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RUTRONIKER


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54
SERIES

Editorial

Markus Krieg

Turning point in electronics

The signs have changed dramatically. The electronics industry is under pressure like never before: Incoming orders are stagnating, customers are keeping their purse strings tight and they are cautious and uncertain about ordering. Following years of rapid growth, many companies are now in a phase of consolidation, where the focus has shifted from pursuing the next innovation to simply surviving in the market.

At the same time, compliance with regulatory standards is becoming ever more complex. The Cyber Resilience Act (CRA) adds a whole new dimension of responsibility: Going forward, suppliers will be judged not only on price and performance but also on their ability to keep products safe and secure in the long term. It forces companies to think outside the box: Updates over the product's entire service life, traceable supply chains and security at software and hardware level are absolutely essential. Rutronik pro-actively supports suppliers to ensure integrity and interoperability. Read more in the article by Bernd Hantsche, Vice President Technology Competence Center at Rutronik, on page 35.

The likelihood of threats from quantum computers is growing and is a notable downside of the digital transformation. Rutronik works closely with European semiconductor suppliers to offer robust security solutions – including post-quantum encryption and resilient communication modules. Read more about this on pages 72 to 73.

Together with Axelera AI as its new franchise partner, Rutronik is bringing European AI inference to the edge. Automotive and industrial applications benefit from energy-efficient, scalable and real-time AI – independent of non-European platforms. This technology makes AI not only accessible but also strategically deployable for the next generation of networked devices. In the CEO interview with Rutronik's Managing Director Thomas Rudel starting on page 28, discover more about Rutronik's strategic direction and key achievements in what has been a challenging year for everyone involved with distribution.

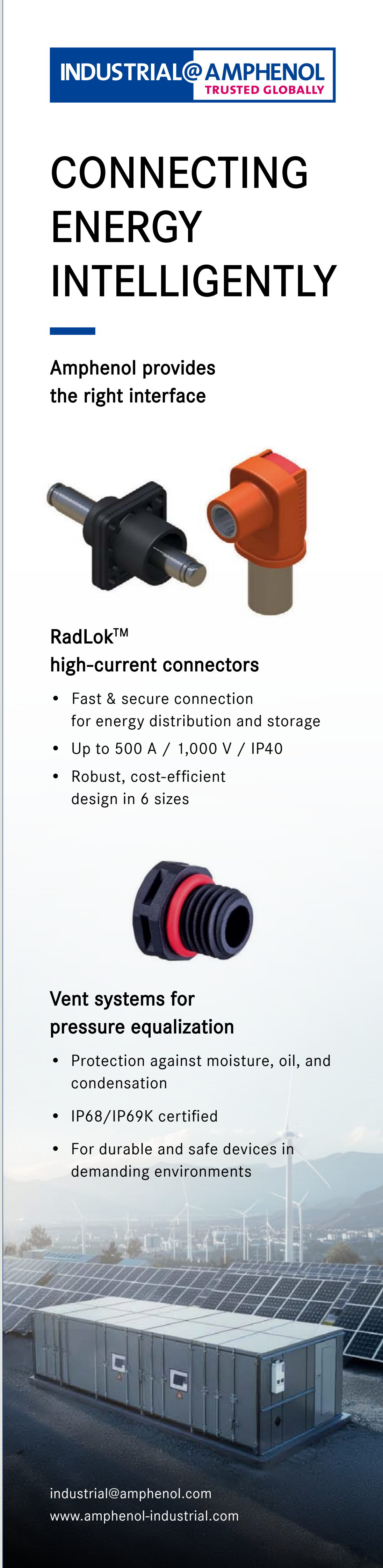
Thanks to solutions like the AI Vision Document Reader and the AI Vision Label Reader from COMI, Rutronik is revolutionizing supply chain management together with the AI specialist. AI-based recognition replaces complex delivery note formats and prevents manual sources of error – regardless of whether the documents are physical or digital. This guarantees that traceability is not only achievable but also measurable and dependable We announced the strategic partnership in RUTRONIKER 2024, and in this issue you can read starting on page 32 about the initial successes of our joint projects, including the two readers developed as part of this still young partnership

Furthermore, we would like to invite you to take part in our large RUTRONIKER reader survey! Let us know the topics that matter most to you and the offerings that are particularly valuable in your daily work. Scan the QR code to access the roughly 10-minute survey, which is available until January 15, 2026. We would like to thank you in advance for your valuable feedback and time!

On behalf of the whole Rutronik team, I wish you lots of fun reading. We hope that the articles, created in collaboration with our suppliers, provide you with an overview of the latest developments and technological innovations and offer both ideas and practical inspiration for your day-to-day work.

Yours truly,

Markus Krieg, Chief Marketing Officer (CMO) at Rutronik



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Sensor system for electrical brake systems

Braking safely with modern position sensors

Hall and TMR technologies offer a range of strengths and can be combined in a targeted way. What really matters when selecting a sensor? And how can system requirements be met reliably and efficiently?

By Frederik Berstecher, Product Line Manager – Fast Hall Sensors at TDK Micronas, Marcus Meyer, Head of Project Engineering at TDK Corporation – Japan, and Jeannette Raquet, Line Manager at Rutronik

Nowadays, developers have access to an array of sensor solutions for detecting positions in electrohydraulic and electromechanical braking systems. Two of the most established ones are Hall and TMR-based sensors. Both offer specific technical advantages when it comes to their mounting flexibility, interference immunity and signal quality. Which principle is best for the job depends largely on the system requirements and the planned security architectures. The key properties of both technologies to facilitate targeted selection for demanding braking applications are compared below.

Hall, TMR – and their combination

Since Hall and TMR sensors are based on varying physical principles, their functionalities complement one another. Their combination opens up additional possibilities for reliably and precisely detecting positions in electrical brake systems.

- **Hall sensors** ensure accurate absolute position detection and sufficient dynamics for rotating measurement tasks, such as BLDC motors (approx. 70 kHz).

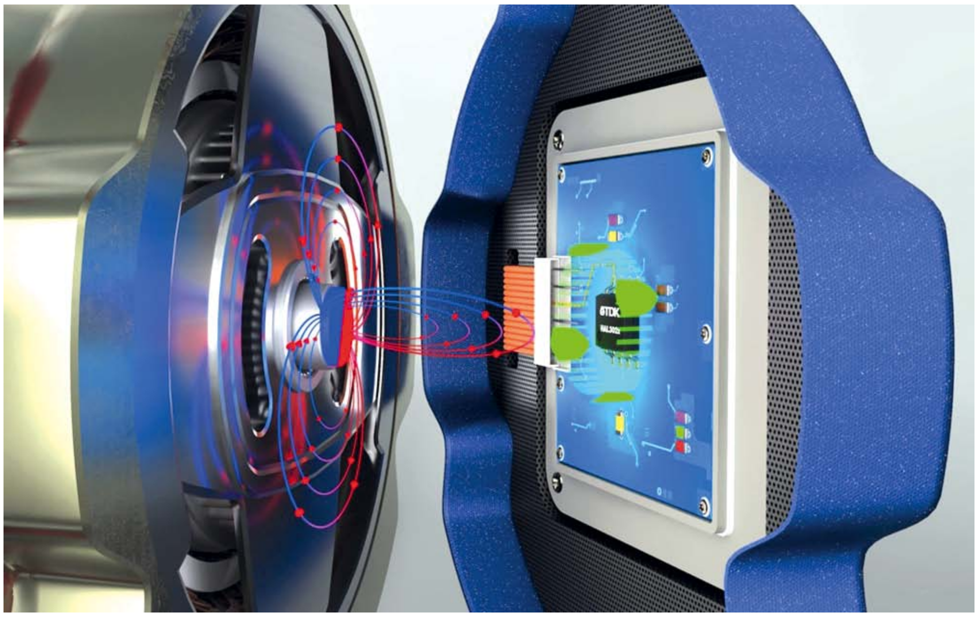


Figure 1: Both TMR and Hall effect sensors can be used to detect the rotor position in brake actuators. The Micronas HAL 302x is best suited for use in high-speed electric motor applications due to its insensitivity to magnetic interference fields. (Source: TDK Micronas)

Figure 2: Brake disk with brake caliper and electric motor. The electromechanical brake mechanism (EMB) uses the rotational movement of the motor to move the brake caliper and apply force to the brake disk. The Micronas HAL 3021 precisely detects the absolute position of the actuator in an end-of-shaft configuration.

- **TMR sensors** deliver very high angular resolution and dynamic performance, especially for periodically moving or rotating components, such as those in BLDC and AC motors as well as actuators. Depending on their setup, TMR sensors provide mechanically absolute or electrically absolute positions. The latter are also referred to as incremental positions, i.e., 2-pole magnet for absolute or multi-pole magnet for incremental measurement.

- **Combined solutions** enable heterogeneous redundancy for safety-critical systems, thereby offering a solid foundation for applications like brake-by-wire or redundant steer-by-wire steering systems.

Table 1 provides an overview of the typical properties, areas of application and differences between the two types of sensors. A combination of both technologies is usually advisable in safety-critical systems. Hall and TMR sensors basically measure the same magnetic signal but rely on differing physical principles. This level of diversity increases system robustness and enables heterogeneous redundancy in accordance with functional safety (e.g., ASIL D). If a homogeneous component, such as a Hall sensor system, should fail completely, the TMR sensor system remains fully functional, thus ensuring that ASIL D can still be achieved even in common cause emergency operation. Since technology-related failure mechanisms vary, they can be monitored in a highly differentiated way, providing extensive diagnostic coverage. This supports fail-operational concepts in applications, thereby enabling very high system availability. Developers need to check which sensor configuration best suits the requirements for accuracy, immunity and safety.

Criterion	Hall sensors	TMR sensors
Measuring principle	Detection of the absolute position (e.g., angle, linear movement) in a setup with multiple horizontal and vertical Hall plates On-axis (2-pole magnet) for dynamic absolute positions / mechanical domains (use of one HAL 302x sensor with up to six Z-sensitive Hall plates)	On-axis (2-pole magnet) for absolute positions / mechanical domains (use of saturated XY-TMR or linear TMR) Off-axis (multi-pole magnet) for incremental measurement / electrical domains, XY saturated or linear TMR
Typical applications	BLDC/AC motor rotor position (for HAL 302x), pedal position, encoder cylinders, limit stops, absolute reference points	BLDC/AC motor rotor position, actuators, dynamic movements
Type of mounting	On-axis layouts, also available as linear and 3D variants	Preferably radial measurement with multi-pole magnet rings
Magnetic stray field behavior	Compensation through differential structures (e.g., 6ZD) possible	Compensation through the application of stronger magnets or magnetic differential linear TMR sensors
Sensitivity	Low-level, integrated amplifiers amplify the sine/cosine signals to 4 Vpp	Very high, enables a direct µC connection without amplification (3 Vpp); linear TMR sensors require an external amplifier
Type of signal	Sine/cosine signals or output of the calculated angle	Sine/cosine signals or output of the calculated angle
Signal processing	Integrated stray field compensation reduces external effort; dynamic error compensation required for very high accuracy of < 0.1°	Direct application of sine/cosine outputs without the need for amplification. For stray field compensated systems, an amplifier that enables intrinsic stray field compensation is recommended.
Strengths	Absolute position, high dynamics, very robust against mechanical tolerances, compact on-axis integration, suitable for remote and on-board applications	High resolution, extensive dynamic range, robust off-axis measurement, high signal stability throughout the life cycle
Weaknesses	Radial mounting demands precise magnet guidance	Does not provide an absolute position without additional reference for off-axis integration

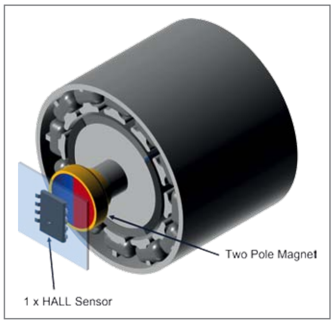
Table 1: Comparison of Hall and TMR sensors in terms of their application.

Position detection in electrohydraulic brake actuators

The various integration options for Hall and TMR sensors and their respective properties are shown using the example of electrohydraulic brake actuators. The implementation variants differ significantly in terms of accuracy, stray field tolerance and system setup:

- **On-axis integration with Hall sensors** (Fig. 3, above): Hall sensors like the HAL 302x series are installed directly in line with the axis. They are compact, resistant to stray fields and enable PCB-free and redundant designs with single-sided PCB assembly. Their absolute accuracy in terms of temperature and lifespan is approximately 0.5 to 0.6° in real-world practical conditions, which is sufficient for most brake and actuator applications. For higher accuracy requirements, an external microcontroller can perform dynamic error compensation and achieve accuracy levels of up to 0.1°.

- **On-axis integration with TMR sensors** (Fig. 3, center): TMR sensors (e.g., TAS224x or TAS214x) achieve an accuracy of 0.3° in a stack configuration and even up to 0.1° with dynamic compensation. The direct connection to the microcontroller without any external amplification simplifies the circuit architecture and enables compact designs. That said, stray field compensation is usually required via software or at least a second TMR sensor. When using two linear TMR sensors, stray field-robust position determination can occur like in Figure 1; in this case, external amplifiers are required. As such, single-sided PCB assembly is possible.



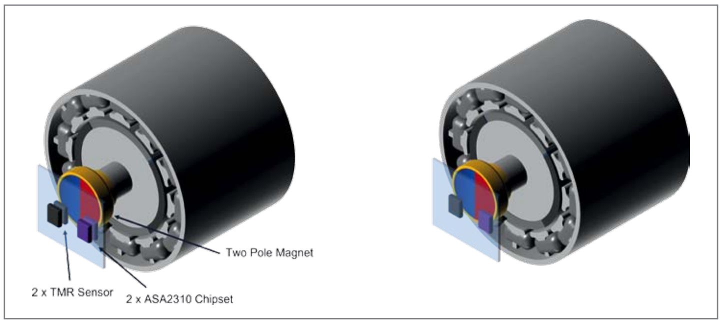
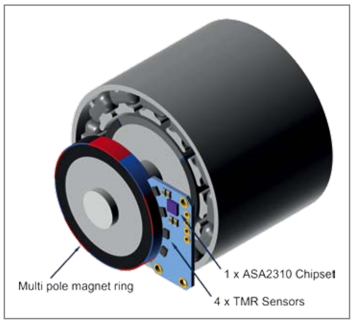


Figure 3: Comparison of the integration of Hall and TMR sensors: On-axis Hall (above) via on-axis-TMR (center) to off-axis TMR solution (below).

- **Off axis integration with TMR sensors** (Fig. 3, below): TMR sensors detect the magnetic period in a radial arrangement with multi-pole magnetic rings. This architecture offers exceptional stray field tolerance already at hardware level and is particularly suitable for dynamic applications, such as BLDC motors, where there is no space at the end of the shaft. The short signal processing latency and high modularity of the sensor modules help ease implementation noticeably. However, it must be noted that they do not provide absolute positions but rather relative positions with an accuracy of 0.5 to 1°. This is often sufficient for electric motor commutation and actuator control.



Technology meets application requirement

The choice of sensor system depends not only on its technological features but, above all, on the specific application: What position needs to be detected? What requirements apply to accuracy, dynamics, EMC and functional safety? On-axis Hall sensors offer robust, simple integration and good stray field tolerance. On-axis TMR sensors provide excellent accuracy but demand compensation against magnetic field interference. Off-axis TMR architectures are inherently insensitive to interference effects and are ideal for dynamic applications, such as the “electrical position” of motors. The best solution depends on the respective safety, accuracy and stability demands. The clear trend shows: The targeted combination of both technologies unites their strengths and ensures a balanced combination of performance, safety and efficiency. ■

The accompanying white paper contains more information.

Efficient heat management for MOSFETs

Cooling from the top side

Optimized heat management is crucial to ensure the reliability of MOSFETs as power densities increase. Top-side cooling has been shown to be a more efficient alternative to conventional heat dissipation via the printed circuit board.

By Ralf Hickl, Product Sales Manager ABU at Rutronik, Julian Werther, Regional Marketing Mosfets at Vishay, and Simon Goodwin, Senior Manager Global Applications Business Development – Automotive at Vishay

The trend toward higher power densities in electronic applications places ever greater demands on heat management: It is becoming a critical factor in ensuring performance, reliability and longevity – especially in high-power applications such as industrial drives, automotive systems and power supplies.

MOSFETs are traditionally cooled via the solder connection between the bottom side of the package and the printed circuit board (bottom-side cooling). The heat generated by the semiconductor chip is conducted through the drain pad connection to the printed circuit board and then from there to a heat sink or cooling plane, typically achieved through an array of thermal vias. This method has several limitations, particularly a comparatively high heat resistance. This results from multiple interfaces – from chip to package, from package to printed circuit board and from there to heat sink – and depends significantly on the PCB material used (e.g., FR4), as well as on the number and placement of the thermal vias. Furthermore, heat dissipation is impacted by the PCB area and layout.

A way to improve heat dissipation is to cool both the top and bottom of the package. In this case, the heat is dissipated both via the bottom of the package to the PCB and via the top of the package to a heat sink. However, this solution also presents several disadvantages:

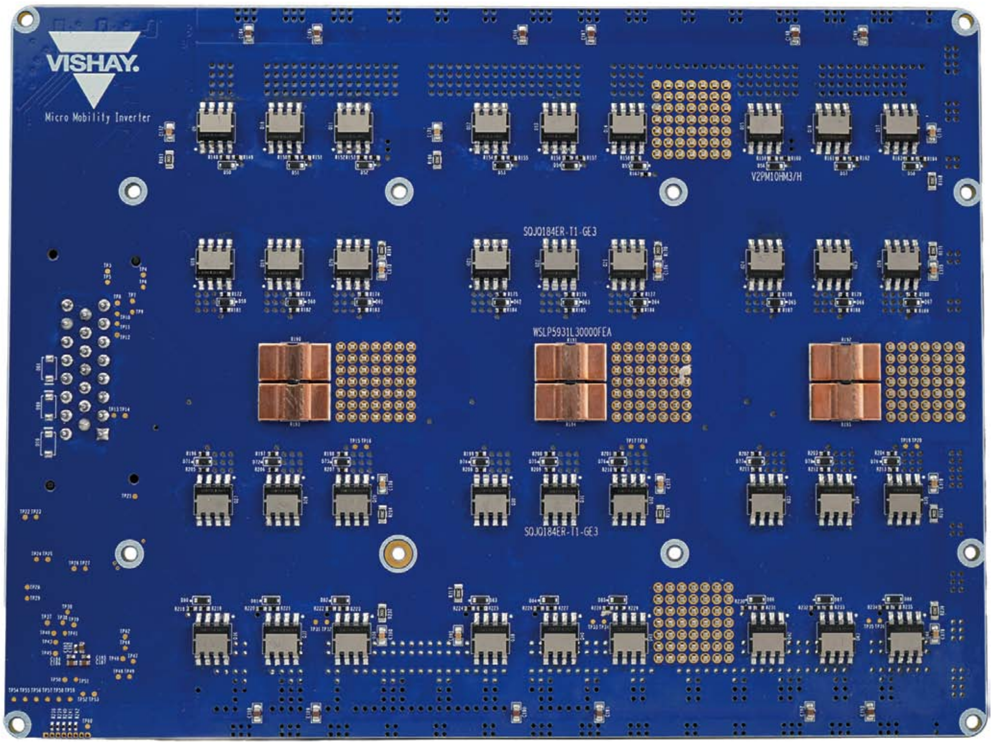
- The complexity of mechanical integration and the soldering process increases, as additional heat sinks or thermal pads are needed.
- The additional cooling measures result in higher costs.
- There are also increased space requirements.
- Further, it creates higher mechanical stress due to the mismatch in thermal expansion between the two sides of the component.

Advantages of top-side cooling

Top-cooled MOSFETs are designed with the drain exposed on the top of the package. This allows the drain to directly contact a heat sink or cooling plate, thus significantly reducing heat resistance.

This approach presents several key advantages: Firstly, overall heat resistance is lower, as the heat path is shorter and offers higher thermal conductivity, as thermal vias are not required to connect the heat sink, for example (Fig. 1). Secondly, due to more efficient cooling performance, developers can increase the power output without exceeding thermal limits, thereby boosting power density. Thirdly, top-side coo-

Figure 1: Circuit board surface area and layout have a significant impact on heat dissipation. (Source: Vishay)



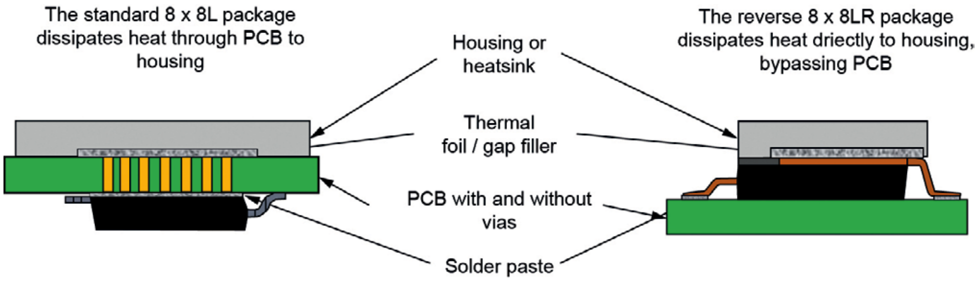


Figure 2: Comparison between the standard 8x8L package (left) and the top-side cooled 8x8LR package (right).

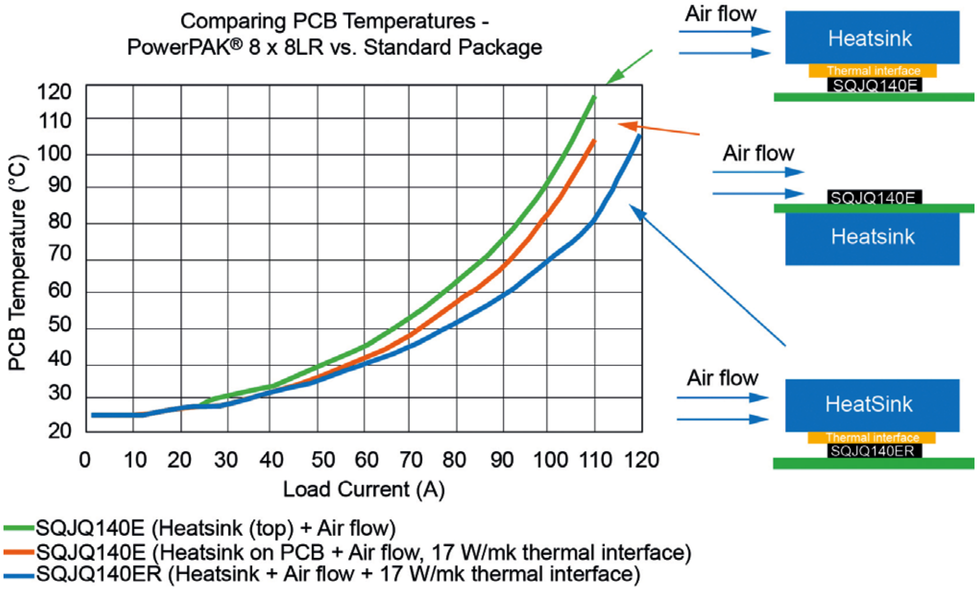


Figure 3: Printed circuit board temperature of standard packages with bottom-side cooling (SQJQ140E) compared to packages with top-side cooling (SQJQ140ER) at differing load currents. The top-side cooling variant shows significantly lower temperatures on the PCB.

ling simplifies the printed circuit board design, as the bottom side can be used fully for electrical connections and is not needed for complex thermal via structures.

Moreover, lower operating temperatures help to extend the lifespan of the components and improve overall system reliability. Yet another advantage is that the heat sink can be mechanically decoupled from the printed circuit board. This helps to reduce stress on the solder joints and to prevent deformation or cracks during temperature cycling.

