motor
- The motor itself

Solar Team Twente has been using self-developed motors in their cars since 2013, which have been surpassing the efficiency of off-the-shelf models. For the 2019 World Solar Challenge, the team decided to seek an additional performance advantage by also abandoning the use of commercial inverters, being used by most of their competitors, and to design a more robust and efficient version themselves from scratch.

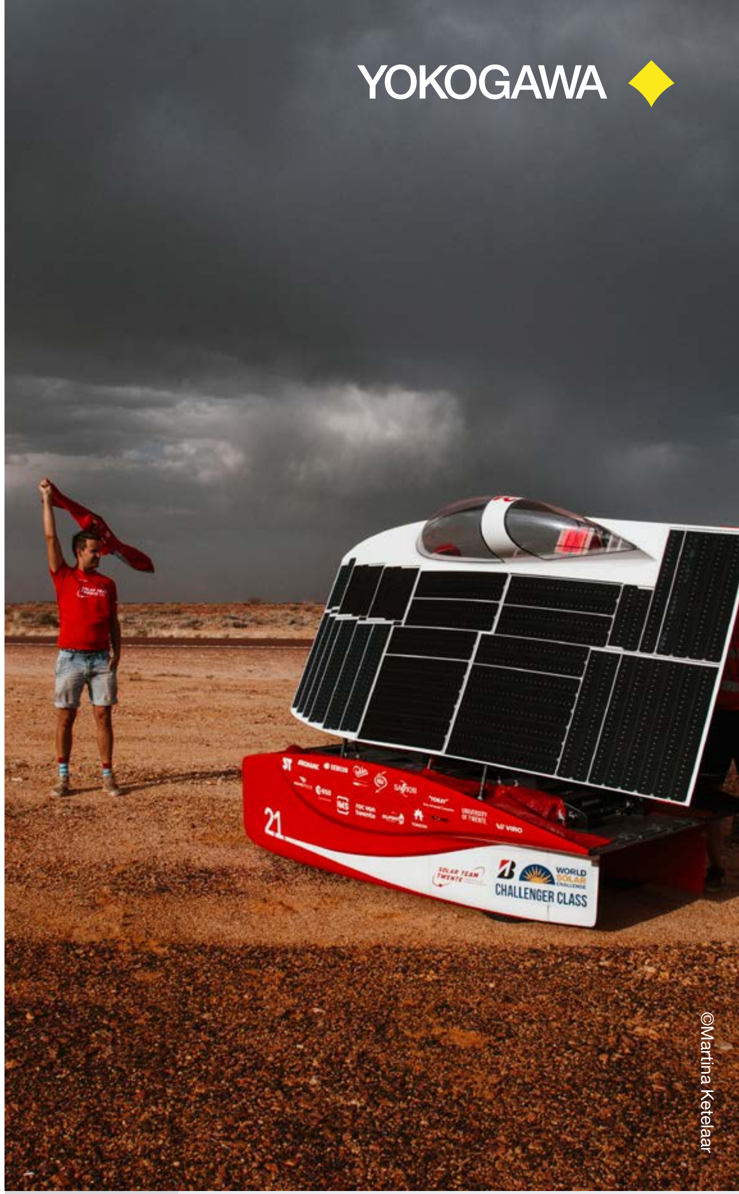
The team's race strategy also called for precise regulation of the battery's state of charge. Every team's goal is to finish the race with zero energy left in the battery to maximize total energy usage, and thus achieve the highest possible speed for the longest possible distance without running out of power. The more accurate the state of charge measurement, the more confidently the race team can set the optimum speed of the car's cruise control, taking into account, the weather, the capacity of the battery, the performance of the competitors and other factors.

The Challenge

RED E's engineering design team needed to repeatedly perform power (concurrent voltage/current) measurements to measure the efficiency of the motor system under various operating conditions. The development process involved multiple iterations of the system design, each one validated to assess the effect on efficiency. The benchmark for the team's design was the off-the-shelf motor that it, and other teams, had used previously – already itself a highly efficient motor system.

As electrical engineer Rob Kräwinkel says, 'We were looking for that extra 1% efficiency to give us an edge over other race cars. When you are already at better than 95% efficiency, eliminating any remaining losses is really hard to do. You have to be able to look at a detailed level at tiny deviations in voltage or current. That means you need a really accurate and sensitive power measurement system.'

The same requirement for measurement accuracy applied to the battery management system: even tenths of a percentage point of extra accuracy in state of charge measurement can make the difference between winning and losing.



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"One of the most important engineering challenges was to optimize the efficiency of the motor and battery-management systems."