Comparison of proven advantages

The top-cooled PowerPAK-8x8LR package from Vishay uses power clips instead of wire bonds to minimize both electrical and thermal resistance. Additionally, it is equipped with gull-wing connections for mechanical relief (strain relief) (Fig. 2). The exposed drain clip on the top side of the package provides a heat path with low heat resistance and forms the basis for the top-side cooling property. This allows the component to achieve greater performance when a heat sink is mounted on the top. Since the heat is dissipated directly to the heat sink, the printed circuit board is no longer the primary heat path. This eliminates the need for thermal vias in the area of the MOSFETs on the printed circuit board. When combined with the miniaturization of the other components, it results in a lower copper content of the printed circuit board and less costs.

The direct comparison of various cooling concepts clearly shows the advantages of top-side cooling (Fig. 3). Three cooling concepts were compared in a test setup: A conventional MOSFET package with top-side cooling (heat sink and airflow), the same package with an additional cooling connection to the PCB by means of a thermal pad (17 W/mK) and the top-side-cooled PowerPAK 8x8LR package with optimized top-side cooling. While there are no discernible differences between the cooling concepts at low currents, the top-side cooling approach shows a clear advantage at higher currents. At 110 A, the standard package with only top-side cooling reaches roughly 115 °C, with additional PCB cooling around 105 °C. The PowerPAK 8x8LR with top-side cooling, on the other hand, only reaches just over 80 °C. The results prove: The effective dissipation of heat losses via the exposed drain pad on the top side is much more efficient than conventional heat dissipation via the printed circuit board. As such, the performance limit of the system can be increased without the need for any additional thermal measures.

Figure 4: Vishay's MOSFET with top-side cooling, PowerPAK 8x8LR.

To ensure the integrity of the connection to the printed circuit board and high reliability at printed circuit board level, the package was also subjected to rigorous stress testing. A maximum junction temperature of up to 175 °C results in a longer lifespan than components with lower temperature limits.

Future-proof cooling concept

Top-side cooling is especially advantageous in devices such as high-power modules, automotive inverters and server power supplies, where space and thermal constraints are critical. Through the advancement of package technologies, MOSFETs with top-side cooling are becoming increasingly popular and cost effective, making them suitable for a wider range of applications. In addition to the 8 mm x 8 mm PowerPAK 8x8LR (Fig. 4), Vishay offers alternatives in various sizes to meet different power requirements, such as the 5 mm x 7 mm PowerPAK SO-10LR and the 10 mm x 15 mm PowerPAK 10x15LR, both of which will be available later on this year.

While bottom-side cooling and double-side cooling still have their place in power electronics, top-side cooling has become an attractive alternative due to its clear advantages in terms of performance, design flexibility and long-term reliability. ■

From digital lighting to OSP

Digital lighting via Open System Protocol

The Open System Protocol (OSP) redefines LED control, enabling both dynamic lighting scenarios and precise color gradients. OSP creates the foundation for flexible communication between light source and control: Open, scalable and ready for a wide range of applications.

By Hermann Senninger,
Senior Marketing Manager at ams OSRAM, and Martin Hetz,
Corporate Product Manager
Opto at Rutronik

Digital lighting enables precise, individual control of the brightness and color of a light source. These light sources are particularly interesting in applications that enable dynamic color effects. This requires anywhere from dozens to hundreds of light sources. The lead image illustrates how this technology can be used to create digital lighting effects in the side doors of a vehicle.

To keep these applications as compact as possible while enabling dynamic light adjustment, these light sources are best controlled intelligently through a suitable protocol. The protocol must deliver high-level color accuracy and update rates while optimizing resource efficiency.

From RGB to OSP

Light colors are typically created by mixing the three primary colors: red, green and blue (RGB). Given the typical color accuracy requirements in the automotive industry (u'v' < 0.01), each primary color requires a resolution of approximately 16 bits. This results in a usable data volume of 3 x 16 bits per light source.

The light sources' update rate should match that of a quality display of around 100 Hz or 10 ms. The protocol should be designed for compact integration within the light source, i.e. to occupy the smallest possible space at the lowest possible cost. The goal was to integrate it into an RGB LED – an LED containing three chips in the primary colors: red, green and blue. With these considerations in mind, a protocol was defined and published as the Open System Protocol, or OSP for short. [1]

OSP allows a microcontroller (µC) to control a chain of light sources bidirectionally or in a ring configuration. Figure 1 shows a possible physical arrangement of the µC and the light sources, here generally called nodes. Electrical data transfer between the

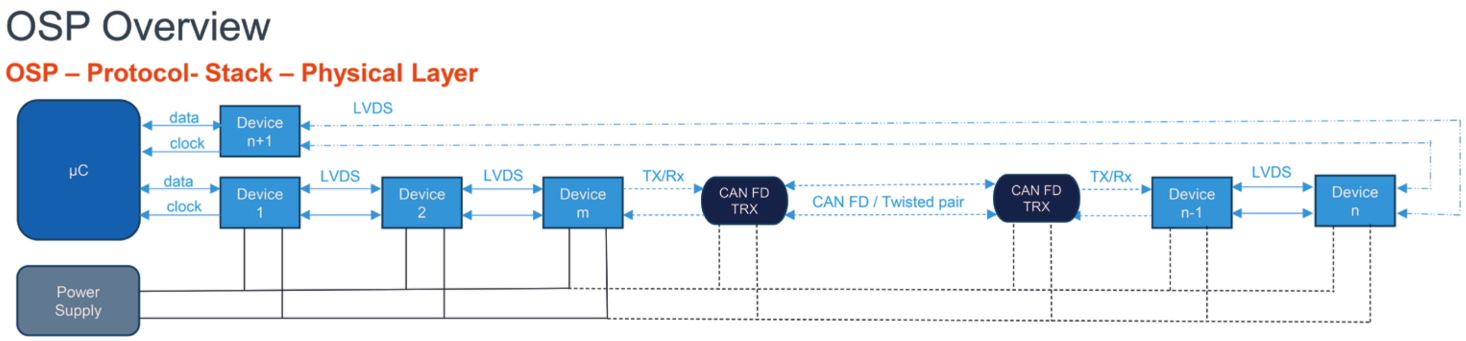


Figure 1: Overview of OSP and a possible physical arrangement of the µC and the light sources. (Source: ams OSRAM)

nodes can take place via LVDS or CAN FD (physical layer). The transmission rate is 2.4 MHz, and the data is Manchester encoded.

True to its name, the Open System Protocol is an open protocol that allows developers to create their own applications without license fees. Standardization of the protocol has just been initiated.

OSP also meets the aforementioned update frequency and color accuracy requirements for strips or areas containing up to 200 RGB LEDs equipped with this intelligence. This would enable implementations like door paneling. Any patterns or real images could be displayed in real time. In principle, OSP allows up to 1,000 nodes to be addressed and controlled with up to 64 bytes of user data per telegram.

Microcontrollers for controlling OSP networks

OSP has already been implemented, resulting in two components: An intelligent RGB LED and a smart stand-alone driver. [2, 3] These two elements can be connected to each other within an OSP network. Usually, this network is controlled by a microcontroller or a gateway controller. To do so, it must have also implemented the OSP protocol or the OSP protocol stack. A number of controllers with this OSP protocol stack are already available, for example controllers from Infineon (Traveo T2G, PSoC) and other MCU suppliers, as well as Arduino-based boards such as the Rutronik Development Kit RDK4 and the current adapter board RAB5 - OSIRE (see box text) for quick and easy commissioning.

OSP now offers a protocol that, in accordance with its basic requirements, enables high-speed downstream data transfer from a controller to the connected OSP nodes. Moreover, OSP also allows the controller to retrieve data from the network. This can serve diagnostic purposes; however, the controller can generally also read data from the network. Furthermore, OSP does not specify the type of nodes in the network. It only knows data, not content. Other node types – such as actuators or sensors – can therefore be integrated into a network and controlled via the controller alongside the light sources. This results in a network capable of performing tasks and functions beyond simple light display.

In order to be recognized and controlled within the OSP network, OSP must be integrated into each node. Alternatively, a device that is not OSP capable can be integrated into the OSP network via a small gateway. The aforementioned smart stand-alone driver offers precisely this function as an OSP-to-I2C gateway. This allows actuators and sensors to be integrated into the OSP network via their I2C interface.

Additional sensors and actuators have already been incorporated into lighting applications in early prototypes. All functions are enabled via one and the same OSP network.

Digital lighting and more

The term »more« refers exclusively to functionality: OSP allows more than simple lighting control and offers an expanded range of applications. While OSP was designed specifically for automotive use, it is equally applicable to other applications. OSP is open to all and allows for the addition of further and specially developed functions. Therefore, OSP can be used and expanded by any developer. To highlight this openness, ams OSRAM has released an OSP software package for Arduino on GitHub. [4, 5] The software provided is freely accessible. ■

Advanced LED solutions: With OSIRE® LEDs from ams OSRAM

Leverage the Rutronik adapter board RAB5 - OSIRE to develop applications for interior and ambient lighting, as well as RGB control elements. The versatile approach of Rutronik System Solutions unlocks a world of further possibilities thanks to the Arduino interface, which enables multiple boards to be stacked.

The RAB5 contains OSIRE® LEDs from ams OSRAM as a key component. The LEDs are designed for dynamic ambient lighting and feature individually addressable chips for maximum flexibility in color and driver selection. Additionally, ams OSRAM's intuitive GUI enables easy programming of each individual LED, thus improving usability and customization options.

The combination of the adapter board RAB5 with the base board RDK4 is particularly effective thanks to the automotive-qualified microcontroller integrated on the RDK4. More specifically, Infineon's PSOC$^{\text{TM}}$ 4100S Max, with its cost-effective Arm® Cortex®-M0+ automotive microcontroller, enhances this setup with seamless integration and advanced control capabilities.

References
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[2] https://look.ams-osram.com/m/46e569ad50283dc5/original/OSIRE-E3731i-Open-System-Protocol.pdf
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[5] https://github.com/ams-OSRAM/OSP_aotop

Integration of power electronics in drive units

Compact modules for modular traction systems

High current density, simple installation and thermal connection – new power modules support the implementation of compact drive units for electric vehicles. The example of an integrated electric axle drive clearly illustrates how design freedom, efficiency and platform capability can be combined.

By Johannes Würden, Key Account Manager at Rohm, and Andreas Münzer, Senior Manager Product Marketing Power at Rutronik

Lighter, more efficient and space-saving drive systems are needed to boost the number of xEVs and to meet climate goals, such as carbon neutrality. The efficiency of the inverter in particular has an impact on the range and size of the battery. Developers are under pressure to come up with systems that are lightweight, highly efficient and simple to integrate.

SiC power electronics enables compact drives

Silicon carbide (SiC) has emerged as a key material for the next generation of power electronics. Modern SiC MOSFETs offer higher switching frequencies with lower losses and serve as a key enabler for more compact, efficient and easier-to-cool traction systems in vehicles.

Electric drives especially require high power density and reliable, yet simple heat dissipation. Although SiC is fundamentally efficient, power loss and thermal coupling must be specifically controlled to enable a compact design without any thermal limitations.

An example of this type of optimized solution is the TRCDrive pack module series from ROHM (Fig. 1). Two complete SiC half-bridges are combined in a 2-in-1 principle within a single module and enable particularly compact, powerful inverter systems.

Overview of the technical highlights:

- Fourth generation SiC MOSFETs (up to 1200 V/600 A_{Rms} per module)
- 2-in-1 half-bridges for particularly compact inverters
- Single-sided, highly efficient heat dissipation
- Top-side press fit pins that leave the underside completely free for thermal connections
- Low parasitic two-layer busbar structure (only 5.7 nH)
- Temperature range from -40 °C to +175 °C

Module variants are available in two package sizes (for various outputs and installation sizes) and with either a sintered silver surface or a pre-applied thermal conductive film. Both variants support single-sided heat dissipation and facilitate integration into the cooling system.

The available versions cover both 750 V and 1,200 V rated systems, making them ideal for integration into an array of vehicle architectures, from compact electric vehicles to powerful SUVs or light commercial vehicles.

Integrated drive with SiC module

A current example of the use of this module technology is the eAxle module from Valeo: The electric motor, inverter and reducer are combined in a shared packaging.

Thanks to the TRCDrive pack modules, single-sided, highly efficient heat dissipation is sufficient, and complex cooling architectures or double-sided contacting are no longer required.

The top-side press fit pins additionally facilitate system integration: All essential electrical signals are top-side connected, thereby leaving the heat-dissipating underside free for the cooling system. This results in a lower overall height, reduced weight and simplified interfaces for installation and servicing.

Due to the low parasitic inductance and high current density, the modules are ideal for modern platform architectures and flexible vehicle concepts. The high degree of modularity enables individual adaptation to various vehicle segments, ranging from compact electric cars to powerful SUVs or commercial vehicles.

The demonstrated system was designed for rear axle applications, among others. The compact integration of motor, inverter and reducer places increased demands on the EMC behavior and heat management. Exactly these requirements can be met efficiently with the selected module concept.

From evaluation to full-scale production

Two coordinated evaluation kits are available for practical development and rapid system integration (Fig. 2). The double-pulse testing kit can be used to characterize individual modules under realistic conditions, for example to analyze switching losses and dynamic behavior. It includes an optimized printed circuit board layout with gate driver, power routing and thermal interface.

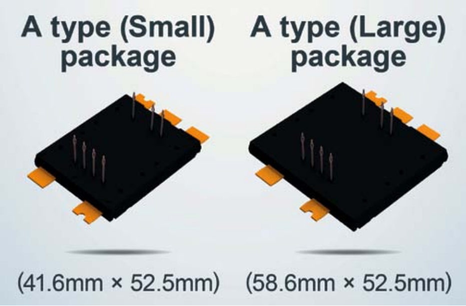

Figure 1: Modules of the TRCDrive pack series with single-sided heat dissipation and press fit pins are available in two package sizes and as various power variants. (Source: Rohm Semiconductor)

The 3-phase full bridge kit maps a complete traction inverter topology. It supports applications with multiple modules and is designed for laboratory setups and early vehicle testing. Suitable gate drivers, DC link connections and mechanical interfaces for installation and cooling are integrated.

Both kits facilitate commissioning, system tuning and thermal evaluation, making them practical tools for transferring developments from the laboratory to full-scale production.

Summary

The combination of modular hardware and available development equipment helps to reduce development times, standardize variants and implement new vehicle concepts efficiently. This supports the development of modular architectures for electric drive trains. ■

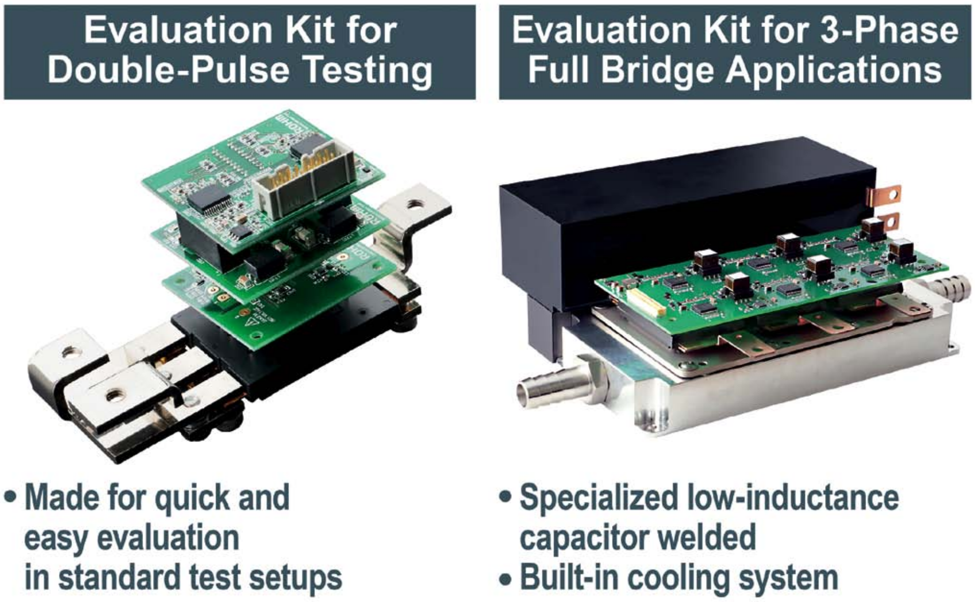

Figure 2: Two coordinated evaluation kits are available for practical development and rapid system integration. They enable the TRCDrive pack modules to be characterized under realistic conditions and tested within the system.

Professional power supplies for factory automation

Greater efficiency in the control cabinet

Modern automation requires space-saving, robust and low-maintenance power supply solutions. New concepts emphasize high power reserves, smart protection mechanisms and easy handling, even under demanding industrial conditions.

By Michael Peters,
Business & Product Manager
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Power at Rutronik

A reliable power supply is the backbone of any automation solution. The requirements are particularly high in industrial applications: Intelligent systems, compact control cabinets, higher ambient temperatures and ever shorter maintenance cycles place tight limits on conventional power supplies. Selection is increasingly driven by the overall system – including additional functions, service life and ease of installation.

Selection criteria for power supplies in factory automation

Selecting the right power supply for factory automation is crucial, directly impacting the reliability, efficiency and safety of the entire plant. Modern manufacturing environments place high requirements on power supplies, as they operate continuously and often under harsh conditions. Therefore, various technical and economic aspects must be carefully considered when making a selection to ensure trouble-free and cost-effective operation:

- Stable output voltage, even with fluctuating loads and harsh environmental conditions.
- Overload, overvoltage and short-circuit protection are essential for the longevity of the power supply and end devices.
- Efficiency exceeding 90% reduces energy losses and minimizes heat generation.
- DIN rail power supplies enable flexible expansion and easy maintenance.
- Compliance with standards like UL, CE and RoHS guarantees suitability for global industrial use.
- Modern power supplies offer remote monitoring and diagnostic functions to enhance plant availability.

Figure 1: The Racpro1 series won the Red Dot Award for Product Design in 2025 – proof of its successful combination of technical innovation and attractive design. (Source: Recom)

- In addition to the sum of all consumers, a reserve of at least 25% should be planned.

- Particularly in the case of motors or actuators, the power supply must be able to handle short-term load peaks without being oversized.

- Temperature range, humidity, vibrations and dust exposure must be taken into account.

- Tool-free installation, compact design and easy diagnostics simplify installation and maintenance.

- Durable components and a high mean time between failures (MTBF > 80,000 hours) offer economic advantages.

It is evident that modern power supplies must do way more than simply deliver stable power to meet the demanding conditions of industrial environments.

In order to guarantee a permanently reliable supply, the thermal performance of power supplies must be considered during the design phase. Derating starts at ambient temperatures above 60 °C: The maximum available output power is reduced depending on the temperature and installation environment. For planners and control cabinet manufacturers, it is therefore essential to take derating characteristics into account, especially for high packing density or limited airflow.

Compact, powerful and ready for peak loads

The Racpro1 series is specifically designed to meet these requirements (Fig. 1). The tool-free push-in terminals in a 25° design ensure time-saving and maintenance-free integration on the DIN rail. The devices also offer a compact design (from 43 mm wide), active switch-on current limitation and a service life exceeding 80,000 hours at 40 °C under full load.

To minimize thermal power losses, the package design utilizes the chimney effect: Warm air rises through vertical channels and creates a draft of cooler air from below. This natural

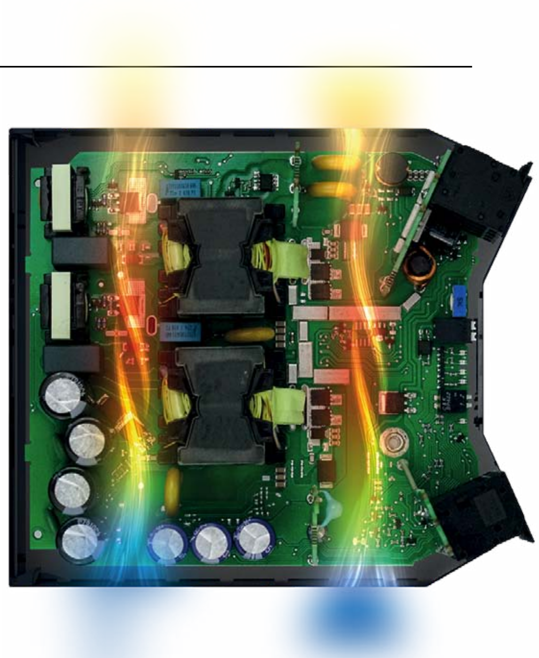

Figure 2: The Racpro1 DIN rail power supplies fully leverage the chimney effect: The internal components are positioned to form two vertical chimneys. As the heat rises, air is drawn through these channels and cools the components.

	Racpro1-T240	Racpro1-T480	Racpro1-T960
Width	43 mm	52 mm	80 mm
Efficiency	up to 94.1%	up to 95.3%	up to 97.1%
Functional characteristics	active switch-on current limitation; 2-phase AC operation 2x350 V to 2x575 V	PFC > 0.9 and active switch-on current limitation; passive load distribution in parallel operation and LED load indicator	PFC > 0.9 and active switch-on current limitation; passive load distribution in parallel operation and LED load indicator
Weight	500 g	800 g	1140 g

Table 1: Comparison of the three Racpro1 models.

convection ensures effective heat dissipation without the need for fans and guarantees full performance of the devices at ambient temperatures up to 60 °C (Fig. 2).

In addition to the package design, the optimized printed circuit board (PCB) layout also contributes to thermal and electrical stability. Large copper areas for heat distribution, strategic placement of heat-generating components and airflow-optimized conductor routing ensure efficient passive cooling. This increases the service life of the components and reduces the probability of failure under full load.

Another advantage is the power reserves: In addition to continuous power at an ambient temperature of 60 °C, the devices enable an additional power output of 120% at a reduced ambient temperature of 45 °C and, at 60 °C, a power boost of 150% for five seconds – ideal for sudden load changes.

The system is supplemented by 4-channel electronic fuses (e-Fuses), allowing users to monitor the 24 V circuits. With selective protection, individual consumers can be selectively shut down in the event of a fault, making sure that important consumers, such as controls, remain in operation. Diode circuits using MOSFET technology allow low-loss connection of multiple power supplies for the redundant supply of safety-critical systems or for enhanced power. Active switch-on current limitation also protects the contacts of the upstream circuit breakers. Table 1 shows a comparison of the Racpro1-T240, -T480 and -T960 models.

Summary and outlook

In modern factory automation, power supplies are no longer »passive« components but central system components. They must combine energy efficiency, operational reliability and ease of maintenance. Beyond supplying power, they increasingly handle diagnostics, protection and communication functions. To meet these requirements, today's power supplies must not only be powerful and compact but also feature intelligent protection mechanisms and robust designs. The power supplies of the Racpro1 series are designed for centralized and decentralized use in control cabinets or directly on the machine. Combined with electronic fuses, redundancy diodes and uninterruptible power supply (UPS) systems, they form a modular supply system that is fully DIN rail compatible and easy to integrate (Fig. 3). Rutronik supports the implementation of a future-proof power supply architecture from source to load with a comprehensive range of products, technical advice and system expertise. ■

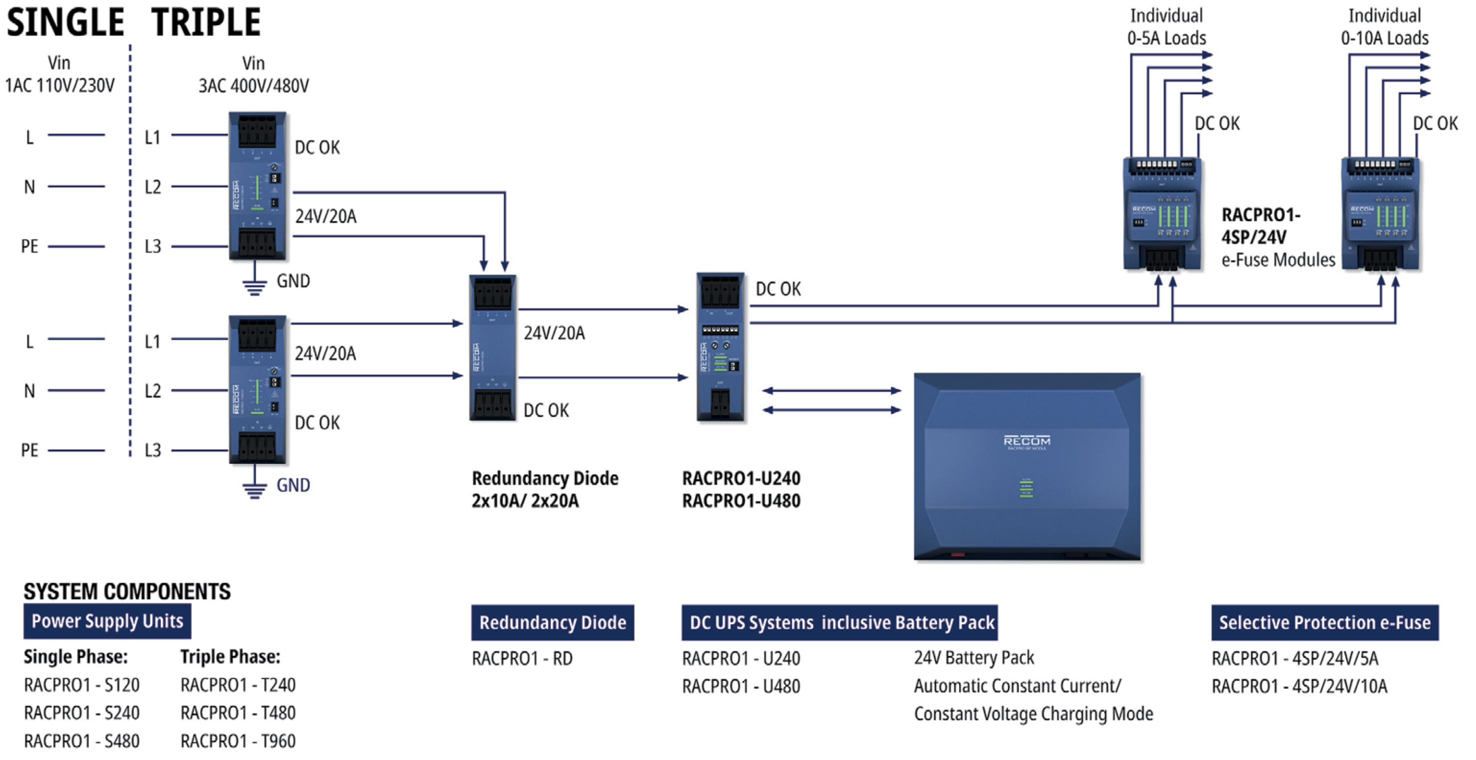

Figure 3: The Racpro1 family offers DIN rail power supply solutions for automation applications.

Edge computing meets AI efficiency

Rapid development, intelligent deployment, efficient evolution

The trend toward intelligence at the network edge is transforming modern system development and requires not only precise AI models but also agile, efficiently integrable platforms.

BY TORSTEN MASSHOLDER,
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Developing intelligent Edge AI solutions requires more than just precision AI models and high-performance hardware. The focus is on agility across the entire AI lifecycle: How rapidly can models be developed and deployed, and how adaptable are they to hardware and software changes?

Modern edge solutions must be able to handle complex tasks such as image and speech recognition or anomaly detection in real time, all while operating under strict resource and energy constraints. This demands a platform architecture that can be seamlessly integrated across diverse applications, from industry to smart retail.

Development platform with a vision

Edge applications place varying requirements on processing power, interfaces, graphics and AI capabilities, depending on their specific use cases. MediaTek's Genio platform tackles these challenges with a holistic approach that combines SoCs (Systems-on-a-Chip) specifically designed for Edge AI applications with NeuroPilot SDK (software development kit). NeuroPilot SDK supports various interfaces, including those for Nvidia TAO AI models. This provides users with consistent SDK and board support across the entire product range.

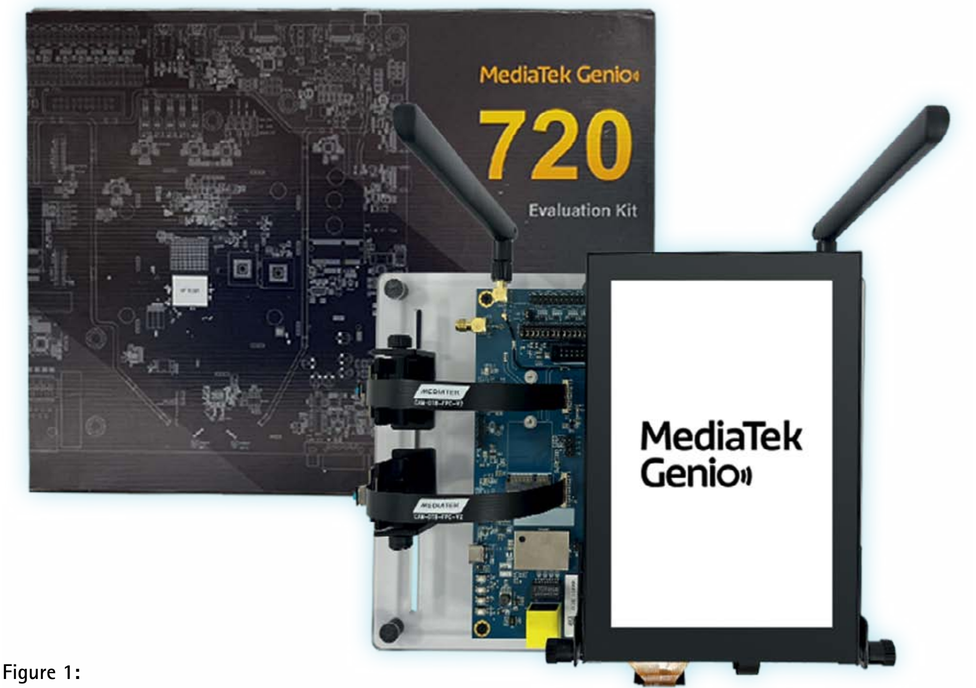


Figure 1:
Genio 720 Evaluation Kit.
(Source: MediaTek)

SoC	Genio 350 (MT8365)	Genio 510 (MT8370)	Genio 700 (MT8390)	Genio 520 (MT8371)	Genio 720 (MT8391)	Genio 1200 (MT8395)
Process	14 nm	6 nm ↔	6 nm	6 nm ↔	6 nm	6 nm
CPU	4x CA53 (2,0 GHz)	2x CA78 (2,0 GHz) 4x CA55 (2,0 GHz)	2x CA78 (2,2 GHz) 6x CA55 (2,0 GHz)	2x CA78 (2,2 - 2,4 GHz) 6x CA55 (1,8 - 2,0 GHz)	2x CA78 (2,4 - 2,6 GHz) 6x CA55 (1,8 - 2,0 GHz)	4x CA78 (2,2 GHz) 4x CA55 (2,0 GHz)
GPU	Mali-G52	Mali-G57 MC2	Mali-G57 MC3	Mali-G57 MC2		Mali-G57 MC5
NPU	1x VP6 0,35 TOPS	1x MDLA3.0 + 1x VP6, 3,2 TOPS	1x MDLA3.0 + 1x VP6 4,0 TOPS	MediaTek 8th Generation NPU 9 TOPS		2x MDLA2.0 + 2x VP6 4,8 TOPS
Audio DSP	HiFi-4	HiFi-5		N/A		HiFi-4
Memory	DDR3L/DDR4/LP3/LP4-3200, up to 4 GB	2-ch or 4-ch 16-bit LP4(x)-3733, up to 8 GB		2-ch 16-bit LP4x-4266, up to 8 GB / 2-ch 16-bit LP5(X)-6400, up to 16 GB		4-ch 16-bit LP4(x)-4266, up to 16 GB
Storage	eMMC5.1	eMMC5.1		eMMC5.1, UFS3.1 2L, SPI NOR		UFS2.1, eMMC5.1
Display	Dual Display FHD60 + HD60	Dual Display FHD60 + 4K60		Single: UW5K60 or 4K60 Dual: 2,5K60 + 2,5K60		Dual Display (4K60 + 4K60) Triple Display (FHD60 + FHD60 + 4K60)
	MIPI-DSI + LVDS/DPI	MIPI-DSI/eDP + HDMI/DP		MIPI-DSI/LVDS/eDP/DP (Type C)		MIPI-DSI + eDP + HDMI/DP
Video Input	2x MIPI CSI-2	2x MIPI CSI-2		2x MIPI CSI-2, 16 MP @ 30 fps ‚or' 6x FHD30 with Virtual Channels	2x MIPI CSI-2, 16+16 MP or 32 MP @ 30 fps ‚or' 6x FHD30 with Virtual Channels	3x MIPI CSI-2, 1x HDMI 2.0
VDEC	1080P60, H.265/H.264/VP9	4K60, AV1/VP9/ H.265/H.264	4K75, AV1/VP9/ H.265/H.264	4K60, H.265/H.264/VP9		4K90, AV1/VP9/H.265/H.264
VENC	1080P60, H.265/H.264	4K30, H.265/H.264		4K30, H.265/H.264		4K60, H.265/H.264
Peripheral	2x USB2 (1x OTG, 1x Host), 3x UART, 4x I^2C	1x PCIe2.0, 1x USB3.1, 2x USB2.0, 4x UART		1x PCIe2.0, 1x USB3.2 Gen1 (Type C) (1 shared with DP), 3x USB2.0		1x PCIe3.0, 1x PCIe2.0/ USB3.1, 1x USB3.1, 2x USB2.0, 6x UART
	10/100 Ethernet MAC	1x GbE MAC (TSN)		1x GbE MAC (TSN)		1x GbE MAC (TSN)
Op. Temp	-20 ~65 °C (Ta)	Consumer: -20 to 90 °C Tj Industrial: -40 to 105 °C Tj		Consumer: -20 to 90 °C Tj Industrial: -40 to 105 °C Tj		Consumer: -20 to 90 °C Tj Industrial: -40 to 105 °C Tj

Table 1: Comparison of different Genio models, ranging from the energy-efficient entry-level variant to the powerful variant. (Source: MediaTek)

Table 1 shows the currently available derivatives that are particularly suitable for demanding Edge AI applications. They range from energy-efficient entry-level variants to high-performance variants designed for vision, HMI and generative AI applications. These platforms not only provide a comprehensive range of services but also set the standard for functionality and future readiness:

- Arm Cortex-A5/A7 multicore architectures for efficient processing,
- 10 years of product support for investment security,
- 6 nm manufacturing technology,
- dedicated APU (Accelerated Processing Unit) for real-time AI,
- security functions at SoC level
- and a uniform SDK for rapid development.

Accelerating AI model time-to-market

Fully equipped kits featuring touch display, camera, WLAN and GPIO are available for quick evaluation on all platform variants. They enable direct testing with video, HMI or AI applications and offer numerous interfaces (including MIPI-DSI, MIPI-CSI, LVDS, HDMI, GbE, PCIe, USB and CAN-FD).

Additionally, SBC solutions come in various form factors like SMARC, OSM and other SOM formats, allowing rapid integration into your own systems. The partner solutions cover various sizes, temperature ranges and operating systems (Yocto Linux, Android, Ubuntu). They enable the direct implementation of Edge AI projects, making them particularly interesting for prototypes and small-to-medium production runs. MediaTek's Genio platform simplifies the development of Edge AI applications thanks to a comprehensive technology stack:

- Nvidia TAO integration: Access to over 100 pre-trained models for image and speech recognition. These models can be adapted and deployed immediately for a variety of Vision AI applications, with no additional training required.
- MediaTek's NeuroPilot SDK is a powerful AI framework that enables efficient execution of AI models on MediaTek NPUs. It offers:
  - Seamless model conversion – for converting ONX models to TFLite for optimized inference.
  - Hardware acceleration – as used by MediaTek's MDLA (Deep Learning Accelerator) for powerful AI processing.
  - Broad compatibility – for supporting multiple AI frameworks, including ONNX Runtime and PyTorch.
- Cross-platform SDK speeds up development and maintenance across the entire Genio family. Once developed, solutions can be flexibly transferred to other products, saving both time and money.

This combination greatly simplifies and accelerates the development, porting and scaling of AI models.

From home training to production line

MediaTek's AI-enabled edge platform is already being used in smart retail, industry, health care and logistics. In any case, customers can reuse trained AI models, rapidly deploy them on OEM boards and maintain product lines over time – achieving minimal development deviation and maximum performance per watt. In addition, Rutronik provides access to a wide partner network in the field of embedded AI, including Advantech, Adlink, Seco and Via. They deliver powerful hardware solutions in multiple form factors, ready for direct use with the platform.

Two real-world use cases illustrate how Edge AI projects can be scaled, from simple consumer products to high-end industrial systems.

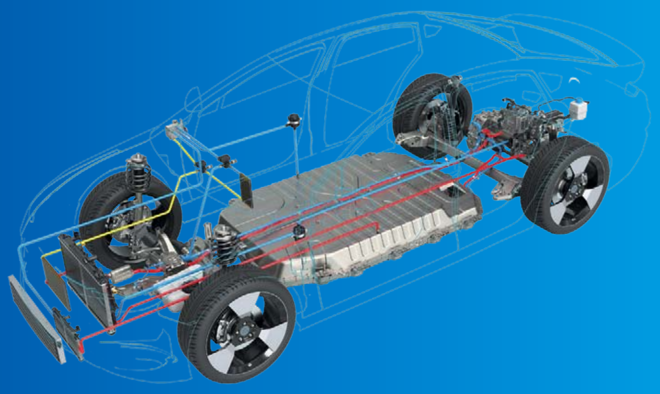
The interactive boxing workout FightCamp is based on the compact Genio 350 SoC and uses integrated motion sensors and a camera to capture punching techniques and posture locally, analyze them in real time and deliver instant feedback to the user without a cloud connection. Low power consumption, a compact design and sufficient AI performance (0.35 TOPS) make for a portable solution that delivers responsive user feedback. Thanks to NeuroPilot SDK, standard models from TensorFlow Lite, for example, can be run directly on the device.

The Genio 720 is used in modern production lines with up to 9 TOPS of AI processing power and supports multiple high-resolution video streams, including up to eight virtual Full HD channels at 30 fps. The platform analyzes quality characteristics like surface defects, labeling or dimensional accuracy directly at the network edge. With HDMI In/Out, dual MIPI-CSI, triple display support and a robust software base, it integrates into existing industrial IT systems.

The fully equipped Genio 720 development kit (Fig. 1) includes a touch display, camera interface, CAN-FD, M.2 slots and GPIO headers, making it the perfect foundation for AI-driven quality assurance in industrial applications.

Ready for the future of AI

The MediaTek Genio platform is well equipped for upcoming AI requirements at the edge. Thanks to the uniform NeuroPilot SDK, which integrates Nvidia TAO, new AI models can be deployed flexibly, efficiently and across platforms. Its modular design, support for various operating systems and long-term product availability secure investments while enabling rapid adaptation to future developments. The platform thus provides a future-proof foundation for innovative Edge AI applications.



GaN motor control with PSOC™ Control C3

Intelligence meets performance

The requirements placed on modern motor controls are continuously rising: They must deliver higher efficiency, enable more compact designs and provide increasingly precise control. By combining wide-bandgap semiconductors with a flexible microcontroller architecture, these rising requirements can be addressed in a forward-looking way.

By Andreas Münzer,
Senior Manager Product Marketing
Power at Rutronik, and
Torsten Massholder,
Senior Manager Product Marketing
Digital at Rutronik

Motor controls are facing intense development pressure: They must become more efficient, compact and precise. Whether robotics, drones, industrial plants or micromobility, solutions are required that deliver higher performance from smaller installation spaces. Wide-bandgap semiconductors, particularly gallium nitride (GaN), play a key role in this regard.

Wide-bandgap technology on the rise

Unlike traditional silicon MOSFETs, GaN transistors offer numerous key advantages (Fig. 1).

A major advantage is their significantly higher switching speed, which enables switching frequencies up to the megahertz range. This permits the use of smaller passive components, like inductors and capacitors, resulting in more compact and lighter designs. At the same time, the fast switching capability reduces switching losses, boosting the efficiency of DC/DC converters, inverters and motor controls.

GaN transistors achieve higher power density due to their ability to handle greater voltages and currents. This is particularly advantageous for high-frequency applications and precise controls. In addition, the lower energy losses lead to reduced heat generation. This enables the use of smaller, or even passive, cooling solutions and lowers thermal requirements.

Another technical advantage is the lower gate charge (QG) of GaN transistors, which enables faster and more energy-efficient control. This is especially beneficial for high-frequency applications and precise controls. Additionally, GaN is characterized by high robustness at high electrical voltages, as the material tolerates stronger electric fields than silicon. This characteristic makes GaN transistors especially well-suited for high-voltage applications, such as electric mobility and industrial drive technology.

Infineon offers a wide range of GaN transistors. The table presents a comparison of selected GaN transistors.

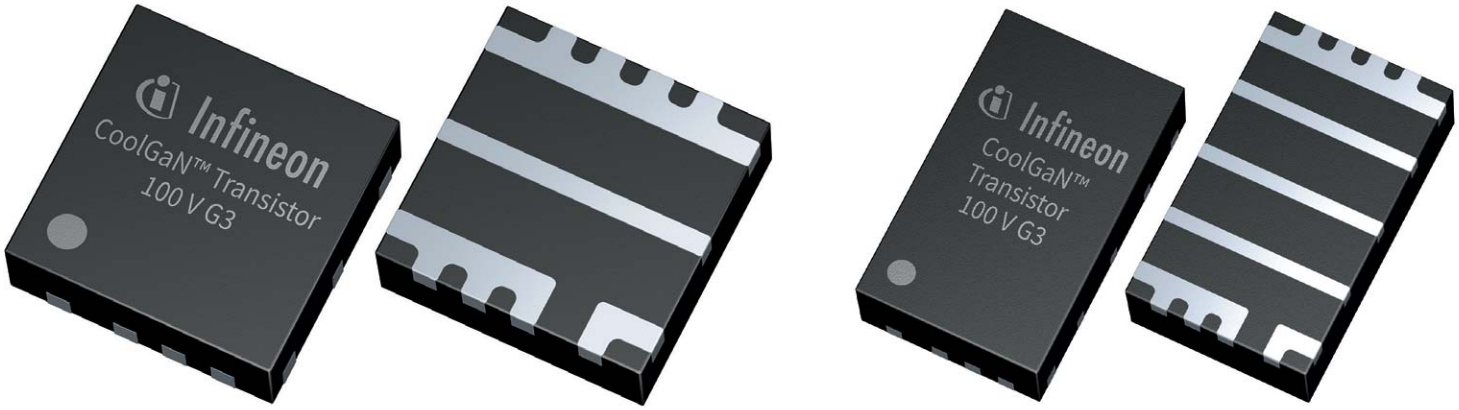


Figure 1: CoolGaN™ transistors in various package variants. (Source: Infineon)

Figure 2: Microcontroller PSOC^{TM} Control C3M with integrated peripheral functions for motor control applications.

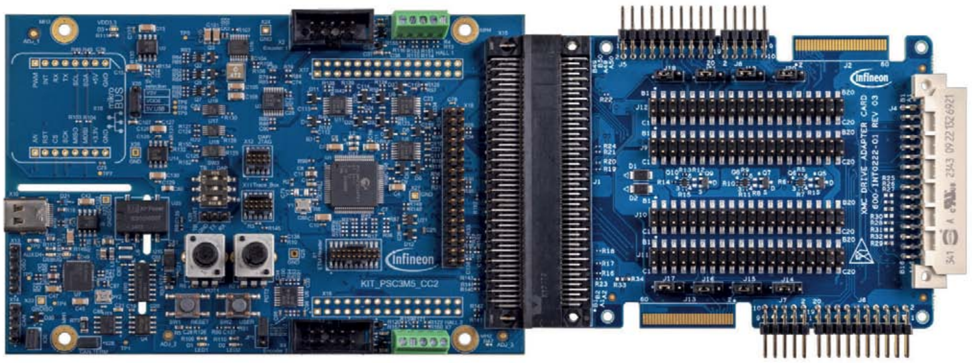


Figure 3: Evaluation board KIT PSC3M5 CC2 with integrated debugger and MADK connection for rapid integration of various motors.

Type	Voltage	$R_{DS(on)}$ (typ)	I_D (@25°C) max	Q_G	Package	Typical Applications
IGC033S101	100 V	2.4 mΩ	75 A	11 nC	PQFN 3x5	Reference component for 48 V motor controls, drones, servo drives
IGC037S12S1	120 V	2.7 mΩ	71 A	10 nC	PQFN 3x5	For industrial drives and applications with higher voltages
IGC090S20S1	200 V	6.7 mΩ	46 A	8,5 nC	PQFN 3x5	Higher voltages, e.g., e-mobility or servo drives
IGC025S08S1	80 V	1.8 mΩ	86 A	12 nC	PQFN 3x5	Compact for robotics and low-speed electric vehicle applications
IGC019S06S1	60 V	1.3 mΩ	99 A	13 nC	PQFN 3x5	Particularly low on-resistance, ideal for 48 V systems

Table 1: Comparison of various Infineon GaN transistors.

Rethinking motor controls

The special properties of gallium nitride transistors open up new possibilities for motor controls, especially in brushless DC motors (BLDC), servo drives, robotics and other electric drive systems.

Rutronik System Solutions launches GaN-based 48 V motor control board for maximum efficiency

The innovative pairing of Infineon PSOC™ C3M5 and RAK-GaN power stage delivers maximum performance, flexibility and a compact design.

The development team at Rutronik System Solutions is currently working on a new motor control board based on the Infineon PSOC™ C3M5 control card. In close collaboration with the Infineon experts, a completely new concept for the 48 V application domain is being developed. The board integrates three half-bridges for BLDC motors, which can also be used for conventional DC motors. All the components required for power control are already on board, including three-phase current measurement based on TMR current sensors and multiple voltage regulators to supply the system.

The board also provides a half bridge for a DC/DC buck converter. A key highlight is the new 100 V CoolGaN™ MOSFETs, which deliver maximum efficiency in the power stages. This is complemented by space-saving low-ESR MLCCs of the latest generation used as DC link capacitors.

On the digital side, the board provides maximum flexibility through the CAN-FD interface. Furthermore, an Arduino-compatible socket enables expansion with additional Rutronik Adapter Boards (RAB).

The result: The ideal pairing of the Infineon PSOC™ C3M5 control card with the new RAK-GaN power stage board – optimized for evaluation of 48 V motor control applications and a DC/DC buck converter, fully supported by ModusToolbox™, Motor Suite and the DCDC Power Conversion Configurator.

Stay tuned! More details and availability will soon be posted on our website:
https://www.rutronik.com/en/innovations

However, GaN transistors sometimes require more sophisticated gate trigger circuits. Further design challenges stem from the different types of GaN, such as depletion mode and enhancement mode. However, these challenges can be overcome by integrating specialized gate drivers and management functions, allowing the full potential of GaN to be exploited in the system.

A practical example of this is a 48 V BLDC drive with 308 watts of power and up to 4,000 revolutions per minute. Raising the field-oriented control (FOC) from 20 kHz to 100 kHz, combined with GaN transistors and the PSOC™ Control C3 microcontroller, boosts efficiency from 89% to over 96% (Fig. 2). Simultaneously, the motor temperature drops from 68 °C to 55 °C, while the GaN components remain stable.

This combination offers numerous practical advantages: Greater efficiency thanks to a higher switching frequency, reduced motor heating, a more compact design due to less cooling requirements and smaller components, as well as quieter, smoother motor operation with minimized current ripple and torque fluctuations. Additionally, precise control and built-in protection mechanisms enhance safety and system stability, for example by preventing overloads.

These advantages make this technology particularly interesting for applications such as robotic arms, drone propulsion systems, industrial servo systems and light electric vehicles. Featuring high-resolution PWM functions, fast analog-to-digital converters (ADCs) and integrated CORDIC and DSP units, the microcontroller provides a powerful control platform. This platform simplifies complex control algorithms and enables precise field-oriented control even at high speeds. The ModusToolbox™ Motor Suite development environment offers ready-made software libraries and tools that shorten development times. Moreover, it provides PSA Level 2 safety features for a safe and reliable system design.