The Solution

Application requirements

Solar Team Twente had two main uses for its power measurement system:

- To validate the accuracy of the ‘fuel gauge’, the car’s on-board sensor measuring the battery’s state of charge. This system measures current flowing into the battery (from the solar panels) and flowing out of the battery (to the motor). By subtracting output from input, it can calculate the residual charge in the battery. This required extremely accurate continuous measurement of current flows.
- To measure the power output of the motor system, including the inverter and the motor itself, at a range of power input values, to enable the team to refine the design and incrementally improve its efficiency. This called for extremely accurate power analysis at high sampling frequency.

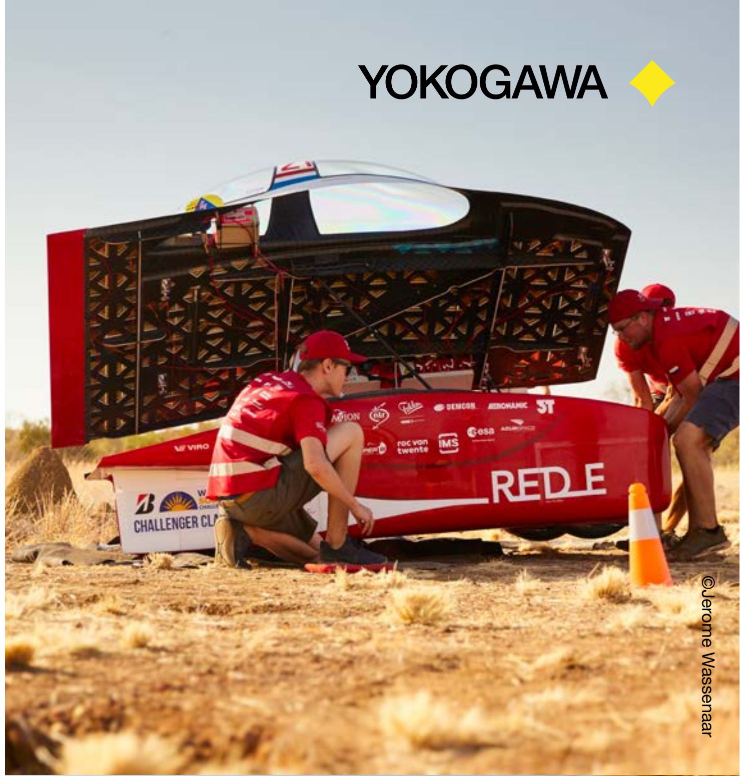
Measurement solution

To achieve the accuracy and precision required for system design and validation, the RED E team chose a WT5000 Power Analyzer from Yokogawa – the world’s most accurate precision power analyzer.

Measurement accuracy is rated at ±0.03% in the instrument’s datasheet. Measurement bandwidth is 10MHz for voltage and 5MHz for current. The maximum sampling rate of 10Msamples/s exceeds the data refresh rate required to validate the fuel gauge system. WT5000 users can make simultaneous measurements on up to seven inputs, and view them on its high-resolution 10.1” touchscreen.

Solar Team Twente’s Rob Kräwinkel says that when the electrical engineers first installed the WT5000-based test set-up, they discovered that the current sensors in the fuel-gauge circuit had a previously undiscovered offset which had been making the state of charge measurements inherently inaccurate.

‘The current sensing circuit we had previously was already better than 99% accuracy, but we were looking for better than that – it was only when we analyzed the sensor with the WT5000 that we were able to compensate for the offset in the current sensor, and so configure the measurement outputs to achieve optimal accuracy. That crucial extra confidence in our state of charge measurements can give the driver a vital extra 1km or 2km of range at a given speed that we would not otherwise have been sure of getting from the battery’, says Kräwinkel.



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Results

Optimized battery and motor drive produce outstanding race performance

The ultimate test of the engineering development work done by Rob Kräwinkel and his team came when RED E competed in the 2019 World Solar Challenge in October 2019. The race was a test of whether Solar Team Twente had produced a more efficient motor system than competitors. The race would also tell whether the battery's fuel gauge was as accurate as the team believed it was.

With over half the race completed, RED E was in the lead and on course to win, with an average speed of 89.7 km/h, when mother nature intervened. The car was irreparably damaged when a very strong cross-wind gust forced the car off the road and down a slope, where it rolled over.

In the event, the race was won by the Belgian team, Agoria, with an average speed of 86.6 km/h. Without the accident, and if RED E had maintained its superior performance, not only would the car have won, but it would also have achieved an average speed nearly 19% faster than it managed in 2017. This improvement in 2019 was in part due to better weather for solar-powered racing before RED E's accident. Nevertheless, the engineering developments implemented in the 2019 car were responsible for a substantial improvement in performance.