Evaluation board as the basis for development

The Infineon KIT PSC3M5 CC2 is a compact evaluation board, providing developers with a versatile basis for evaluating motor controls (Fig. 3). The board features a PSOC™ Control C3M5 microcontroller, offering high-resolution PWM, fast ADCs, as well as integrated CORDIC and DSP units. Various power levels, motor types and sensor systems can be connected via standardized interfaces, making the board highly versatile.

The KIT is part of a modular platform concept and can be used both as a stand-alone control unit and alongside other evaluation boards, such as GaN power stages. This modularity enables rapid development and testing of various motor control topologies, including BLDC and permanent magnet synchronous motors (PMSM), as well as more complex multiphase applications.

The ModusToolbox™ Motor Suite also offers practical tools for configuration, runtime and static parameterization, signal analysis and a high-sampling-rate oscilloscope function. The ecosystem is further strengthened by the comprehensive availability of reference designs and complete evaluation kits, which enable particularly fast implementation and system integration.

Developers benefit from accelerated prototyping, shorter development cycles and an easy introduction to high-frequency, GaN-based motor controls.

Summary

The combination of wide-bandgap power electronics and modern control technology forms the basis for compact, efficient and powerful motor controls. It unites efficiency, intelligence and safety, thereby making it ideal for robotics, industry and electromobility.

CO_2 sensors for interior space monitoring

Precise measurements for better air quality

Increased CO_2 concentrations in interior spaces affect not only your general well-being but also sleep quality, concentration and overall safety. Cutting-edge sensors based on the principles of photoacoustics and thermal conductivity enable reliable CO_2 detection – from certified buildings to wearables.

BY JOAS VAN IPEREN, SALES DIRECTOR MOBILE & CONSUMER ELECTRONICS AT SENSIRION, ALEXANDRA SEREDA, BUSINESS DEVELOPMENT MANAGER AT SENSIRION, AND MANUEL GAUSS, SENIOR MANAGER PRODUCT MARKETING ANALOG & SENSORS AT RUTRONIK

Sleep is essential for good health, and we spend up to roughly one-third of our lives asleep. Quality sleep contributes to brain health, emotional balance and physical recovery. [1] Chronic sleep deprivation is linked to many serious health problems such as cardiovascular diseases, metabolic disorders (e.g., diabetes), a weakened immune system, a decline in cognitive functions as well as an increased risk of mental health issues such as depression and anxiety.

According to ResMed's 2025 Global Sleep Survey [2], about one-third of the respondents reported difficulty falling or staying asleep three or more times per week and rated only four out of seven nights as restful.

Despite greater awareness of the importance of sleep, there is a silent disruptive factor that is often overlooked: the air we breathe at night. And it is frequently worse than thought. In modern, air-tight homes, CO_2 levels in bedrooms can rise rapidly. Levels of 1,000 ppm are reached after just one hour.

In the morning, levels of 3,000 to 5,000 ppm are not uncommon in poorly ventilated rooms. This means that CO_2 concentrations are way above the recommended ranges specified in common building and IAQ standards. [3 to 7]

Unlike poor sleep, noise or light, which we immediately feel and perceive, elevated CO_2 levels are invisible and odorless. The majority of people are, therefore, unaware that this is negatively impacting their sleep. But scientists agree on one thing: Inadequate ventilation leads to increased CO_2 levels and possibly other biological risk factors and air pollutants.

This is clearly linked to sleep inefficiency and reduced deep sleep and impaired cognitive performance the next day. The complete causal relationship between CO_2 levels in the environment and sleep quality is still being investigated. However, the latest findings already point to several mechanisms through which elevated CO_2 levels during sleep can negatively impact the body – from stimulation of respiration to metabolic and neurological stress responses.

CO_2 and cognitive performance

Sleep and cognitive performance are closely intertwined. Decreased sleep results in increased memory problems, poor decision-making abilities and emotional dysregulation. Inadequate ventilation and high CO_2 levels in indoor air not only impair sleep but can also have a direct impact on brain health.

In studies where the participants slept in rooms with reduced CO_2 exposure (from ~2,500 ppm to ~900 ppm), they showed improved verbal reasoning skills, better working memory and higher alertness the next morning. They also reported feeling emotionally refreshed and mentally clearer. [8] Even during waking hours, the ability to make decisions declines significantly at CO_2 levels of ~1,000 ppm and reaches an almost dysfunctional level at 2,500 ppm, a CO_2 concentrati-


Image: Kusumawardhana/stock.adobe.com

The right CO$_2$ sensor for every market segment

SCD41 – the compact all-rounder

- Measuring range: 400 – 5.000 ppm
- Accuracy: ± (50 ppm + 2.5% of reading) up to 1,000 ppm, ±(50 pm + 3% of reading) up to 2,000 ppm, ± (40 ppm + 5% of reading) up to 5,000 ppm
- Current consumption: ~15 mA for measurement interval operation
- Supply: 2.4 – 5.5 V
- Energy-saving and single shot modes available
- Integrated temperature and humidity measurement for compensation
- Interface: I^{2}C
- Size: 10.1 × 10.1 × 6.5 mm^3
- Typical applications: DCV regulations, thermostats, IAQ monitors

SCD43 – standards compliant precision

- Measuring range: 400 – 5.000 ppm
- Improved accuracy: ± (30 ppm + 3% of reading)
- Certification: optimized for WELL, LEED, RESET, ASHRAE
- Identical footprint to SCD41 (10.1 × 10.1 × 6.5 mm^3)
- Comparable power consumption to SCD41
- Single shot operation possible
- Typical applications: Building automation, certified air quality measuring devices and demand-controlled ventilation (DCV), upgrades in line with stricter standards

STCC4 – ultra-compact TC sensor

- Measuring range: 400 – 5.000 ppm
- Accuracy: ± 100 ppm + 10% of reading)
- Size: 4 × 3 × 1.2 mm^3 (SMD compliant, tape and reel)
- Current consumption: ~950 µA at 1 Hz measuring rate
- Interface: I^{2}C
- τ 63% response time: ~20 s
- Typical applications: Wearables, smart speakers, mobile devices and cost-sensitive IAQ products, thermostats
- Advantage: Particularly suitable for close-to-the-battery and cost-critical designs

on frequently observed in classrooms, offices and motor vehicles. Activities that required strategic thinking, initiative and the use of information were particularly affected. [9]

CO$_2$ is, therefore, not only a comfort parameter but also a tangible control quantity for demand-based ventilation and a simple proxy for nighttime interior space air quality.

More intelligent sensors for a healthier life

Sensors allow users to monitor air quality in real time, optimize HVAC systems (heating, ventilation and air conditioning) and thus create a healthier indoor climate. In the development stage, the question is not whether CO$_2$ is measured, but how it is measured.

Two technical approaches dominate:

- **Photoacoustic NDIR (PA-NDIR):** A modulated infrared beam hits CO$_2$ molecules, whose vibrations generate pressure fluctuations. These fluctuations are picked up by an MEMS microphone. Advantages include a high level of selectivity, long-term stability and strict compliance with standards.
- **Thermal conductivity (TC):** In this case, the change in thermal conductivity of the gas mixture due to the CO$_2$ content is measured. Advantages include an extremely compact design, low energy consumption and reduced costs. A disadvantage, on the other hand, is the lower selectivity toward gas mixtures.

Both approaches are well established but differ in terms of their integration level, form factor and suitability for standards compliant IAQ applications (indoor air quality).

Sensors for various integration scenarios

Sensirion offers an array of sensors. The SCD41 and SCD43 sensors are based on non-dispersive infrared photoacoustic technology, ensure a high level of accuracy and are ideal for certified buildings that want to satisfy green standards such as WELL, LEED, RESET and Fitwel.

These sensors can be integrated into smart thermostats, air cleaners and building management systems to enable demand-driven ventilation and ensure optimal indoor air quality (Fig. 1).

When it comes to consumer electronics, the STCC4 sensor is a cost-effective solution with direct CO$_2$ measurement based on the principle of thermal conductivity. It can be integrated into alarm clocks, smartphones, laptops and even wearable health monitors, thereby allowing users to track their exposure to poor air quality both day and night (Fig. 2).

The combination of CO$_2$ readings with ventilation rates, sleep parameters and cognitive performance indicators enables the use of sensors for predictive health management. If the air quality deteriorates, users can be warned without delay and take the appropriate measures. Intelligent sensor technology thus creates the basis for interior spaces that actively adapt to human needs and support health and performance in the long term.

Selection, integration and practical aspects

The selection of a suitable CO$_2$ sensor depends largely on the application scenario. In the field of building automation, high measuring accuracy, long-term stability and compliance with standards are essential, particularly for DCV applications and certified air quality devices. While in the smart home and consumer sector, compact designs, low power consumption and simple integration into battery-powered systems play a key role. Short response times and reduced energy consumption are also crucial for wearables and mobile devices. Accordingly, the current sensor portfolio has suitable solutions for every market segment:

- SCD41: universal solution for compact devices with a high demand for accuracy
- SCD43: for applications that need to meet strict standards and certification requirements
- STCC4: when a small footprint and low power consumption are decisive

The accuracy and long-term stability of the readings depend crucially on the level of integration into the target system. Recommended:

- Location in a lightly ventilated area with a clearly defined airflow route
- Avoidance of temperature hot spots (e.g., due to power supplies or power electronics)
- Utilization of automatic baseline and drift compensation (ASC) with PA-NDIR sensors
- Combination with temperature and humidity sensors for precise compensation
- Regular cross-checking of readings during field operation

With PA-NDIR sensors (SCD41, SCD43), fast control loops can be achieved when using short, periodic measurement intervals. In contrast, single shot operation is suitable for power-saving telemetry. TC sensors such as the STCC4, on the other hand, benefit from exact environmental compensation in order to minimize the influence of other gases or temperature gradients. This makes the CO_2 level a robust reference variable for ventilation strategies, be it in certified buildings or in mobile applications that have a direct impact on health, sleep quality and cognitive performance.

Summary

The CO_2 sensor is a technical tool that has a direct impact on health, performance and comfort. The SCD4x platform ensures precise, standards compliant solutions for building automation. The STCC4 augments the portfolio for mobile and ultra-compact applications. This allows for the implementation of demand-based ventilation – from smart home to wearable level.

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Optical sensing for diagnostics and pharmaceuticals

Spectral sensors for smart medical technology

Spectral sensors deliver detailed optical signatures, enabling precise, non-invasive analyses ranging from skin analysis and microfluidic testing to drug monitoring. They are compact, energy efficient and also suitable for portable systems.

BY MANUEL GAUSS,
SENIOR MANAGER PRODUCT MARKETING
ANALOG & SENSORS AT RUTRONIK, AND
FLORIAN LEX, PRODUCT MARKETING
MANAGER AT AMS OSRAM

The requirements placed on medical diagnostic systems are steadily increasing: They need to be precise, portable and as non-invasive as possible. For engineers, this means smarter use of optical sensing.

Spectral sensors, particularly those detecting both visible and near-infrared light, are emerging as key components in this regard. One example is the TCS3448 from ams Osram, which is used in applications ranging from skin analysis to microfluidic diagnostic systems.

Capabilities of spectral sensors

Unlike conventional color sensors that measure only broad red, green and blue channels, spectral sensors such as the TCS3448 deliver

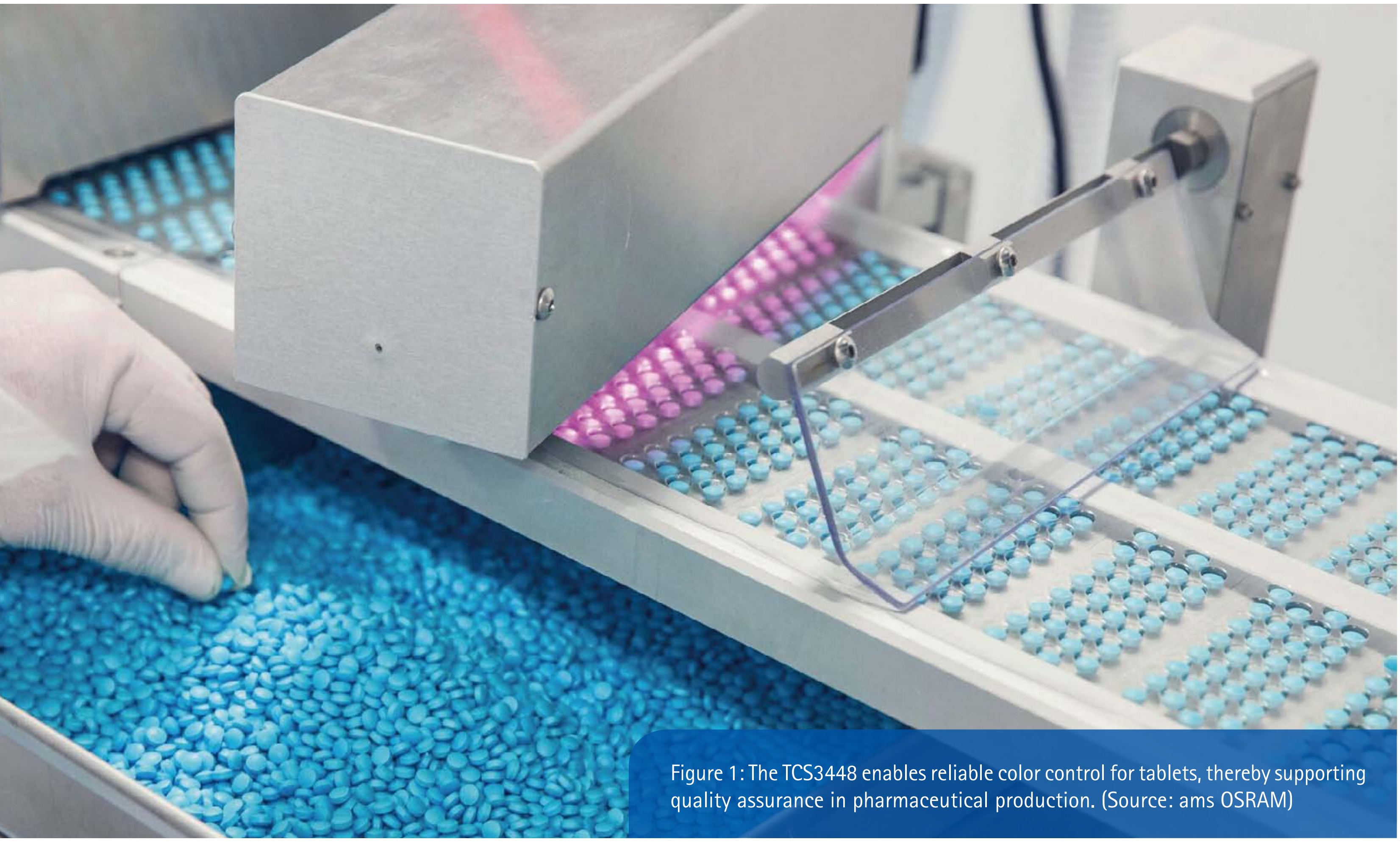


Figure 1: The TCS3448 enables reliable color control for tablets, thereby supporting quality assurance in pharmaceutical production. (Source: ams OSRAM)

finely resolved, multi-channel data. They capture light intensity across multiple defined wavelength ranges. This enables more precise characterization of materials, biological tissues and fluids based on their specific spectral signatures.

In medical technology, this allows contactless, real-time analysis, such as assessing skin changes (e.g., melanoma evaluation) or analyzing test strips in point-of-care diagnostic systems. Invasive procedures are thus minimized, making diagnostics more mobile and patient centered.

Integration and technical features

The TCS3448 is a 14-channel spectral sensor, covering the range from 380 to 1,000 nm. In addition to eleven channels centered in the visible spectrum, a NIR channel, a clear channel and a flicker detection channel are also available. The latter detects interference from artificial lighting up to 2 kHz, which is crucial for reproducible diagnostics. Integrated 16-bit ADCs, along with configurable integration times and gain ratios, allow flexible adaptation to various measurement environments.

With a typical power consumption of 280 µA in active mode and 5 µA in sleep mode, the sensor is especially suited for battery-operated systems. The compact OLGA-8 package (3.1 × 2.0 × 1.0 mm) facilitates integration even in space-constrained designs. Thanks to high-precision interference filters directly deposited on photodiodes, which are embedded in CMOS silicon, no additional optics are required, which reduces the size and increases measurement accuracy. For use in medical technology, compliance with regulatory standards (e.g., ISO 13485, CE or FDA) is essential, facilitated by standardized, non-invasive measurement methods.

Applications ranging from skin diagnostics to pharmaceuticals

These features open up a broad range of applications in medical technology. Spectral sensors deliver objective and reproducible data, for example in skin diagnostics, microfluidic testing or in laboratory and pharmaceutical applications. Furthermore, they can be integrated into compact, mobile systems.

Skin conditions like neurodermatitis or psoriasis often involve redness (erythema) and pigment alterations. However, these signs are difficult to assess subjectively and vary greatly. A spectral sensor such as the TCS3448 enables the objective measurement of erythema and pigment values, documentation of their progression and tracking of therapy effects. This is especially valuable in telemedicine or home monitoring applications, as it provides reproducible data for digital patient records or apps.

In lab-on-a-chip systems or rapid tests for infectious diseases, a color change indicates the presence of an analyte. However, especially at low concentrations or under varying light conditions, the human eye quickly reaches its limits. The TCS3448 detects the smallest color changes with high spectral resolution, making it ideal for portable, battery-efficient diagnostic systems. This approach also enables more reliable evaluation of multiplex assays with overlapping color signals.

In the pharmaceutical industry and laboratory technology, color is a critical quality criterion. Deviations may indicate contamination, degradation or incorrect formulations. The TCS3448 enables reliable and automatable color control, e.g., for tablets, reagents or culture media. It also provides robust and objective measurement data for digital pathology and laboratory automation.

In addition to color analysis, the sensor also captures parts of the near-infrared range, allowing straightforward fluorescence measurements. This capability is increasingly important for compact point-of-care devices, such as those for testing malaria, HIV or iron deficiency. Its low energy consumption and compact design further support use in portable diagnostic devices.

Smart diagnostics with optical signatures

As wearables and AI-supported diagnostics become more widespread, optical sensor signals are growing in importance. The quality of the input data is crucial in this context: The TCS3448 provides spectrally resolved information across multiple wavelength ranges, which can be fed into machine learning models with minimal preprocessing. This enables detection of patterns in tissues, fluids or surfaces that are invisible to the human eye.

Potential applications include smart skin patches for measuring hydration or oxygen saturation, compact home care devices and smartphone accessories for mobile health checks.

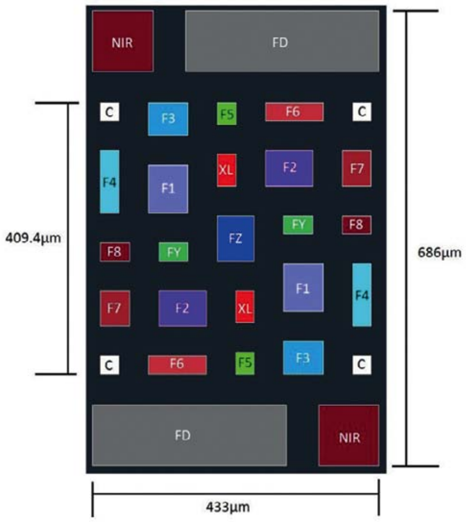


Figure 2: Multi-sensor array on chip covers a spectral range from 380 to 900 nm.

Comprehensive health profiles can be generated, particularly when combined with other sensor data, such as temperature. In combination with cloud connectivity and AI algorithms, this opens up new avenues in personalized medicine – for example through continuous, non-invasive monitoring in daily life. Spectral sensors can also support digital pathology or automated laboratory processes in clinical settings by supplying reproducible, objective data for diagnosis and therapy.

Summary

Spectral sensors such as the TCS3448 enable developers to create modern, portable diagnostic systems that are contact free, data driven and compact. Whether in skin analysis, microfluidic test systems or pharmaceutical quality assurance: They deliver precise data with minimal integration effort, forming a key foundation for the next generation of smart diagnostic systems. ■

CEO interview

»We can no longer wait for better times to come – we need to create them ourselves.«

An interview with Thomas Rudel, CEO of Rutronik, about economic challenges, AI as a strategic lever and practical tool, and why the SME sector has to take the lead.

Mr. Rudel, the economic situation is challenging. How do you see the situation for the electronics industry and for Rutronik?
Thomas Rudel: The order situation is a cause for concern in many areas – particularly in the automotive and industrial sectors. Customers are taking a careful approach, investments are being put off. This had already become apparent by mid-2024.

We have gone through various turbulent periods in the past: the oil crisis in the 1980s, the financial crisis in 2009, the COVID pandemic in 2020, and each one was significant in its own right. But what we are facing today is a convergence of challenges: geopolitical tensions, supply chain instability, technological upheavals, high energy prices, regulatory requirements and a noticeable reluctance to invest. This complex situation exceeds anything we have witnessed before.

But: 2025 is not a year for procrastinators. Those who merely manage risk losing out. We can no longer wait for better times to come but need to create them ourselves. That is why we at Rutronik set the course early on and constantly develop our business model further – with a clear vision toward digital transformation and AI integration, technological substance and a high commitment to change.

What does this mean exactly for Rutronik?
We did more than just talk about transformation, we actually initiated it internally, thereby providing impetus to our suppliers, partners and business partners. Our 30% stake in the AI specialist COMI sends out a clear signal.

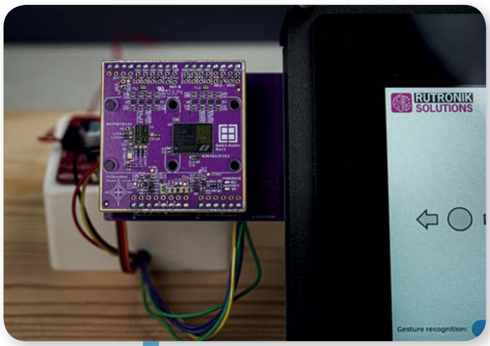
Within six months, we jointly piloted two AI-based solutions at our logistics center in Eisingen: the Vision AI Document Reader and the Vision AI Label Reader. These systems automate reading delivery notes and product labels with outstanding precision and at an amazing speed.

January 2025

Pilot testing of two AI-based solutions at the logistics center in Eisingen

February 2025

Exclusive insights into AI-optimized processes in goods receipt and acceptance at AI Vision Day



March 2025

AI on the Edge: New demo for AI control with radar-based gesture control using Infineon's PSOC^{TM} Edge E84

April 2025

Expansion of partnership with GCT

Images: Rutronik

Thomas Rudel, CEO at Rutronik

> *We do not view AI as an individual project but as a platform.*

Discover more about the Vision AI Readers

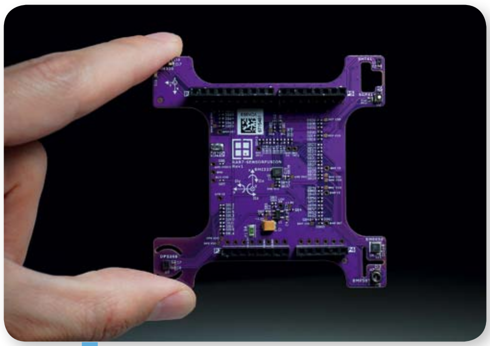
What are the benefits?

Time savings, less manual errors, greater quality. But above all else: Our employees claim that AI enhances their work rather than replaces it. That is the crucial point for me: AI is not an end in itself but a tool at our logistics center. And we demonstrate how humans and machines can work together as partners. Since there are around 1,000 delivery note formats, whose layouts often change or require ongoing adjustments, making manual capture time consuming and error prone even for well-trained staff, the process of reading delivery notes can be significantly accelerated. However, the Document Reader is also suitable for capturing other documents, regardless of whether they are physical or already stored digitally, e.g., as PDFs, image files or similar.

The contents can be captured in a structured fashion and stored accordingly. In the future at Rutronik, AI will also support various applications in areas such as order entry, contract reviews and reading product information. We are, therefore, aiming to also introduce AI-based processes in many other business areas, thus meeting their unique challenges and minimizing repetitive tasks.

Can customers and suppliers also profit from this technology?

Yes, of course. Take EMS firms as an example. They have become a central pillar of the modern electronics industry. They manage a substantial part of the value chain for OEMs (Original Equipment Manufacturers). EMS firms, as well as suppliers of electronic components, also need a fully automated, robust and scalable goods receipt process that ranges from the reliable capture of delivery information – even from printed delivery notes – to the clear capture of item information from the supplier product labels. AI-based label recognition not only works faster and more accurately, it can also be integrated seamlessly into the existing system landscape. In other words, we not only develop solutions for ourselves but for the entire industry.



May 2025

Launch of the next-generation Adapter Board RAB7 for sensor fusion

July 2025

Just two months before his death, Rutronik founder Helmut Rudel receives the Baden-Württemberg Founder Award 2025 in the »Lifetime Achievement« category.

June 2025

Cyber Resilience Act: Rutronik supports its partners in implementing complex EU regulations

August 2025

Rutronik adds Edge AI pioneer Axelera AI to its portfolio

How does Rutronik deal with the topic of artificial intelligence from a strategical viewpoint?
We design holistic solutions and tailored AI-supported processes. With Rutronik GPT, we aim to build an infrastructure that not only impacts our internal operations but is also available to our customers. This is the SME sector with a platform mindset – scalable, practical, open. We do not view AI as an individual project but as a platform. In real terms, this means:

- Intuitive configuration options for all components ensure that the platform is easy and straightforward to use, both for the internal team and for external partners.
- Comprehensive monitoring and alarm systems guarantee that relevant events can be detected in real time and dealt with efficiently.
- The platform scales flexibly, from IoT sensors to individual PCs and machines to supercomputer clusters, and is thus capable of adapting to growing requirements.

We want to ensure a modular structure that allows the platform to be expanded along with customer-specific components as needed to make bespoke adjustments. Availability should be provided both in the cloud and on-premise to enable optimal deployment based on specific requirements.

September 2025

Autumn events at Rutronik with our Tech Fairs in Dresden, Hamburg and Lucerne

October 2025

New conference: Around 120 decision-makers from the automotive and industrial sectors gathered at the first Rutronik AI³ Connect

Further, we are expanding our portfolio and, since the second half of the year, have added Axelera AI, a Dutch hardware and software company and European pioneer in the field of AI inference, as a serious alternative to the previous market leader Nvidia in the embedded market. Axelera AI ensures a significantly more attractive cost-benefit ratio with an optimal processing power-to-energy consumption ratio. In the edge environment, specialized hardware with an innovative design is needed, and that is exactly what Axelera AI delivers.

What other transformation initiatives are there at Rutronik besides the AI projects?
As already mentioned, we take digital transformation seriously and see it as a great opportunity. To create an ideal foundation within Rutronik, we are currently converting our entire ERP system into SAP. We see this as a necessity in order to maintain a consistent system architecture. This has always been our approach at Rutronik and how we plan to continue in the future, but now within the world of SAP. This enables us to build the necessary foundations for cutting-edge and innovative processes that will benefit our employees and business partners in the long term.

How are you dealing with the rising complexity in distribution systems?
We keep over 100 billion components on the move annually, with more than 1.5 million order items and over 50 million forecast changes. Changes to delivery times, volatile markets, and geopolitical tensions are the current reality and pose daily challenges in many areas of the company. But rather than give up, we see it as an opportunity to become even more professional. Our answer is: transparency, automation and two-way communication. We are navigators in a complex ecosystem, and that is exactly what our customers expect from us.

How do you ensure effortless communication with both customers and partners?
With over 40,000 business partners, roughly 200 suppliers and over one million items in our portfolio, efficient data communication is essential. The goal must be to enhance digital connectivity with our suppliers and customers, thereby enabling the fast and efficient processing of inquiries and orders regardless of time or location. In the area of EDI data transfer, we achieve a success rate of 99.76% with around four million EDI messages a year. Besides being technically robust, this approach is also data driven, strategically forward looking, and requires minimal manual intervention.

What makes Rutronik different from other distributors?
We are more than a traditional distributor. We are a system provider with in-house development. Our latest developer board, the Rutronik Adapter Board RAB7, is a prime example: It combines state-of-the-art sensor fusion with AI functionality, making it ideal for Industry 4.0 applications, smart cities or the automotive sector. This enables our customers to create their own sensor fusion applications faster.

Moreover, we offer guidance and advice on complex issues such as the Cyber Resilience Act. Through webinars and related on-demand offerings, we work with business partners like Infineon and TÜV Süd to get our customers ready for the new EU requirements that are set to come into effect in 2027.

Learn more about the Cyber Resilience Act in our on-demand webinar

What were the highlights of the year for you personally?
There are so many. Our first joint trade fair with COMI at embedded world 2025 sent out a strong signal. Furthermore, it was the third year in a row that readers of the trade magazine Elektronik voted us »Distributor of the

Year« – proof that our approach works. And we are all extremely proud that our founder, Helmut Rudel, received the Baden-Württemberg Founder Award in the »Lifetime Achievement« category. That is entrepreneurship with purpose and impact. Yet another highlight is our new congress: The first Rutronik AI^3 Connect was held at Motorworld Munich from October 14 to 15. Decision-makers from the automotive and industrial sectors came together. Two parallel tracks showcased specific use cases, from onboard charging and intelligent battery management systems to predictive maintenance and edge computing. There was also an exclusive networking dinner and plenty of opportunity to discuss matters.

But our commitment outside our core business is also important to me: Our Rutronik Stars Keltern won the 2025 German women's basketball championship. Rutronik Racing won the GT World Challenge Europe Endurance Cup – an amazing achievement. And in the middle of 2025, as part of the Week, of Welfare and Social Work, we handed over a Rutronik fleet vehicle to the Diakoniestation Ispringen. All this goes to show: responsibility for the local region of our headquarters and beyond.

Thomas Rudel, CEO at Rutronik

> *»We need greater entrepreneurial spirit, more willingness to embrace technology and belief and confidence in our own ability to bring about change.«*

What are your hopes for the German and European economy?

More courage. More pace. And more confidence in one's own strengths. Europe has enormous potential – we just have to release it. And that does not just start at management level, but in the offices, production and logistics facilities, laboratories and lecture halls. Here in Germany, we have an excellent educational landscape, elite universities and a dual study system that is unparalleled worldwide. The SME sector is the backbone of our economy and remains innovative, adaptable and down to earth. But: Many enterprises are now facing a generational change. And this also means: Pace and courage are needed more than ever. Anyone who takes on responsibility today must be willing to go beyond management and actively shape the future. We need greater entrepreneurial spirit, more willingness to embrace technology and belief and confidence in our own ability to bring about change. Progress does not start with perfection but with the first step. And it is exactly this step that we are taking at Rutronik: resolutely and with our gaze fixed firmly on what lies ahead. ■

In memory of Helmut Rudel

Rutronik and the entire electronics industry bid a sad farewell to Helmut Rudel, the Rutronik founder and president. Helmut Rudel died recently after a brief and serious illness, aged 87. He was a member of the executive management right up to the end.

It is with great sadness and deep regret that the executive management and workforce of Rutronik bid farewell to Helmut Rudel, founder and president of Rutronik Elektronische Bauelemente GmbH, who passed away on September 20, 2025, aged 87.

Helmut Rudel was not only a visionary entrepreneur but also a person of exceptional foresight, determination and social responsibility. With the founding of Rutronik in 1973, he laid the foundation for what has become one of the leading distribution companies for electronic components in Europe.

He was a pioneer in what was then a new business model for authorized component distribution. Only in July of this year Helmut Rudel had received the Baden-Württemberg Founder Award 2025 from the Baden-Württemberg Association of Savings Banks for his impressive lifetime achievements. The award, presented by the Minister of Economic Affairs of the State of Baden-Württemberg, honored his entrepreneurial accomplishments and his enduring impact on the state's economy.

With the death of Helmut Rudel, we have lost not only an absolutely outstanding entrepreneur but also a person whose influence on Rutronik is unparalleled. His legacy will live on – in the values he embodied, in the structures he created and in the memories of those who knew and worked with him. We will honor Helmut Rudel's memory.

The executive management and workforce of Rutronik Elektronische Bauelemente GmbH

Helmut Rudel, Rutronik founder and president, giving his welcoming speech at the Rutronik 50th anniversary celebrations in November 2023.

Automation of goods receipt and goods inwards at Rutronik

AI-based readers as key components of complete traceability

Modern supply chains place ever-increasing demands on transparency, traceability and speed. Especially companies from the EMS industry (Electronic Manufacturing Services), with a wide range of electronic components from different suppliers, numerous variants and constant changes, are confronted with an enormous volume of data.

By Tobias Husemann, Senior Consultant at collective mind (COMI), Markus Förste, Head of AI at collective mind (COMI), and Christian Krebs, Head of Projects & Process Management at Rutronik

Much of the data is produced in the goods receipt area, and distribution companies, among others, experience a similar scenario. Rutronik, as one of the leading broadline distributors in Europe, and COMI, a machine vision company, are working on a joint project to demonstrate how artificial intelligence (AI) can be used to efficiently overcome this challenge.

The goal: A fully automated, robust and scalable goods receipt process that ranges from the reliable capture of delivery information – even from printed delivery notes – to the clear capture of item information from the supplier product labels. AI-based label recognition not only works faster and more accurately, it can also be integrated seamlessly into the existing system landscape.

COMI's AI Vision Label Reader for AI-based product label recognition. (Image: COMI)

From manual inspection to automated recognition

Thousands of deliveries are handled every day at the Rutronik logistics center in Eisingen. Until now, the data from physical delivery notes was predominantly captured manually. This involved tediously entering the data by hand and comparing the information with corresponding data in the ERP system. Item numbers were either read using handheld scanners or typed in, while trace and date codes were checked visually and quantity details were added. The subsequent, manual capture of delivery notes that were not available in digital form was not only time consuming but also prone to errors. Sometimes, key additional information, such as batch numbers or countries of origin, had to be documented manually. This, in turn, proved to be a critical factor for traceability.

Other disadvantages of manually capturing data included incomplete or incorrect inventory data, limited transparency in the supply chain and a significant investment of time and effort for post-processing. The need for a structured, automated solution was plain for all to see.

Strategic partnership

Rutronik has had a 30% stake in COMI since October 2024. The aim of the partnership is to jointly develop scalable AI applications for trade and industry. The combination of distribution and machine vision expertise creates real-world practical and internationally applicable reader technologies for the automation of processes in industry, logistics, supply chain management and various other areas.

Rutronik set itself ambitious goals. The aim of the initial step was to implement automated document capture (COMI Vision AI Document Reader):

- Reading, interpreting and assigning delivery note information was to be automated using AI-based scanning.
- Variable document layouts had to be recognized just as reliably as different languages, units and designations.

Automated item capture (COMI Vision AI Label Reader) was considered as part of the further process:

- The manual scanning of product labels was to be replaced by camera-based data capture.
- Different label layouts and variably positioned QR and barcode labels had to be reliably recognized.

All information obtained was then to be handled in a structured manner and transferred directly to the ERP system. Yet another goal was to make the entire process flexible

Increasing relevance of EMS firms in electronics manufacturing

EMS firms have become a central pillar of the modern electronics industry. They manage the complete value chain (design and prototyping, PCB assembly, test methods, logistics) for OEMs (Original Equipment Manufacturers), thus allowing them to focus on their core competencies, such as R&D, while at the same time benefiting from economies of scale, cost efficiency and faster time-to-market.

The global EMS market was estimated at USD 573.75 billion in 2024 and is expected to rise to USD 1.1 trillion by 2032 – with a compound annual growth rate (CAGR) of 7.4%. [1]

The drivers of growth include rising demand for electric vehicles (EV), IoT devices and consumer electronics, as well as the increasing complexity and miniaturization of electronic appliances, which require specialized manufacturing processes.

[1] https://www.fortunebusinessinsights.com/electronic-manufacturing-services-ems-market-105519

enough to respond to new types of products or operational requirements. Particular attention was dedicated to optimizing the read rate with a target value of over 99%, as well as the ability to read and evaluate multiple codes at the same time.

The goods receipt solution for automated delivery note capture: Vision AI Document Reader

The »Vision AI Document Reader«, developed jointly by Rutronik and COMI, expands goods inwards to include the automated processing of delivery notes. Instead of tediously typing out data manually, printed delivery notes are simply scanned and analyzed by an AI system.

Thanks to several specialized Large Language Models (LLMs), the system is capable of reliably interpreting even complex documents. It is irrelevant which layouts, languages or abbreviations are used for items – such as for quantities, units of measure, items or order numbers.

This helps eliminate the typical errors associated with manual entry and that arise when interpreting delivery note data. The captured information is compared automatically with the data provided by the ERP system (e.g., based on the order or supplier number). This allows workers to see immediately whether a delivery is complete and correct.

Finally, all the information is structured and transferred to the relevant IT systems within the process chain and therefore made available in real time for further processing.

The goods inwards solution for automated item capture: Vision AI Label Reader

Together with COMI, Rutronik developed the »Vision AI Label Reader«, a system that pairs industrial cameras with AI-supported software. The reader automatically recognizes all common 1D and 2D codes, such as barcode and QR code labels, regardless of their position and alignment. Moreover, the system is able to reliably capture printed text and handwritten comments. This is a key advantage, especially for companies in the EMS industry, where handwritten notes, for instance for changing rolls, are commonplace.

Intelligent parser algorithms extract item numbers, quantities, production data and origin information and transfer them directly to the logistics database. In addition, the system reliably processes labels with inconsistent layouts and provides all the relevant information in real time.

Thanks to a visual front end, workers can instantly check the data captured and resolve any problems on the spot. This boosts process reliability and minimizes the amount of training required.

Demonstrable added value: Time, quality, transparency

Transition to the AI-supported system has shown measurable effects:

- Over 99% increase in the label reading rate
- More than 50% reduction in the average inspection period per delivery note
- Almost complete elimination of input errors
- Structured storage of all the information – seamless traceability is guaranteed

The Label Reader and Document Reader offer a clear competitive advantage, especially for EMS suppliers with customers in highly regulated industries, such as the automotive, medical or pharmaceutical sectors, where traceability is demanded by law.

Scalability for further applications

The systems have a modular design and can be simply applied to other processes. For example, the Document Reader can also be used in order entry applications to automatically process incoming orders – whether by email or as PDF files. Routine software updates ensure that both systems remain flexible and are fit to meet future requirements.

Summary: Automation as a strategic lever

The collaboration between Rutronik and COMI demonstrates how AI technology can be used in electronics industry logistics services to automate manual processes, improve data quality and ensure competitiveness. The Vision AI Label Reader and the Vision AI Document Reader are therefore much more than just individual tools, they are strategic modules for sustainable, digital logistics processes. ■

Cybersecurity and component strategy

The Cyber Resilience Act – a fine mess

The Cyber Resilience Act enters into force in December 2027: Suppliers then have to provide security updates for a minimum of five years – even for products that have past their expected lifespan. It will additionally force device suppliers to select chips and radio stacks more strategically.

BY BERND HANTSCHE, VICE PRESIDENT
TECHNOLOGY COMPETENCE CENTER
AT RUTRONIK

It is Friday, December 10, 2027. As every year: Only two weeks to Christmas – and I am still wondering what presents to get. My nephew, a real techie, wants a smart ring, while my aunt dreams of a new food processor – so a trip to the electronics store it is. However, they were just about to close, so I decided to return on the Saturday.

Actually, a blessing in disguise: Because the devices I bought on December 11, 2027, were subject to a new regulation – the Cyber Resilience Act (CRA). At the time, I did not realize that this »unsuccessful« Friday would one day prove to be decisive.

Five years later in 2032. The presents are still being used – until suddenly problems arise. The ring displays inaccurate health values, and the food processor makes weird purchasing suggestions. An examination in a digital forensics laboratory reveals: Both devices have been compromised. The firmware of the ring has been updated, but not by the supplier. While the kitchen appliance has been reprogrammed using a wireless method by an unknown third party. This type of manipulation is possible with devices that have a computing core for software and an interface for modifying the software – and this is where the CRA comes into play.

Rethinking quality

To better protect European consumers from cyberattacks, the European Union officially adopted the CRA in 2024. It obliges suppliers to provide security updates for a minimum of five years for all products sold in the EU economic area from December 11, 2027, and to ensure full traceability.

The example of the smart fitness tracker ring shows the consequences of the CRA. The supplier must plug any security gaps that it becomes aware of during the expected service life of the device, in my case at least until De-

Image: Rutronik

cember 11, 2032. For instance, if the Bluetooth pairing process is manipulated, responsibility lies primarily with the supplier of the ring. The latter must, in turn, contact the provider of the built-in Bluetooth system chip. If the chip is in perfect working order, the problem is not in the hardware but in the protocol software, i.e. in the Bluetooth stack. And the stack often originates from third-party suppliers, usually based in Asia. Then you can only hope that the chip supplier has also signed a long-term support agreement with the stack development firm. At present, five years is not the default period in standard contracts. In industrial environments, the expected service life is usually much longer.

This scenario is not as fictitious as it may sound: A serious security gap was indeed discovered in 2020. All the suppliers of Bluetooth ICs – and thus of software stacks – had adopted this error and incorporated it into their products. If semiconductor suppliers had corrected this error by themselves, their software would no longer have been Bluetooth compliant. It was only after the Bluetooth Special Interest Group (BSIG) had corrected the specification that semiconductor suppliers were able to create updates and patch the devices. [1]

The lesson learned from this: Suppliers who have control of their processes will benefit from the CRA, while others will struggle to meet the new high requirements. It is no longer enough for an assembly to merely work. The decisive factor is whether updates will still be available after five years – and whether suppliers will be able to guarantee them. Looking forward, it is best to pick chip suppliers who develop hardware and software under the same roof. By consolidating all the expertise in one place, customers receive a reliable and secure solution. The time-consuming task of rectifying issues with interfaces from various subcontractors is eliminated, as are negotiations with partners for whom the EU is often not the primary sales market.

However, the challenge lies in the fact that chip designs and radio stacks are frequently marketed as coming from a single source, even though this is not always the case. Some Bluetooth chip suppliers focus on hardware design, while the stacks are procured from third parties. It is this separation that makes subsequent updates challenging and complicates legal protection.

Rutronik therefore consciously pursues a redundant, everything-from-a-single-source strategy: For Bluetooth and WiFi SoC solutions, chips from two competing suppliers are marketed, but since each of them programs their own software, the hardware and software effectively come from a single source. Infineon and Nordic Semiconductor – both European suppliers – utilize in-house expertise, both in terms of silicon design and algorithms. A chip scheduled for discontinuation in 2027 can be updated without any problems in 2032, as no other firms are involved in its development and no »black boxes« are installed.

Another trend that is expected to rise: AI software for microcontrollers is becoming increasingly important, and suppliers do not want to rely solely on third-party suppliers. Besides their in-house radio stacks, Infineon and Nordic now also offer their own machine learning tools. Infineon uses Imagimob Deepcraft for its PSoC microcontrollers, while Nordic is repositioning its nRF controllers with Neuton – for applications ranging from motion and noise detection to predictive maintenance scenarios. Both suppliers plan to keep improving the energy efficiency of the AI functions created by customers, using specially optimized computing cores.

In general, the CRA has already influenced the distributor's supplier management quality process and will also be incorporated into the component selection of device suppliers in the medium term. European semiconductor suppliers that utilize their own software offer more peace of mind to device suppliers regarding the many CRA requirements than when using SoCs with procured and relabeled stacks.

An act with far-reaching consequences

The CRA splits opinions: For some, it is a bureaucratic monster that reduces their competitiveness compared to other regions of the world; for others, it is a necessary protective shield – not least because it weeds out less professional market participants and strengthens the reputation of reliable suppliers. It is part of the cybersecurity agenda of the Federal Ministry of the Interior of Germany. Further, it also reinforces the Federal Office for Information Security (BSI) as a central point of contact and emphasizes that cybersecurity is the joint responsibility of business, government and society. [2]

It is foreseeable that: The requirements will present hurdles, especially for startups and small businesses. Depending on the actual application, the CRA imposes a 24 to 72 hour response period for reporting incidents, regardless of whether it is a working day or a public holiday. As such, the CE mark will serve

Technology decisions within the context of the CRA

The CRA is helping to shift the focus of many suppliers: It is no longer enough to simply purchase chips that "work", as the update requirement demands strategic decisions. Strict liability applies. In other words, device suppliers are liable for the cybersecurity of their device and cannot simply blame security gaps on built-in components and parts.

An example: A supplier utilizes a Bluetooth chip in their product. Should security gaps appear in the radio stack over the next five years, the supplier must provide patches. If the chip supplier only purchased the radio stack, it often results in tedious re-negotiations, unclear responsibilities and a race against deadlines for the device supplier.

Providers like Infineon and Nordic Semiconductor, who develop hardware and radio stacks under one roof, are definitely in a better position. As this reduces the risk of support gaps and simplifies legal protection.

For OEMs, it means fewer interfaces, more control and, above all, a realistic chance of still being able to deliver updates in 2032 for chips that were announced back in 2027.

The on-demand webinar "Cyber Resilience Act: What Every Electronic Device Manufacturer Must Know to Sell Products in the EU After November 2027" featuring experts from Infineon, TÜV Süd and 1ACUE can be found here.

as proof of cybersecurity compliance from the end of 2027. This will significantly increase certification and documentation requirements.

A major challenge is the fact that suppliers must continue to provide security updates for at least five years after the last product has been sold, unless the expected service life is longer, even when the device is no longer on the market. Large corporations are naturally better equipped to deal with this challenge than small-scale suppliers who provide niche products manufactured almost by hand. It is also clear that: The size or age of a company must not compromise product safety. Distributors like Rutronik have therefore already started assisting customers through advice, webinars and partnerships, for example with TÜV Süd, to ensure CRA requirements are put into practice properly. [3]

The professional association FBDi (Fachverband der Bauelemente Distribution e.V.) supports its members from the outset with legal assistance, FAQs and guidelines to make the CRA requirements tangible from the start. A dedicated project group is working on classifying products, interpreting reporting requirements and supporting distributors to ensure that the new obligations remain realistic and practical. The association not only helps reduce the burden on its members but also provides guidance for those device suppliers who depend on reliable supply chains and legally compliant advice. A group of experts appointed by the EU Commission, including Infineon, a semiconductor specialist and Rutronik's largest franchise partner as part of Eurosmart, is working on more precise specifications for the risk assessment of electronic components, among other things. By the end of this year, legal standards should clarify when a microcontroller qualifies as being tamper proof or when it merely provides security-related functions.

Summary

The CRA will fundamentally change the industry. In the future, device suppliers will not make decisions based solely on the price and performance but also need to consider the question: »Who helps me stay secure for five years?« Suppliers offering in-house developed hardware and software will be able to give their customers peace of mind and assurance.

Since one thing is clear: Food processors should not be re-purposed by third parties as advertising media, and smart fitness tracker rings should not display false health warnings. These examples might seem harmless compared to the scenarios that arise when locking systems and identification or access functions are compromised or botnets are set up for DDoS attacks, these examples seem harmless. Therefore: We must act together today – as a European distributor, Rutronik supports suppliers worldwide in adapting their products to the requirements of the European market – even after December 11, 2027. ■

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[2] https://www.bmi.bund.de/SharedDocs/downloads/DE/veroeffentlichungen/themen/sicherheit/cybersicherheitsagenda-20-legislatur.pdf
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Gestures, language, display: Compact HMI with Edge AI

Multimodal interface based on PSOC™

Touch, language, gestures: A demonstrator shows how modern human-machine interaction can be implemented in confined spaces. Embedded intelligence combined with flexible interfaces enables responsive and intuitive operating concepts.

By Jordan Rose,
Field Application Engineer
at Rutronik, and Stephan Menze,
Head of Global Innovation
Management at Rutronik

The way humans interact with machines is evolving at a rapid pace. While touch displays are now the norm, contactless operating concepts are becoming increasingly vital, especially for applications where hygiene, environmental influences or physical limitations matter.

The demonstrator presented here (Fig. 1) shows how different sensor principles – radar, speech and touch – can be combined in a single embedded system to form a robust human-machine interface (HMI). The goal was to showcase the robustness of the recognition system against external influences such as bright sunlight, rain, ambient noise, or when hands are dirty or gloves are worn.