WT5000 Precision Power Analyzer

Offering the best in isolation, noise immunity, current sensing and filtering in a modular architecture, the WT5000 is an extensible measurement platform that provides precision power analysis backed by the world's leading in-house calibration facility for power analyzers, in Amersfoort, The Netherlands.

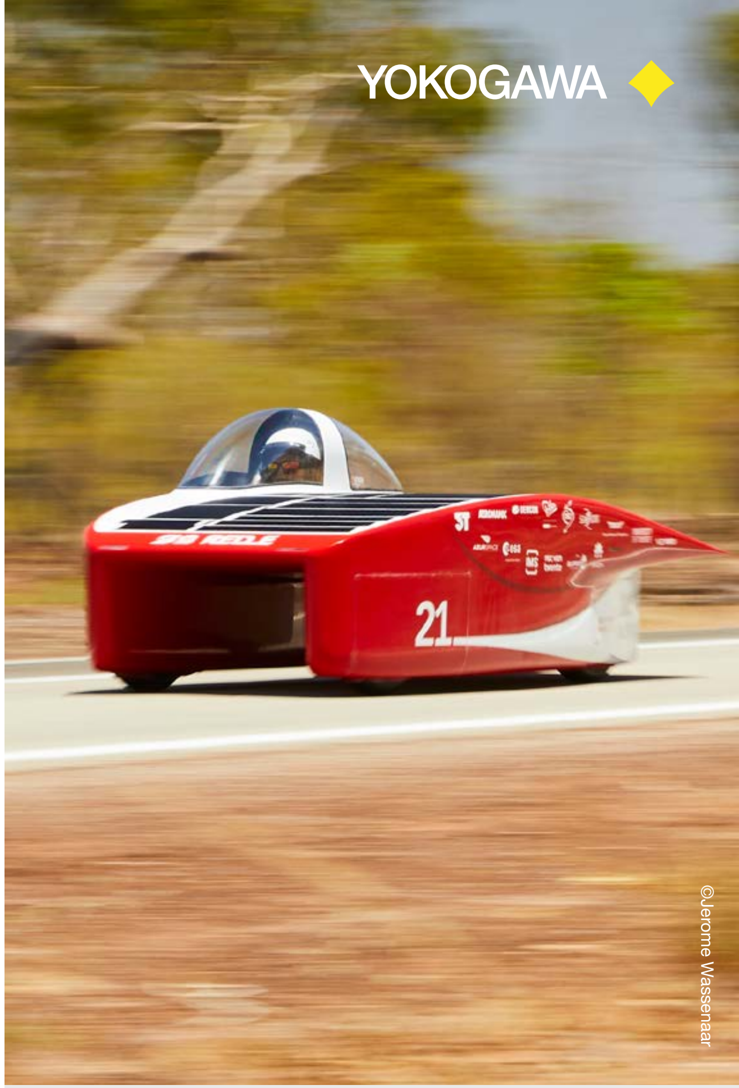
Users can make simultaneous measurements on up to seven inputs and compare them in split-screen mode on the high-resolution 10.1" touchscreen. The modular architecture of the WT5000 provides seven slots supporting various types of input modules, providing a flexible measurement system.

The WT5000 also offers advanced filtering options, including:

- Synchronization source filter
- Enhanced frequency filter
- Digital parallel path filters

Operable by a touchscreen and hardware controls, the WT5000 offers an intuitive measurement experience. As Rob Kräwinkel says, 'The WT5000 is a very nice instrument to use, it's intuitive, and it's easy to find your way around the controls. It's also easy to tweak the display so that it shows exactly the measurement outputs you are interested in, like when it clearly demonstrated that our new inverter design outperformed the equivalent off-the-shelf model by a significant margin'.

For more information on the WT5000, visit tmi.yokogawa.com.



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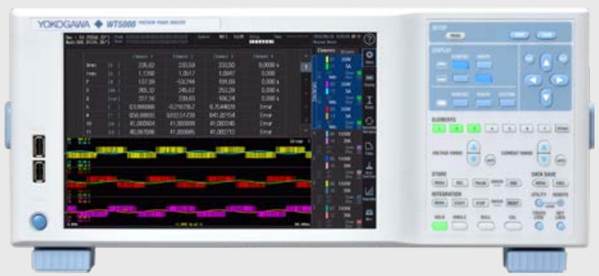