Developed as part of customer and internal development projects, the demonstrator serves as a practical basis for providing expertise in hardware, software and algorithms for radar gesture recognition and voice control.

Overview of the system architecture

The demonstrator combines all the key elements of a modern, multimodal human-machine interface in a compact design. The integration of gesture and voice control, motor control and graphical display requires a carefully coordinated architecture that accommodates diverse sensor and actuator interfaces while supporting real-time parallel processing.

A key challenge was integrating heterogeneous components with varying electrical interfaces – ranging from high-speed display connections to latency-critical sensor inputs – onto a single microcontroller platform. The Infineon PSOC™ Edge supplies the processing power and peripherals for signal processing and control, while the FreeRTOS real-time operating system orchestrates individual tasks and manages data streams and control commands via the internal AHB interconnect bus.

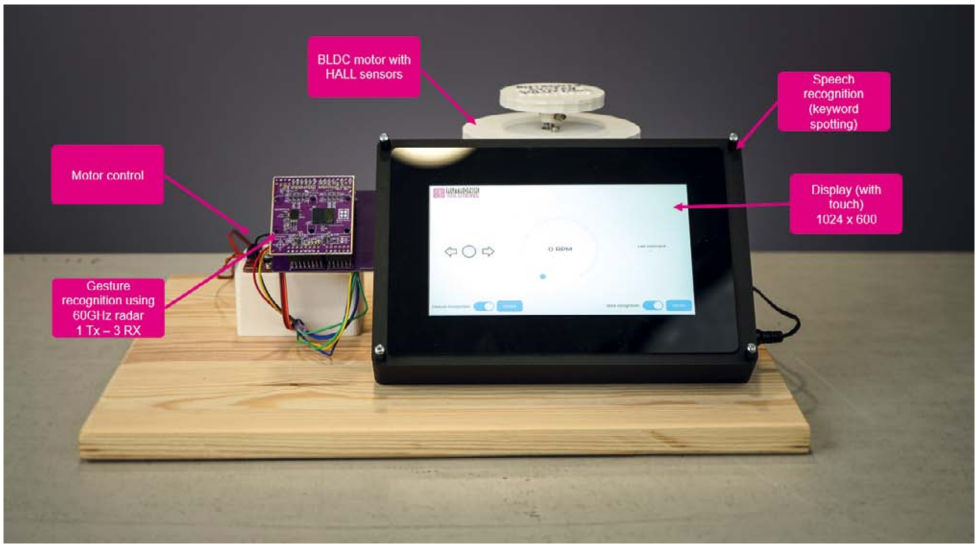


Figure 1: Overall view of the demonstrator with display, radar module, microcontroller board, display and motor. (Source: Rutronik System Solutions)

Table 1 below shows the key hardware components of the demonstrator together with their most important properties and functions.

Gesture recognition with 60 GHz radar

Gesture recognition is the key control element of the demonstrator. Left and right motions are detected, which cause the motor to turn faster or slower, as well as a »push« motion to stop the motor. At the core lies a 60 GHz FMCW radar sensor for motion detection. Signal processing is performed entirely on the Cortex-M55 core of the PSOC^{TM} Edge. As machine learning is not used here, development time is reduced and the need for training eliminated.

Gesture recognition process in the demonstrator (Fig. 2):

- **Input data:** Magnitude and AoA (azimuth only, as currently only the directions »left« and »right« are distinguished).
- **Capture:** A 60 GHz FMCW radar sensor, featuring one transmitting and three receiving antennas, provides a separate signal per antenna.
- **Motion detection:** Doppler FFT per antenna signal for identifying moving targets and suppressing static objects.
- **Direction determination:** Calculation of the azimuth angle from the phase differences of the receiving antenna.
- **Gesture classification:** Evaluation of the temporal progression of the azimuth angle to detect motion types such as »left swipe«, »right swipe« or »click«.

The latency period is approximately 10 milliseconds after the motion has stopped. Gestures can be recognized at distances of around 5 to 30 centimeters, or also from a greater distance if configured accordingly, even under complex reflection conditions and typical environmental factors such as sunlight. Incorporating elevation (vertical angle) enables potential recognition of additional gestures such as »up/down«.

Gesture recognition is supplemented by voice control using keyword spotting. Voice signals are captured by a MEMS microphone, preprocessed on the PSOC^{TM} Edge Cortex-M55 and evaluated using a trained neural network. The network with multiple convolution layers is specifically optimized to recognize a limited set of clearly defined keywords, such as »start« or »stop«.

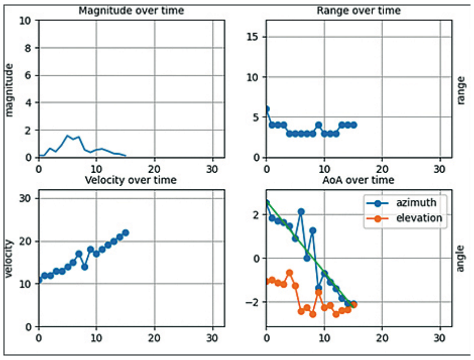


Figure 2: Gesture recognition with the BGT60TR13C radar from Infineon.

Component	Property	Function
BLDC motor with Hall sensors	Control via PWM and GPIOs (Hall sensors)	Rotational speed and direction are adjustable, feedback of the rotor position
IM69D130 XENSIV MEMS digital microphone from Infineon	Connection via digital PDM interface	Capturing audio signals for keyword spotting
1024-600 IPS TFT LCD touch display from Raystar	Connection via MIPI DSI, capacitive touch technology	Visualization of system states, touch operation
60 GHz radar IC BGT60TR13C from Infineon	Connection via SPI and GPIOs	Gesture recognition through analysis of magnitude, range and azimuth
IFX007T motor control board from Infineon	Triple half-bridge module	Power control of the BLDC motor
Evaluation board with PSOC^{TM} Edge from Infineon	Multi-core microcontroller with NPU (neural processing unit)	Central processing of radar, audio, display and motor control signals

Table 1: Key hardware components of the demonstrator with their properties and functions.

The model was developed in Python using the Keras and TensorFlow libraries and subsequently ported to the PSOC^{TM} Edge for use with Infineon's ML Configurator. Inference runs on the Cortex-M55 with an optimized TensorFlow Lite micro runtime environment.

Keyword spotting process flow (Fig. 3):

- **Audio recording:** The digital MEMS microphone (16 kHz sampling rate) provides PDM data.
- **Pre-processing:** Conversion to a MEL filter bank using window slicing (duration: ~530 µs).
- **Inference:** Evaluation of MEL spectra by CNN (multiple convolution layers).
- **Result:** The recognized keyword is transmitted as a control command to the motor control or other system functions.

Motor control for BLDC with Hall sensors

A brushless DC motor (24 V, max. 4,800 RPM), controlled directly by the microcontroller, provides direct feedback for the gesture or voice commands. Using integrated Hall sensors, the system detects the current speed and adjusts it based on gesture or voice commands.

The IFX007T triple half-bridge module from Infineon is used for control, which in turn is controlled via PWM signals and digital control lines. The motor speed is regulated at a sampling rate of 1 kHz, ensuring that changes in speed are implemented quickly and precisely. The motor function primarily serves as a de-

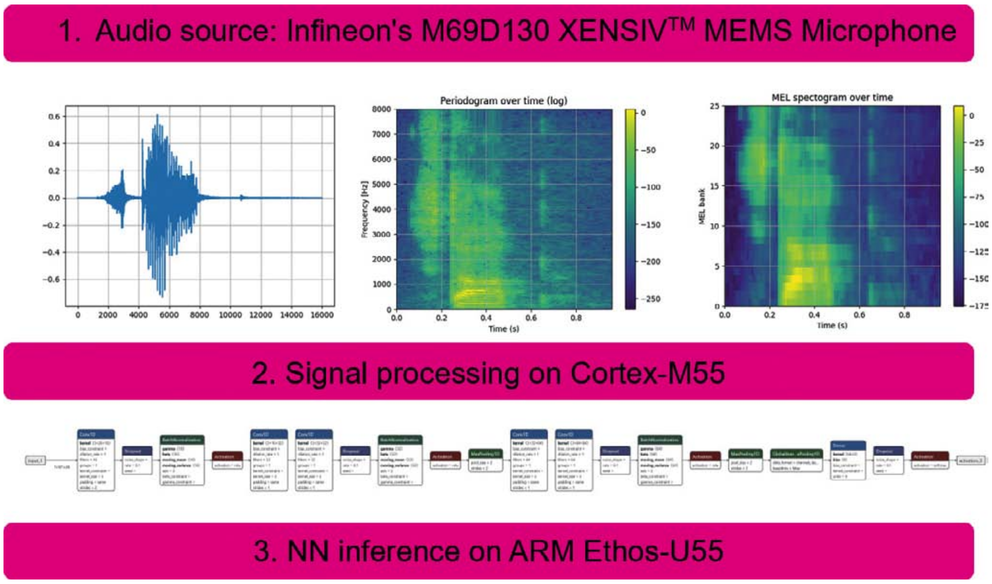


Figure 3: Keyword spotting process.

monstration object but can easily be replaced by other actuators or display systems.

User interface with touch display

A capacitive 7" touch display (with a resolution of 1,024 × 600 pixels) is used to visualize the system states. It displays, among other data, speed values, recognized gestures and the voice control status.

The graphical user interface is generated directly on the microcontroller using the open source LVGL library. Efficient utilization of memory and processing resources enables real-time concurrent execution of the user interface, gesture recognition and speech processing. The refresh rate of approximately 10 FPS is sufficient for status displays and operational feedback.

Special challenges and learning

A key feature of the demonstrator is the direct comparison of two approaches: conventional signal processing and machine learning (ML). ML was intentionally omitted for 60 GHz radar gesture recognition, as it was not functionally necessary. This allows for more robust, low-latency recognition without the need for training. The method is insensitive to extraneous light, noise interference and variations in hand position.

In contrast, voice control via keyword spotting uses a pre-trained neural network specifically optimized for a limited set of clearly defined keywords such as "start" and "stop". This is where machine learning excels, enabling specific responses to recurring, precisely specified events. The algorithms are based on publicly available datasets that were used to improve recognition stability.

This hybrid approach – applying conventional signal processing where it offers speed and robustness, and machine learning where it enhances recognition – shows how different methods can be optimally combined to create a versatile and practical HMI solution.

Another goal was to demonstrate that all functions, such as gesture recognition, voice control, motor control and graphical display, could be implemented entirely on a single microcontroller. Achieving this required seamless integration of hardware and software components as well as real-time processing of multiple sensor data streams within the limited resources of an embedded platform. This involved coordinating different interfaces, minimizing latency and assigning priorities in a sensible manner. The modular architecture and strict separation of functional units allow flexible adaptation to diverse application scenarios and offer developers a ready-to-use foundation for custom projects.

Outlook and transferability to real-world applications

The combination of radar, audio and motor control in a single system serves not only as a technical feasibility study but also establishes a practical platform for knowledge transfer. Customers benefit from ready-to-use software examples that they can use to perform their own tests or quickly develop their own environments based on them. This saves a considerable amount of time during project implementation.

The demonstrator is suitable as a reference platform and can be adapted to customer projects as needed. It can also be used in special laboratory environments like clean rooms or glove boxes. The hardware and software base, together with supplementary resources, including sample code, circuit diagrams, application notes and instructions, can be provided upon request. Adjustments to individual requirements can be implemented, for instance, by integrating additional functions, making changes to speech recognition or adding enhancements for gesture recognition.

An example of transferability is deploying a neural network on an RDK2 platform in conjunction with an RAB3 radar. Once the principles of data collection, training and neural network deployment are understood, these methods can be transferred to other platforms. Infineon's toolset supports this process and simplifies porting.

Moreover, further developments in radar technology are planned to implement additional application examples and expand the range of functions. The demonstrator is therefore not only an actual technology component but also an open platform for developing smart, sensor-based HMI solutions in embedded environments. ■

Reference
[1] https://github.com/RutronikSystemSolutions/RAB3-Radar_Documents/blob/main/RAB3-Radar_AppNote_Signal_Processing.pdf (App Note "Signal Processing" von Rutronik System Solutions, August 2024

Timing components for automotive and industry

Optimally matching crystals to ICs

Clock signals are the heart of every digital circuit. However, even the smallest deviations in the periphery can lead to instability. Discover why exact circuit matching is essential and how typical errors can be avoided.

By Alexander Rzymek,
Senior Manager Product Marketing
Inductors at Rutronik

In the world of electronics, precise clock pulse generators are at the heart of many applications – from automotive engineering to industrial automation. While integrated circuits (ICs) generally work with a wide range of timing components, crystal units are often the best choice due to their high frequency stability and reliability.

However, the full potential of these components can only be realized by carefully matching the peripheral circuit.

What is a crystal unit?

A crystal unit is a passive component based on the piezoelectric effect: When voltage is applied to a quartz crystal, it begins to oscillate. These mechanical oscillations are converted into electrical signals and provide a precise frequency. However, a suitable oscillator circuit is required to produce these oscillations. The actual crystal determines the clock frequency of the entire system.

Challenges of circuit matching

Correct functioning of a crystal unit depends largely on the design of the surrounding circuit (Fig. 1). The key parameters are:

- Load capacitances (C_1, C_2) influence the resonance frequency and the stability.
- Feedback resistance (R_F) ensures the necessary amplification.
- Damping resistance (R_D) prevents unwanted oscillations.
- Layout-related parasitic capacitances may impact the total load capacitance.

Incorrect scaling of these components can lead to malfunctions, such as start-up problems and frequency deviations, or result in unstable operation.

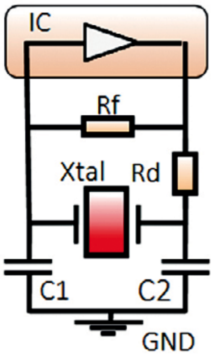


Figure 1: Typical circuit for controlling a crystal with external load capacitors (C_1, C_2), feedback resistance (R_F) and damping resistance (R_D). Correct scaling of these components is decisive for stable oscillation. (Source: Kyocera AVX)

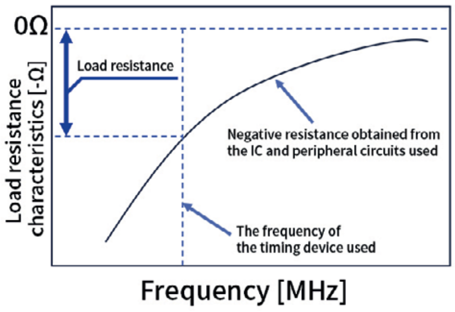
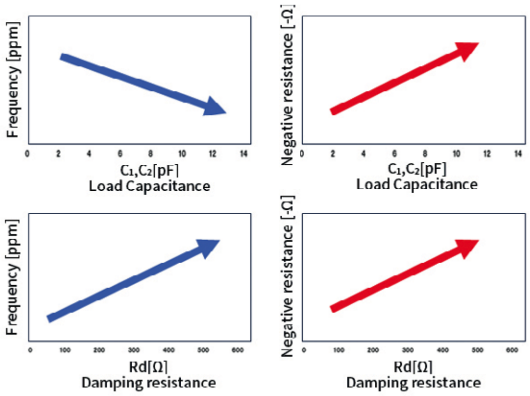


Figure 2: Presentation of the load resistance characteristics depending on the frequency. The negative resistance of the circuit must be greater in magnitude than the resonance resistance of the crystal to ensure stable oscillation.



How to calculate the load capacitance C_L

$$C_L = \frac{C_1 \times C_2}{C_1 + C_2} + C\alpha$$

*$C\alpha$ is the stray capacitance of patterns, etc. and the input/output capacitance of the IC, and is about 5 pF.

Figure 3: Impact of load and damping resistances on frequency and negative resistance. The load capacitance C_L is calculated from C_1, C_2 and parasitic components (e.g., conductor capacitance) according to the calculation formula shown.

The principle of negative resistance

A key criterion for reliable oscillation is the ratio between the negative resistance of the circuit and the resonance resistance of the crystal (R_L). The circuit can only compensate for the losses of the crystal and generate stable oscillations when the negative resistance is large enough:

Start condition of oscillation: $R_L < |-R|$

Operating state of oscillation $R_L = |-R|$

with R_L = resonance resistance of the crystal unit under load

Figure 2 shows the load resistance characteristics depending on the frequency.

If this condition is not met, oscillation will not start, or unstable clock signals will occur. Typical errors due to non-optimized crystal circuits are:

- No oscillation or sporadic starting behavior
- Frequency deviation beyond tolerance limits
- Instable communication with peripheral ICs
- Impairment of EMC properties

Influence of the peripheral circuit

The choice and matching of the circuit components impact both oscillation frequency and stability. This is particularly critical in modern, highly integrated ICs that often place very specific demands on the clock pulse generator. Even small deviations in the capacitance values can lead to significant frequency shifts or even failure of the circuit.

Matching service and design support

A remedy is provided by exact calculations and simulations of the circuit, including a matching service. In doing so, realistic IC parameters, layout conditions and environmental influences are considered. The matching reports contain specific recommendations for the C_1/C_2 values, oscillator amplification and layout adaptations. Kyocera AVX offers a comprehensive portfolio of crystals for a wide range of applications. An overview is provided in Table 1.

Summary

The choice and correct integration of a crystal unit is crucial for the reliability and precision of electronic circuits. Matching services, a sophisticated circuit design and the selection of the appropriate crystal series offer developers in the automotive and industrial sectors real-world practical solutions.

Global support centers provide technical advice on circuit matching and IC compatibility testing in collaboration with semiconductor suppliers. Approvals for crystal products are specifically obtained, such as for use in Bluetooth ICs, from a leading Nordic supplier. These services help to shorten design cycles and to ensure system stability from an early stage. ■

Series	Package (mm)	Frequency (MHz)	Temperature (°C)	Tolerance (ppm)	Applications
CX2016SA	2.0 x 1,6	16 - 60	-40 to +125	±15 / ±50	Automotive: ADAS (camera, radar, LiDAR), ECU, BMS, Infotainment, EPS, inverter, Eps, V2X
CX3225GA	3.2 x 2.5	12 - 30	-40 to +150	±15 / ±150	
CX2016DB	2.0 x 1.6	12 - 50	-40 to +85	±10 bis ±30	Industry: Factory automation, measuring devices, safety, energy Consumers: Wearables, household appliances
CX2016FB	2.0 x 1.6	12 - 50	-40 to +85	±20 bis ±50	
CX3225FB	3.2 x 2.5	8 - 54	-40 to +85	±20 bis ±50	

Table 1: Comparison of crystal series.

Aluminium electrolytic capacitors in rectangular design

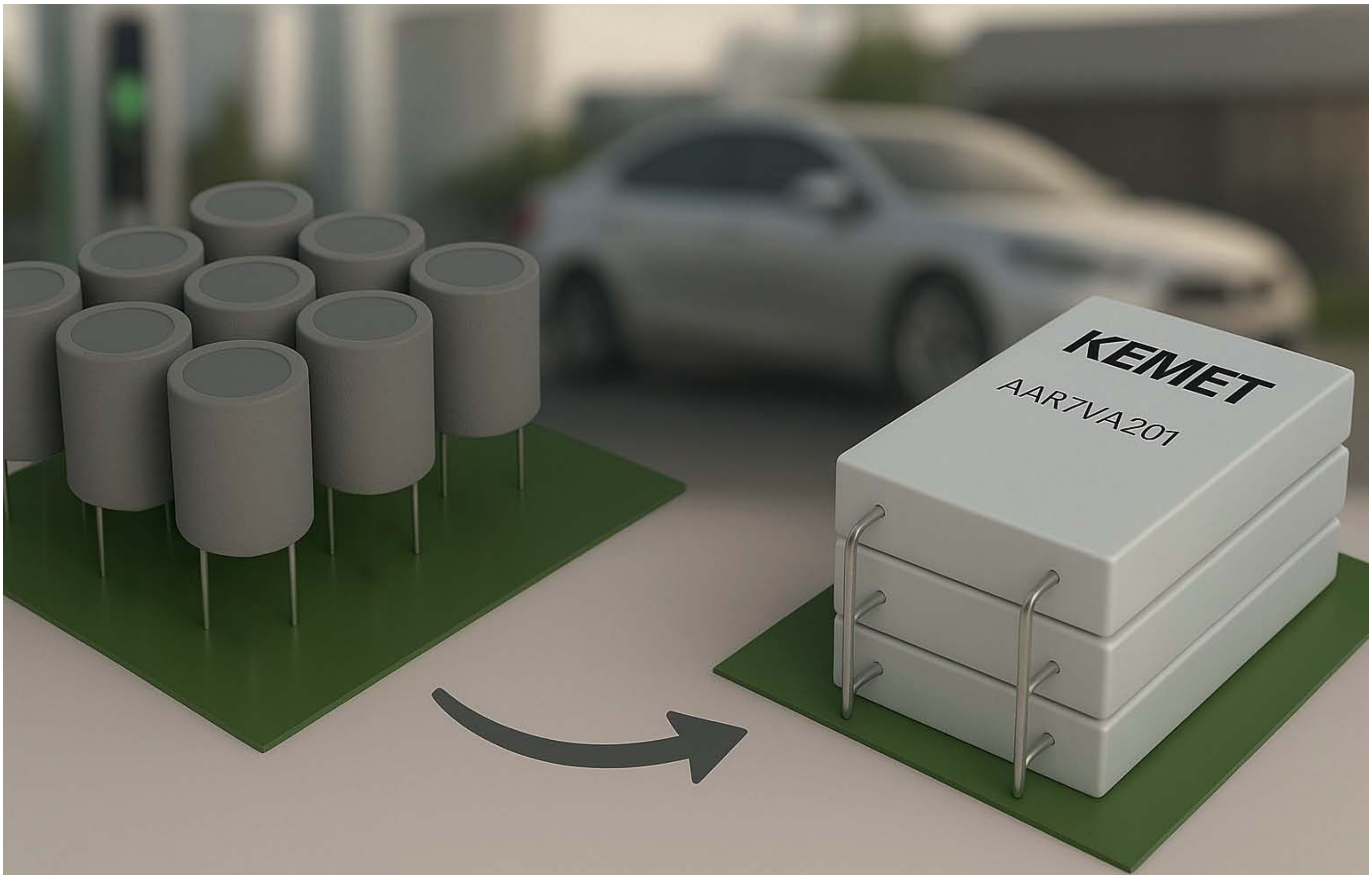
From round to square – using space more efficiently

Rectangular aluminum electrolytic capacitors combine space-saving, modular design with high current carrying capacity. They impress with efficient cooling, high vibration resistance and a small footprint, and are now also available as an SMD version for automated production.

BY GERD FISCHER,
LINE MANAGER AT RUTRONIK

The power density of modern power electronics is rising steadily, particularly in the areas of electromobility and decentralized energy supply. At the same time, higher demands are being placed on reliability, vibration resistance, thermal management and integration into ever more compact assemblies. The choice of suitable passive components, especially aluminum electrolytic capacitors, is crucial here.

Cylindrical standard designs are increasingly reaching their limits in terms of high requirements for packing density and thermal management, as they do not make optimal use of the available installation space, offer limited mechanical integration and can only be cooled efficiently to a certain extent. Rectangular aluminum electrolytic capacitors with liquid electrolyte provide an alternative solution.



Source: Yageo/Kemet

Following the installation recommendations significantly enhances thermal performance, packing density and mechanical robustness.

Modular stackable, vibration resistant and now also SMD compatible

This is where the rectangular AAR capacitors in low-profile aluminum packages with liquid electrolyte come into play. Their geometry allows for particularly efficient use of space. Compared to conventional cylindrical snap-in capacitors, the footprint of a capacitor bank system can be reduced by up to 35 percent. Their compact design makes them particularly attractive for applications with limited installation space, such as on-board chargers, inverters or wall charging stations (Fig. 1).