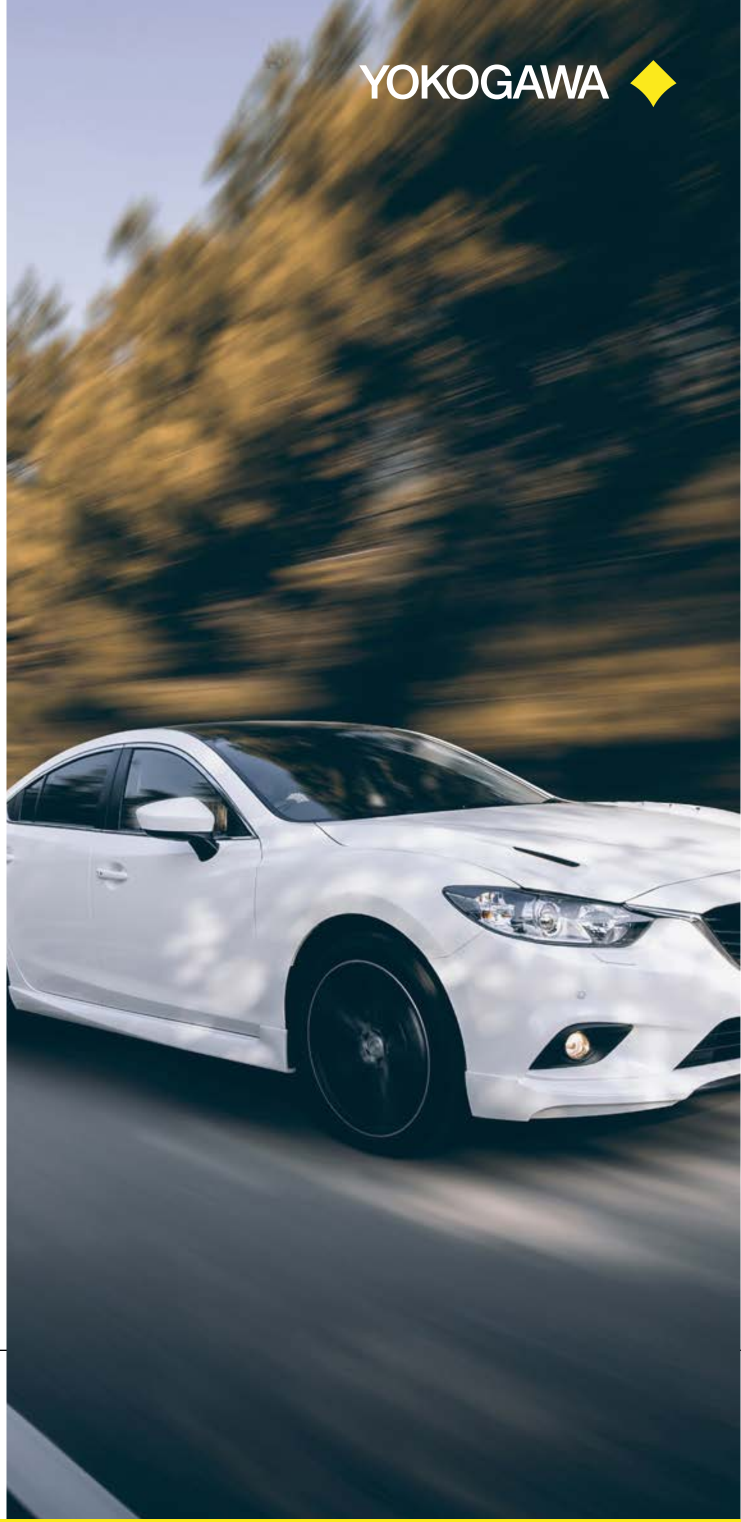
About Yokogawa Test & Measurement

Yokogawa has been developing measurement solutions for 100 years, consistently finding new ways to give R&D teams the tools they need to gain the best insights from their measurement strategies. The company has pioneered accurate power measurement throughout its history, and is the market leader in digital power analyzers.

Yokogawa instruments are renowned for maintaining high levels of precision and for continuing to deliver value for far longer than the typical shelf-life of such equipment. Yokogawa believes that precise and effective measurement lies at the heart of successful innovation – and has focused its own R&D on providing the tools that researchers and engineers need to address challenges great and small.

Yokogawa takes pride in its reputation for quality, both in the products it delivers – often adding new features in response to specific client requests – and the level of service and advice provided to clients, helping to devise measurement strategies for even the most challenging environments.

The guaranteed accuracy and precision of Yokogawa's instruments results from the fact that Yokogawa has its own European standards laboratory at its European headquarters in The Netherlands.
This facility is the only industrial (i.e. non-government or national) organization in the world to offer accredited power calibration, at frequencies up to 100 kHz. ISO/IEC17025 accreditation (RvA K164) demonstrates the international competence of the laboratory.



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