AAR capacitors can be combined into stackable modules, arranged either horizontally or vertically. They feature a mechanically robust design. The AAR70 series can withstand sinusoidal vibrations of up to 40 g and the AAR80 series up to 20 g – in both cases, this is based on what is known as SIN vibration. This is a standardized test with a sinusoidal vibration profile across a defined frequency range, as specified, for example, in the AEC-Q200 qualification for automotive components. Achieving this vibration resistance requires rigid mounting of the component on the printed circuit board or package, ideally using a thermally conductive adhesive. This is the only way to reliably obtain high mechanical resilience in the application. Without sufficient reinforcement of the connection, wire connections are prone to fatigue fractures.

Figure 1: The rectangular aluminum electrolytic capacitor AAR7V is primarily used in the field of electromobility, for example in on-board chargers, inverters or wall boxes that require a higher voltage capacity.

Figure 2: The AAR8S series was developed for fully automatic assembly and is particularly suited to high-volume applications, such as those typically found in the automotive industry and electromobility.

The AAR8S series (Fig. 2) is the first ever available SMD-compatible version of these capacitors. It was developed for fully automatic assembly and is particularly suited to high-volume applications, such as those typically found in the automotive industry and

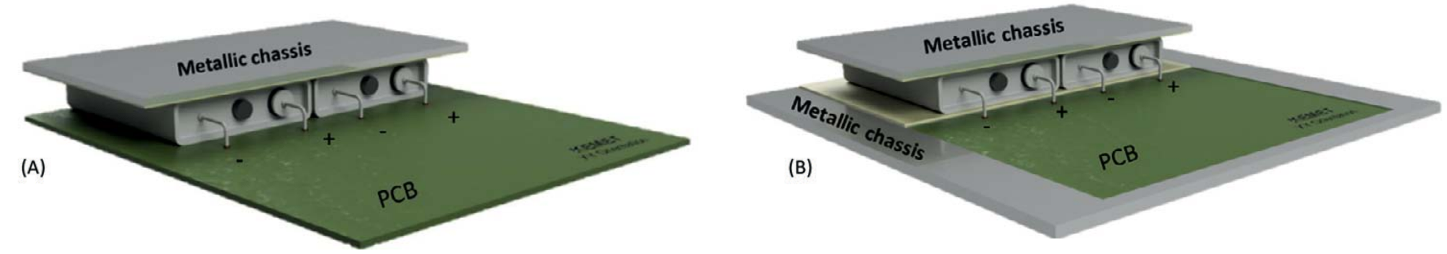


Figure 3: (A) Horizontal installation position with heat dissipation on one side. (B) Horizontal installation position with heat input on two sides. The bends in the lines are illustrative.

electromobility. The AAR8S series offers high capacity, strong ripple current capability and a compact, low-profile form factor. The latter is particularly advantageous for applications with limited installation height. The series is rated for operating temperatures up to 105°C. Its package geometry facilitates thermal coupling to a heat sink, enhancing heat management and thus significantly boosting the component's lifespan and reliability. The AAR series is AEC-Q200 qualified and therefore also suitable for use in automotive environments.

Mechanically secure and thermally optimized mounting

AAR capacitors can be mounted flexibly – horizontally or vertically, with or without heat sinks. Thermal coupling of the package to a metal chassis significantly increases the ripple current carrying capacity. Thermally conductive adhesive or paste also contributes to better heat dissipation (Fig. 3 and Fig. 4).

Rigid mounting is crucial for vibration resistance: An insufficiently secured printed circuit board can vibrate like a membrane and generate resonance peaks that amplify accelerations by up to tenfold. Relative movement of the capacitor on the printed circuit board can lead to fatigue fractures at the wire connections. Therefore, the mounting points on the printed circuit board should be placed close together, and the capacitor should be rigidly connected to the printed circuit board or chassis.

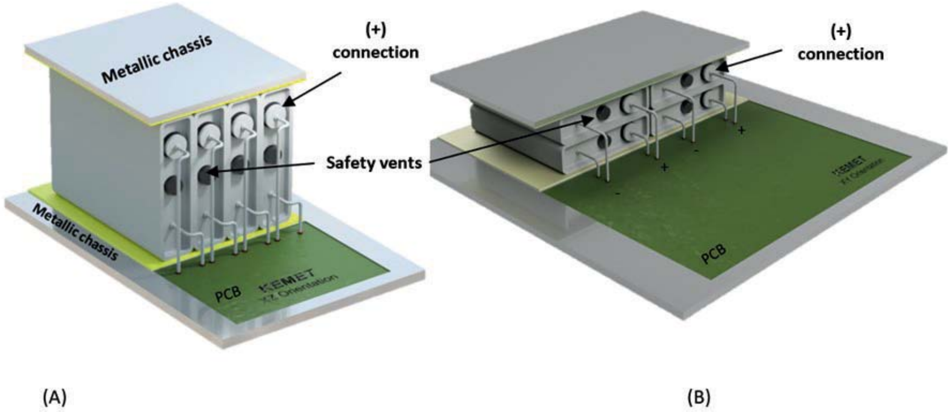


Figure 4: (A) Upright position with double-sided heat sinks in row arrangement. (B) Horizontal installation position with double-sided heat sink and stackable assembly. The bends in the lines are illustrative.

Mounting instructions:

- Fix the capacitor rigidly to the printed circuit board or chassis
- Use thermal adhesive or paste for efficient cooling
- Do not cover the safety valve and rubber seal on the positive terminal with adhesive
- Do not point the safety valve downward (except for vertical PCBs)
- Do not use halogenated hydrocarbons (e.g., chlorinated solvents) for cleaning to avoid damage to the capacitors
- Custom solutions: Insulation and other mounting options are available upon request

Summary

The AAR series offers an advanced solution for high-performance and compact capacitor applications. Its special form enables modular designs with high vibration resistance, improved heat dissipation and optimized space utilization. The introduction of the SMD-compatible AAR8S series allows for fully automated production, marking a significant advance toward modern power electronics. ■

Characteristic	AAR8S	AAR70	AAR7V	AAR80
Type of mounting	SMD	THT	THT	THT
Manufacturing	can be fully automated	can be partially automated	can be partially automated	can be partially automated
Installation height	very low	Standard	Standard	Standard
Heat sink connection	easily possible	possible	possible	possible
AEC-Q200 qualification	yes	yes	yes	yes
Vibration resistance	up to 20 g (SIN)	up to 40 g (SIN)	up to 40 g (SIN)	up to 20 g (SIN)
Temperature range	-40 bis +105 °C	-40 to +85 °C	-40 to +85 °C	-40 to +105 °C
Voltages	450 V	400 to 450 V	500 V	450 V
Special characteristics	SMD compatible, low profile, optimized for higher temperatures	highest vibration resistance, modular stackable	high voltage up to 500 VDC, modular stackable	optimized for higher temperatures, modular stackable

Table 1: Differences and strengths of AAR capacitors.

New alloys for power electronics

Inductors for the AI age

With increasing power density and rising current strengths in AI systems, traditional ferrite materials are gradually reaching their limits. A new nanocrystalline Fe alloy offers significant advantages in terms of efficiency, size and energy losses.

By Gerd Fischer,
Line Manager at Rutronik

Rapid advancements in artificial intelligence (AI) are causing a significant increase in the energy demands of state-of-the-art data centers and AI systems. AI servers now consume up to three times more energy than conventional systems. While the energy requirements of data centers are rising exponentially and already account for over 2% of global power consumption. The total power demands of some hyperscale data centers exceed > 20 MW.

Today, high-performance components such as CPUs, GPUs and FPGAs require currents of well over 1,000 A at DC link voltage levels, while compact sizes and maximum energy efficiency are always expected. In this regard, conventional magnetic materials are being gradually pushed to their limits. Compact, highly efficient inductors that can easily deal with extreme currents and high switching frequencies are the main focus of ongoing technical developments.

The demand for higher processing power requires electronic components with special properties. However, higher performance also leads to increased parasitic losses in the components, thereby necessitating capacitive and magnetic components with extremely low losses. At the same time, these components must offer extensive reliability under harsh conditions. Since a large number of components are required to support AI processors, miniaturization of the components is also essential. However, components with extremely low losses are also in demand in high-performance applications in industrial environments or in the field of rail technology. Voltage levels such as 48 V, 400 V and 800 V are usually present in the said sectors.

High saturation magnetic flux density (B_S) and low coercive field strength (H_C) are required for the efficient performance of inductors in electronic devices. A high B_S value enables the inductor to cope with stronger magnetic fields wit-

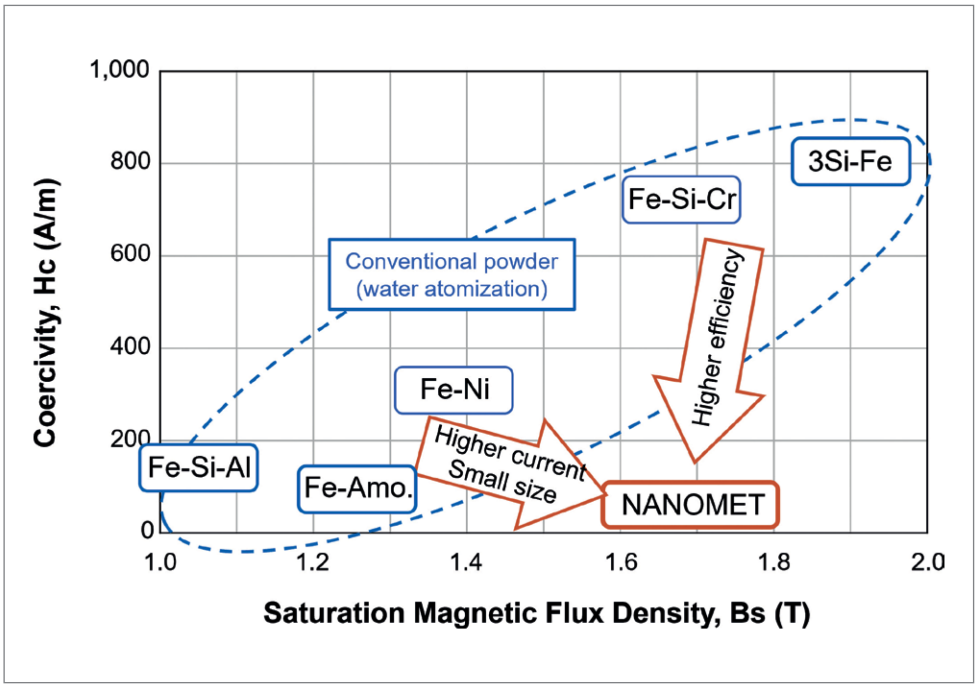


Figure 1: Comparison of magnetic parameters of common core materials. (Source: Yageo Group)

hout reaching saturation. This allows it to transmit higher currents and store greater energy. This is particularly important for applications that demand compact designs coupled with high performance, such as AI systems. A low H_C value means that the material requires less energy for magnetization and demagnetization. This helps reduce energy losses and improve overall efficiency. Conventional magnetic core materials, such as Mn/Ni-Zn ferrites or Fe-Si alloys, have long been applied for these applications but often fail to achieve the right balance between a high B_S value and a low H_C value.

Formability, integration and AC losses in high-frequency operation

The combination of high saturation flux density and low core losses has long been the goal for the developers of magnetic materials. Particular focus is placed on nanocrystalline Fe-B-P-Cu alloys (Fig. 1).

The new material Nanomet is built on an Fe-based alloy. The Fe-B-P-Cu alloy produces a fine, spherical powder when rapidly quenched. Further, the alloy can be transformed into complex 3D shapes using the hot-press process. This minimizes stray fields and enables optimal adaptation to the printed circuit board layout. The spherical morphology of the powder particles promotes dense and uniform packing. The resulting cores offer uniform magnetic field distribution, reduced hot spots and optimized magnetic flux guidance. After targeted annealing, a nanocrystalline structure with optimized magnetic properties forms.

The result is magnetic cores with a saturation flux density of 1.55 T combined with a coercive field strength of just 23 A/m (Tab. 1). This combination of materials was not previously achievable with conventional ferrites or Fe-Si alloys. For comparison: Fe-Si-Cr-based powder core materials only achieve B_S = 1.28 T and H_C = 720 A/m.

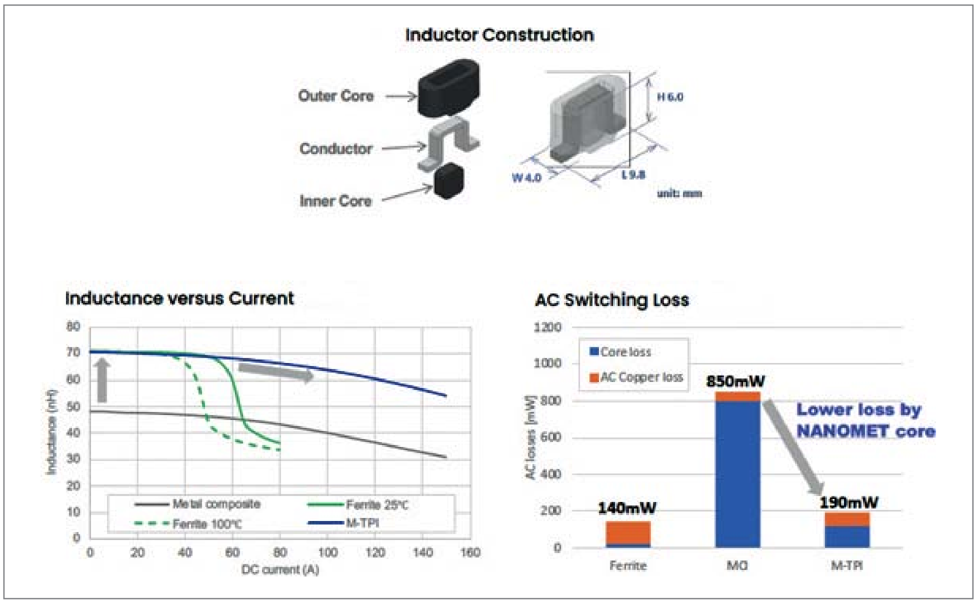


Figure 2: Application in the buck controller: a) Schematic structure, b) Inductance based on the current, c) Comparison of AC switching losses.

The potential of the material is also clearly evident in high-frequency conditions. At 1 MHz, the AC losses of the new cores are up to 4.5 times lower than those of conventional metallic composite cores and only roughly 50 mW higher than traditional ferrites. Moreover, the alloy exhibits »soft saturating« behavior, which additionally boosts energy efficiency.

Application of a buck converter

A typical voltage conversion example shows how the aforesaid material properties have a specific impact when applied: A buck converter that converts an input voltage of 6 V to 1.8 V at a clock frequency of 1 MHz (Fig. 2). This configuration utilizes a 70 nH inductor based on the new Fe-B-P-Cu alloy. It achieves magnetic saturation above 160 A, even at elevated temperatures. For comparison: Under exactly the same conditions, an identically sized ferrite core exhibits saturation behavior at around 50 A (at 100 °C).

The new alloy thus enables 40% higher energy buffering in an identical installation space. The formula for the calculation is:

$E = 0.5 \cdot L \cdot I^2$;

where E = energy (J), L = inductance (H) and I = current (A)

This property enables the use of smaller coils for the same power or, given a certain volume, the power density to be further enhanced.

In addition, the inductor exhibits stable behavior across a wide temperature range, offering a decisive advantage in thermally demanding applications such as GPU power supplies and other high-performance power supplies. The improved current carrying capacity results in fewer parallel circuits and thus a simplified layout, reduced component costs and potentially lower system costs.

Summary

The combination of high magnetic performance, low power loss and thermomechanical formability makes the new nanocrystalline Fe alloy an ideal material for next-generation AI power electronics. This can help achieve a considerable increase in efficiency, particularly for CPU/GPU power supply applications and high-performance power supplies, and make a decisive contribution to slashing the CO_2 footprint. ■

Material	B_S (T)	H_C (A/m)	AC losses at 1 MHz
Fe-B-P-Cu / Nanomet	1.55	23	very low
Fe-Si-Cr	1.28	720	high
Ferrit	0.49	32	low

Table 1: Comparison of magnetic parameters. (Source: Yageo Group)

Power and data supply via a single coaxial cable

Joint transmission of power and data

Camera systems in vehicles demand space-saving and interference-free transmission of data and power. Power-over-Coax becomes the key – but only when the filter technology is right.

BY JOCHEN NELLER,
TECHNICAL EXPERT INDUCTORS
AT RUTRONIK

Advanced driver assistance systems (ADAS) have become an indispensable part of modern vehicles. They help improve driving dynamics, safety and comfort through various functions like emergency braking or lane departure warning system (Fig. 1). ADAS depend on multiple cameras to accurately monitor the driving environment and to detect obstacles. With the increasing demand for such systems, there is also a growing need for components that meet the high performance requirements and ensure stable signal integrity.

Power-over-Coax (PoC) is a transmission concept that uses a single coaxial cable to transmit direct current, data and control signals (Fig. 2). This offers major advantages, particularly in vehicle applications, as the three separate cables that are usually required – for power supply, control data (control backend) and video data (data frontend) – can be replaced by a single cable. Besides greatly simplifying cabling, this also helps minimize costs, weight and space requirements – provided that the DC line filtering precisely matches the system.

Separation of direct current and high frequency

Coaxial cables are ideal for the combined transmission of power and data, as they provide excellent electromagnetic shielding. The cables are most effective when both cable ends are grounded together, since this significantly reduces the susceptibility to and emission of interference. In ADAS camera systems with highly sensitive electronics, even the smallest interferences can impair image quality or lead to malfunctions that can potentially impact driving safety. Therefore, a clear separation of direct current (DC) and high-frequency (AC) components is crucial.

Matching filter and decoupling circuits are used for separation, for example by combining coils and capacitors.

Decoupling and filter design for PoC cables

Clear DC decoupling ensures that the power supply can be fed into the coaxial cable without interference and without impacting parallel high-frequency transmission.

The key filter requirements are:

- **Low DC resistance:** To avoid voltage losses and to ensure a stable power supply, the impedance of the direct current path must be less than 1 Ω.
- **High current carrying capacity:** Magnetic saturation must be avoided even at currents as high as 300 mA.
- **High HF impedance:** In the operating frequency range – both for the control interface (1 - 5 MHz) and for the camera signal (35 Mhz - 2 Ghz) – the filter must create an impedance greater than 1 kΩ to prevent any negative impact on data transmission.

Real-world practice shows: These requirements can only be met with specifically coordinated inductors and damping networks that

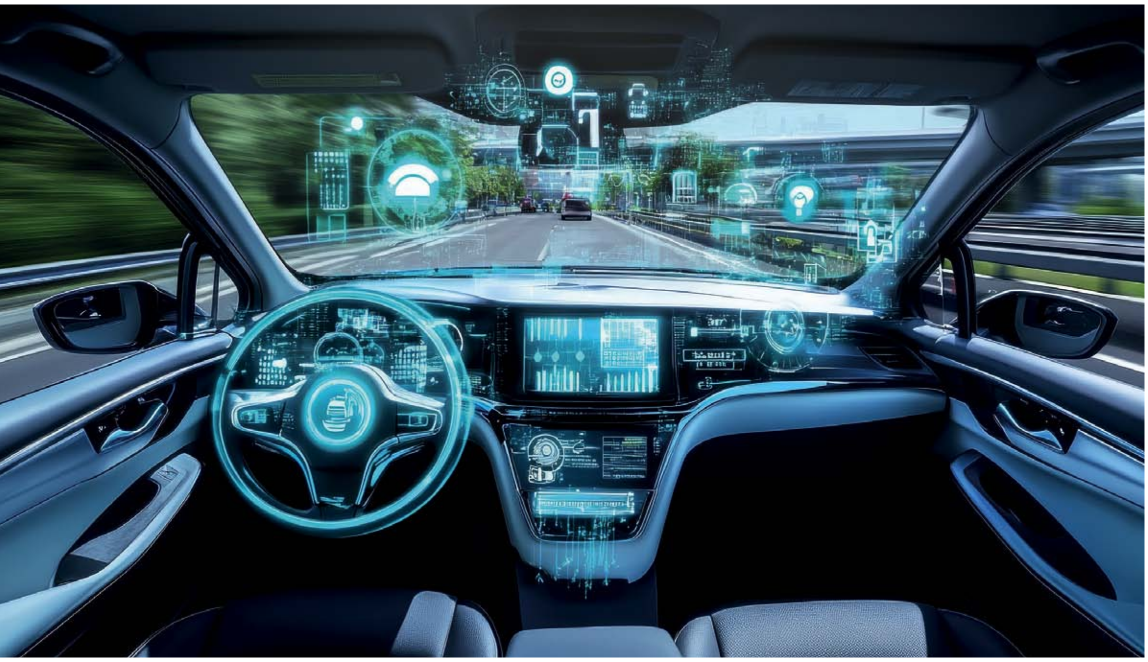


Figure 1:
Advanced driver assistance systems (ADAS) have become an indispensable part of modern vehicles. They help improve comfort, safety and driving dynamics through various functions like lane departure warning system, emergency braking or distance control. (Image: Anastasiia/stock.adobe.com)

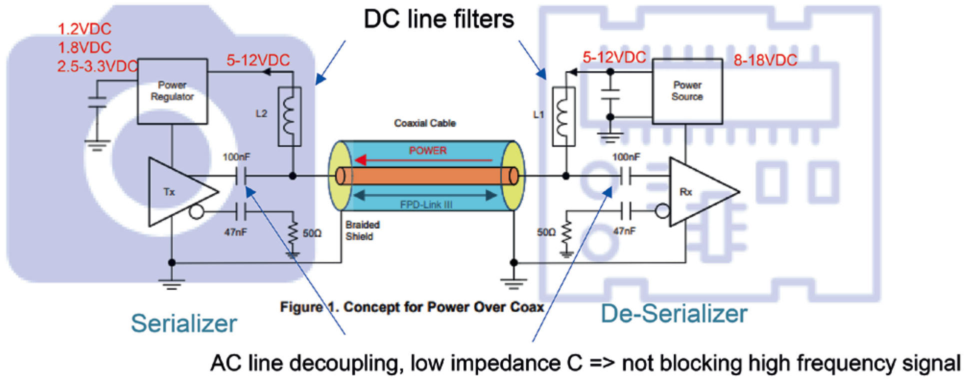


Figure 2: Joint transmission of power and data via one coaxial cable: Combining DC supply and high-frequency data on a single cable reduces the number of separate cables required. This requires a clear separation of both signal components and continuous grounding to minimize common-mode interference.
(Source: Eaton)

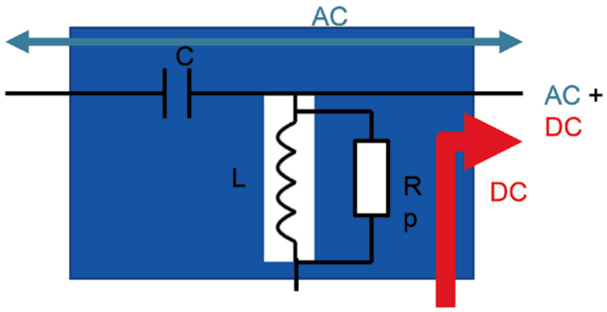


Figure 3: Typical design of a coordinated PoC filter topology for decoupling DC and HF.

are fully optimized for the respective vehicle architecture.

Technical implementation is based on an LC filter concept with the following elements (Fig. 3):

- **Serial inductor (L):** An inductor is inserted into the DC line that provides high reactance for high frequencies, thereby ensuring effective decoupling between the DC and the high-frequency signals.

- **Parallel damping resistance (Rp):** To avoid unwanted resonance effects and excessive choking at certain frequencies, a resistor ranging from 1 to 5 kΩ is connected in parallel to the inductor. This helps reduce the reactance effect at very high frequencies.

This filter topology ensures that direct current is transmitted efficiently, signal transmission in the HF range remains stable and the system is protected against interference couplings via the supply cable.

Automotive-compatible solution

To meet these requirements, Eaton has developed the PCA family of PoC inductors. The PCA1V and PCA2V series offer an extensive range of high current ratings and high natural resonance frequencies, as required for broadband filtering in Power-over-Coax (PoC) applications (Fig. 4). Due to the high level of impedance over a wide frequency range, this component simplifies the PoC filter design.

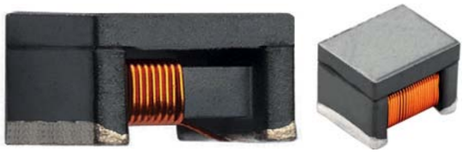


Figure 4: PCA family from Eaton: Automotive-compatible PoC inductors for broadband filtering.

The inductors are packaged in the popular and compact industrial size 1210 (3225 metric) and take up less space on the PCB. Precise coil winding supports stable filter properties for various PoC applications in the automotive sector. They are tested according to AEC-Q200 for the automotive industry. The magnetic shielding contributes to EMI immunity, and the products offer a wide operating temperature range from -55 °C to +150 °C.

	PCA1V3223	PCA2V3223	PCA1V3230
AEC-Q200 standard	yes	yes	yes
Operating temperature range	-55 °C to +150 °C	-55 °C to +150 °C	-55 °C to +140 °C
Standard PAD layout	3225	3225	3225
Height (mm)	2.3	2.3	3.0
I_{sat} @ 25 °C (Amps)	1.0	1.1	2.2
I_{Rms} @ 25 °C (Amps)	1.0	1.35	1.9
I_{Rms} @ 125 °C (Amps)	0.52	1.05	1.0

Table 1: Overview of properties of the PCA family from Eaton.

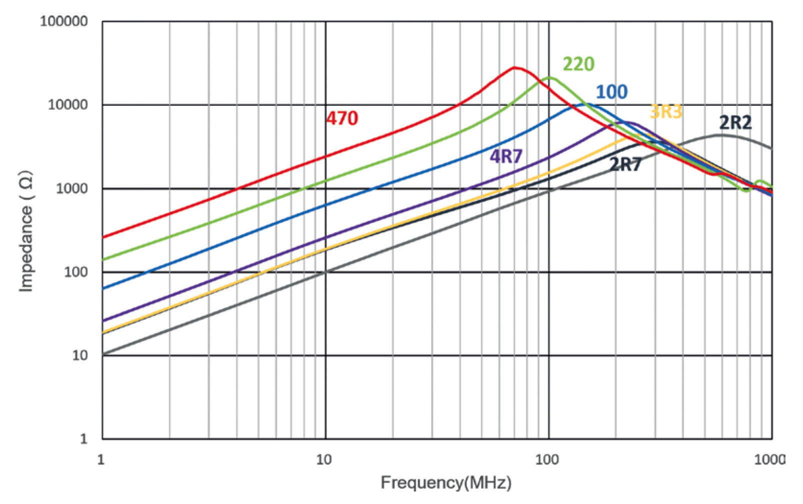


Figure 5: Impedance over frequency of the PCA1V3223.

Summary

PoC inductors support the decoupling of direct current and high-frequency components in ADAS camera systems. Thanks to their compact design, they can be integrated directly into camera modules, which eliminates the need for external filter components. This ultimately enables space-saving integration, for example in vehicles with a small form factor. ■

Relays for high-current and high-voltage applications

Efficient switching in the smallest of spaces

Rising requirements in energy and charging call for compact solutions capable of switching high currents and voltages. PCB-mounted relays combine low power loss with high switching durability and enable space-saving designs.

By Norman Majer,
Corporate Product Manager
Mechanics at Rutronik, and Martin
Unsöld, Senior Manager Product
Marketing Mechanics at Rutronik

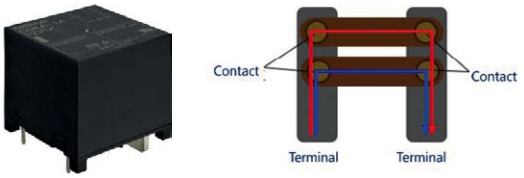


Figure 1: The G9KA relay (left) features a space-saving double contact structure (right). (Source: Omron)

Figure 2: G9KB employs a reliable permanent magnet system for arc suppression.

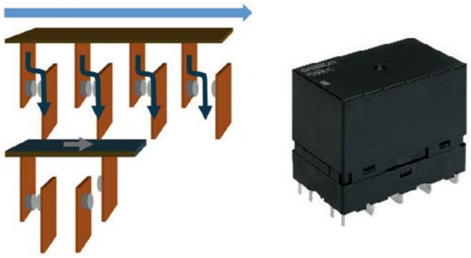


Figure 3: Four-pole version of G9KC with integrated mirror contact.

The trend toward ever-larger vehicle battery capacities alongside ever-smaller charger packages with maximum charging power and durability has been unstoppable for years. For end users, whether at home or on the go, fast charging and range anxiety are key criteria when choosing a charger.

As a result, technical requirements are also increasing: Higher currents and voltages need to be switched safely in confined spaces. At the same time, thermal losses must be minimized, compliance with standards like IEC 62109, IEC 61851, IEC 60947-4-1 and IEC 2955 ensured and the service life of components maximized, since chargers are expected to deliver reliable performance for many years.

Limits of conventional relays

Whether in photovoltaic systems, battery storage systems, fast charging stations or industrial energy systems, conventional relays are still commonly used to switch high currents. Although tried and tested, they often require significant space, screw terminals, complex wiring and relatively high holding power. Moreover, their high contact resistance generates heat losses, increasing the need for additional cooling.

PCB relays as a compact alternative

A newly developed relay family provides a space-saving, energy-efficient option. OMRON's G9K series, designed for PCB mounting, cuts installation time and costs while eliminating potential wiring-related errors (Fig. 1–3). Compared to DIN rail or panel mounting, PCB mounting also offers significant space savings.

Low contact resistance reduces heat loss and increases energy efficiency. Robust contacts and optimized mechanics guarantee a long service life, even under high loads. Energy-efficient coils enable a lower holding current. Certain versions also support control via pulse width modulation (PWM).

With a continuous current carrying capacity of up to 300 A (AC and DC) and a switching current of up to 100 A (DC), these relays are ideal for demanding high-load applications. The broad operating temperature range, typically from -40 °C to +85 °C, allows for use across diverse environments. Thanks to international approvals, including UL, IEC and VDE, this series can be easily integrated into devices for multiple markets.

The series includes several models with additional functions tailored to specific applications. Table 1 provides an overview.

Contact resistance as a critical factor

Low and stable contact resistance is crucial for all charging applications. A simulation study carried out by OMRON found that even a 1 mΩ increase in contact resistance can raise the temperature at the load connection by up to 18 °C. This not only reduces the service life of the contacts but also increases thermal stress on nearby components.

Simulations demonstrate that the multipole design (G9KC) can lower the temperature rise by at least 10 °C, thereby significantly enhan-

Model	Switching configuration	Max. voltage and current	Coil voltage	Contact resistance	Special characteristics	Applications
G9KA	SPST-NO, double-break contact +A Aux (optional)	up to 1,000 VAC at 300 A continuous load; 10 kV pulse strength	12 V / 24 V DC	0,2 mΩ (@200 A 6 VDC min. 30 mins)	Ultra-low resistance due to twin-contact design, high energy efficiency	Photovoltaic inverters, UPS systems and industrial energy storage devices.
G9KB	SPST-NO, bidirectional	up to 800 VDC, 100 A	12 V / 24 VDC	≤5 mΩ	Polarity-free design, arc cut-off technology, bidirectional direct current	Focus on energy storage (DC-DC converters, DC fast chargers, solar power systems, battery storage systems, vehicle-to-grid systems)
G9KC	4PST-NO + Aux (option)	480 VAC, 40 A per pole, short-circuit-proof up to 10 kA	12 V / 24 VDC	≤6 mΩ (Typ. 1 mΩ, 40 A @ 480 VAC ref. only)	Multi-phase AC switching, mirror contact	three-phase wall boxes (up to 22 kW), HVAC systems, industrial motor controls

Table 1: Key technical data for the model variants.

cing the reliability of long-lasting chargers. In practice, G9KC's reduced heat generation enables more efficient and faster charge cycles, as the lower operating temperatures allow for decreased output current limiting (crowbar).

Summary

The G9K series offers a technically advanced, space-saving and energy-efficient alternative to conventional relays. By combining low contact resistance, high switching capacity and specific model variants, both AC and DC applications can be implemented fully in line with standards. This creates new opportunities for developers of charging infrastructures, photovoltaic systems and energy storage devices to design compact, efficient and reliable systems.

The trend toward enhanced monitoring capabilities and further miniaturization is expected to continue. The G9K series thus provides a solid technical foundation for the next generation of powerful, sustainable energy systems. ■

Tactile switches for robust applications

Reliable switching of the battery indicator

A European supplier was looking for a battery indicator switch for its new generation of portable cordless tools that was compact, durable and reliable even in dusty, humid and demanding conditions. The solution was a sealed switch design.

By Paulius Juskevicius, Strategic Marketing Manager for the Electronics Business Unit at Littelfuse, and Jeannette Raquet, Line Manager at Rutronik

When developing new hand-held cordless tools like drills and grinders, the engineers at a European supplier encountered a seemingly simple but critical detail: the battery indicator switch. However, professional use quickly revealed the sensitivity of this function. Dust, moisture and high switching frequencies can drastically reduce the service life of conventional switches, while integration into the compact assembly architecture of the tools adds further challenges.

The solution therefore needed to be compact and robust, withstand daily wear over many years, resist dust, moisture and mechanical shocks, provide clear haptic feedback, even when wearing gloves, and integrate reliably into the battery management system's protection and energy management concepts.

The battery level indicator is a key element of the user interface, as it allows users to quickly check the remaining battery capacity with a simple press. For professional users, this function must work reliably under all conditions and throughout the tool's entire service life – often several years of intensive use.

Initial approaches and their limitations

Early prototypes employed standard switches,

Image: BillionPhotos.com/stock.adobe.com similar to those used in consumer electronics. However, typical limitations already became apparent during the initial stress tests. Mechanical wear occurred far sooner than allowed for the service life of professional tools; designed for around 100,000 actuations, these switches would have failed within a year under the harsh conditions of a construction site.

Leak tightness also proved to be a problem: Fine drilling dust penetrated through cracks into the interior, causing mechanisms to jam and contacts to malfunction, while moisture and condensation caused corrosion processes. Their design – higher and wider than intended – also made them poorly suited to the compact layout of the control board in the tool handle. In addition, the vague switching feel caused unintentional activation or unreliable contact, thereby raising safety concerns.

Compact, sealed SMD tactile switch as the solution

After further extensive testing and consultation, the team opted for a sealed tactile switch for surface mounting: the KSC222J from Littelfuse (Fig. 1). This switch delivered the right combination of robustness, compactness and electrical performance to meet all application requirements.

Measuring just 6.2 mm × 6.2 mm × 3.5 mm, the switch occupies 20% less space on the printed circuit board than its predecessor, thus simplifying integration into the drill's already densely populated control board layout. Its tight dimensional tolerance of ±0.2 mm also reduced alignment problems by 50% and improved both placement accuracy and overall assembly yield rate.

Why electrical height is important for precise integration

Two key measurements define the operation of a tactile switch: the electrical travel (Te), i.e., the distance that the actuator must travel to close the circuit, and the electrical height (He), i.e., the height from the printed circuit board to the electrical switching point (Fig. 2). Application of electrical travel for stack-up calculations often results in composite tolerances of ±0.4 mm or more, potentially compromising tactile feel and reliability. Prioritizing the electrical height, on the other hand, enables more direct and precise measurement from the printed circuit board, reducing summation tolerances and greatly en-

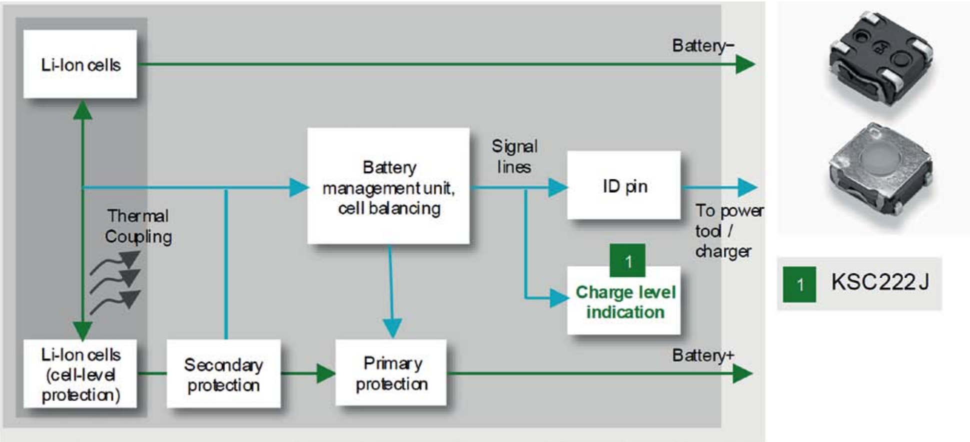


Figure 1: Tactile switch for charge status indicator. (Source: Littelfuse)

hancing mechanical fit.

In practice, this significantly lowers the error rate when fitting the switch. With standard tolerances of just ±0.2 mm, the electrical height ensures more consistent switching performance, simplifies mechanical alignment during assembly and enables more robust integration.

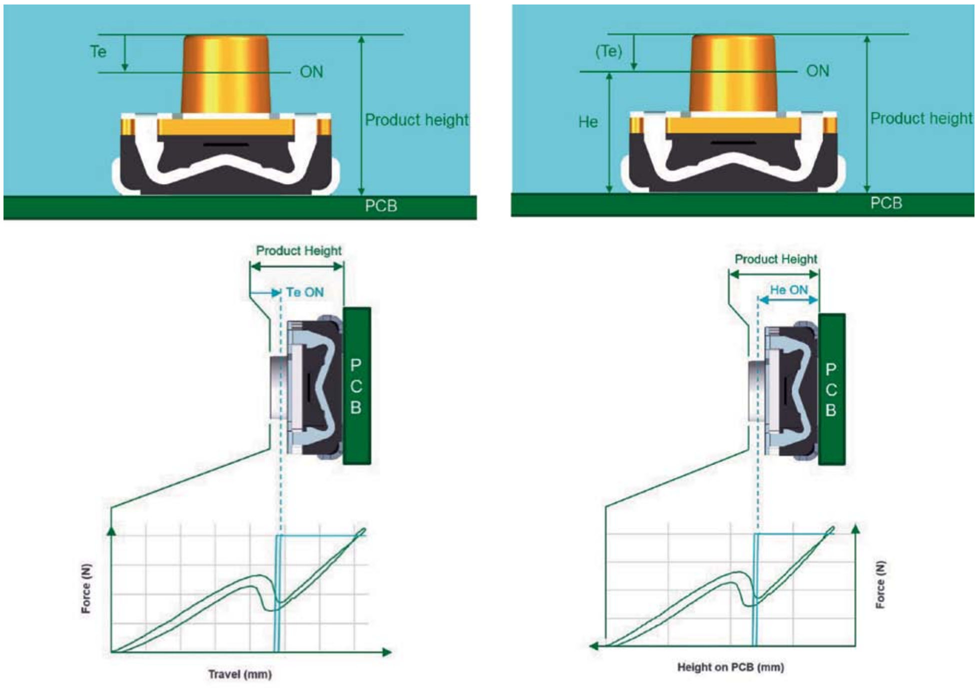
In addition, the electrical connection was also straightforward: The tactile switch functions as a momentary normally open contact, activates the battery management system and stays galvanically isolated, thereby offering the advantage of long-term reliability. Thanks to complete sealing, moisture and conductive dust particles are also reliably prevented from reaching the signal paths.

Solution validated through field testing

Field tests confirmed that the compact, sealed switch simplified the layout and operated reliably even in dusty conditions. The tactile feedback mechanism was calibrated to remain clearly perceptible, even when wearing gloves, while preventing accidental activation, which is a common problem with overly sensitive designs. This enhanced both usability and operational reliability, particularly when working at heights or in awkward positions. The direct connection to the battery management system enabled reliable charge status display without impacting the main control loop. Simultaneously, the full sealing offered reliable protection against moisture and conductive dust, preventing contact errors. For the supplier, this resulted in higher operational reliability, reduced assembly rework, less warranty claims and overall improved tool usability.

Summary

Inconspicuous components such as switches, in particular, can often be crucial to delivering robust end products. Choosing a sealed, long-lasting switch that meets mechanical and electronic requirements ensures durable and



Electrical Travel (Te) **Electrical Height (He)**

Figure 2: Comparison between electrical height (He) and electrical travel (Te).

Key technical data of the SMD tactile switch used

- **Dimensions:** 6.2 mm × 6.2 mm × 3.5 mm
- **Package height tolerance:** ±0.2 mm – facilitates precise integration and reduces assembly errors
- **Electrical data:** 12 V DC; switching current in the µA – mA range; contact resistance < 100 mΩ – ideal for logic inputs in battery management systems
- **Service life:** Up to 1 million actuations – around 10 times more than standard switches for consumer electronics
- **Rating:** IP67 – dustproof and submersible for up to 30 minutes at a depth of 1 meter; resistant to dust, splashes and moisture
- **Special feature:** Precise characterization via electrical height instead of electrical travel – enhances consistency and assembly accuracy

Energy-efficient power supply for compact electronics

Switching regulators as replacements for LDOs

Linear voltage regulators are still used billions of times over, but they waste a significant amount of energy as heat. Modern switching regulators minimize these losses, eliminate the need for heat sinks, reduce material and production costs and thereby support decarbonization.

By Andreas Münzer,
Senior Manager Product Marketing
Power at Rutronik

The impacts of global warming are unmistakable: Heat waves in spring, snowfall in typically warm regions, prolonged rainfall and storms that devastate entire forests. Many people wonder how they can help reduce CO_2 emissions without feeling that their individual impact is insignificant. A comparison may be helpful here: A single sandbag cannot stop a flood, but a million sandbags can protect an entire community against flooding.

Technical improvements follow the same principle: Even if the savings for a single component seem minor, the sum of millions or billions of units has a substantial impact. This is exactly the case for linear voltage regulators (LDOs, Fig. 1), which are used billions of times worldwide. However, their low efficiency leads to significant energy losses, creating substantial potential savings. Modern switching regulators can minimize these losses and thus enhance both energy efficiency and sustainability.

The low efficiency of linear regulators can be clearly demonstrated using a simple example (see Information box). Even under small loads, many times the required power is dissipated as heat. Switching regulators, on the other hand, convert the same energy with far lower losses.

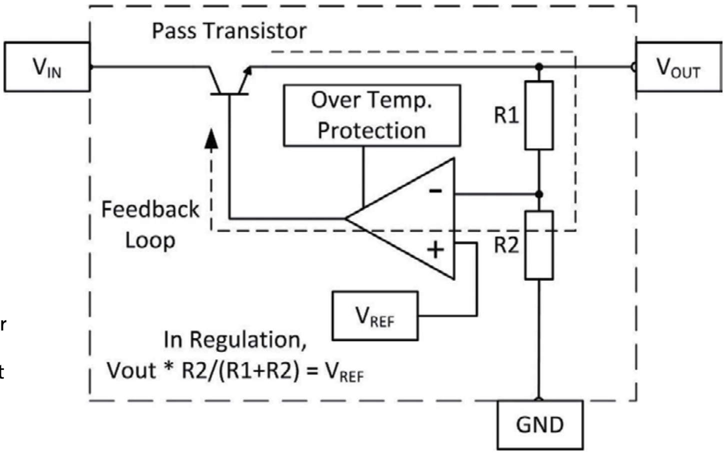


Figure 1: A linear regulator is basically just a transistor operating as a variable power resistor in its linear mode. The difference between input power and output power is dissipated as heat. (Source: Recom)

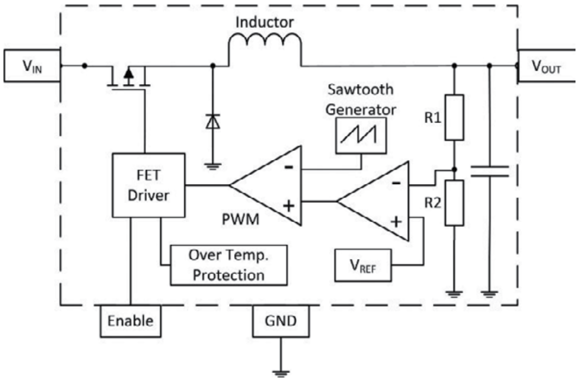
Drop-in alternative with switching regulators

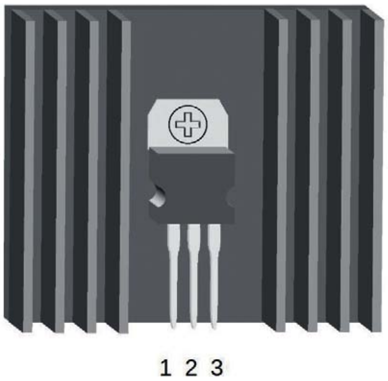
Switching regulators (Fig. 2) are regarded as a more energy-efficient alternative to linear regulators. They regulate the output voltage by rapidly switching the power transistor on and off. This reduces the power loss. Heat is only generated during the brief switching operations; in the on and off states, however, there is hardly any heat generation. As a result, switching regulators do not require heat sinks, even at ambient temperatures of 90 °C.

Additionally, their standby current (without load) is much lower than that of linear regulators, as the internal control loops switch off when not in use. A linear regulator typically requires about 8 mA of standby current to supply the internal comparator. This current is independent of the load current. The R-78-K-0.5 series switching regulators feature a typical standby current of just 1 mA.

The R-78 series from Recom is pin-compatible with the conventional 78xx regulators. The new R-78K series continues this tradition and offers higher efficiency, a wider input voltage range and lower weight. In the same scenario as above, the switching regulator dissipates only 0.2 W and does not require a heat sink.

Besides efficiency under load, standby current plays a crucial role, especially for devices that are permanently switched on but rarely become active. A design with a linear regulator consumes around 2 W in standby mode at an input voltage of 24 V, which is equivalent to





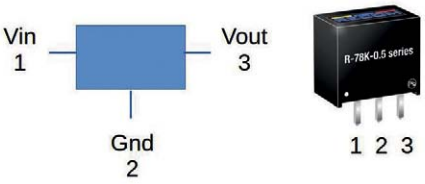


Figure 2: Circuit diagram of the switching regulator (left) and pin and function-compatible switching regulators of the 78xx and R-78k series (right)

Characteristics	R-78-K-0.5	R-78-K-1.0	R-78-K-2.0
Input voltage	4.5 36 V DC (depending on model)	4.5 36 V DC (depending on model)	4.5 36 V DC (depending on model)
Efficiency	up to 93%, without heat sink	up to 95%, without heat sink	up to 96%, without heat sink
Operating temperature	-40 °C to +90 °C without derating	-40 °C to +90 °C without derating	-40 °C to +90 °C without derating
Protective function	Undervoltage and short-circuit protection	Undervoltage and short-circuit protection	Undervoltage and short-circuit protection

Table 1: Comparison of the models in the R-78K series of non-isolated switching regulators.

roughly 1.75 kWh per year. A switching regulator, in contrast, only needs about one-eighth of that. Since switching regulators are available in TO-220 format (Fig. 2), they can be used as direct replacements and retrofitted into existing designs. Despite the higher unit price, the total costs are reduced, as heat sinks, thermal paste, mounting materials and installation are unnecessary.

In summary, this offers the following advantages:

- No heat sink required ➜ Savings on material, installation effort and production costs.
- Low standby current ➜ Typically 1 mA instead of approx. 8 mA with LDOs
- High ambient temperatures up to 90 °C without additional cooling
- Compact design and low weight, suitable for space-critical designs
- Manufactured in Asia, thus enabling competitive pricing

The potential savings become especially evident when the losses of a single controller are extrapolated. In typical applications (28 V ➜ 5 V, 0.5 A), a linear regulator generates around 11.5 W of heat loss, while an efficient switching regulator produces only around 0.55 W. With annual sales of one billion linear regulators, this translates to a global potential savings of roughly 11 GW – equivalent to the output of nine medium-sized nuclear power plants. Even minor efficiency improvements in standard components can therefore make a significant contribution to global energy savings.

Door opening system in an IP67 package

When calculating total cost of ownership, other factors must also be considered. A supplier planned a stand-alone door opening system featuring a fingerprint reader, a microcontroller in an IP67 package, a door release solenoid and a 12 V battery with charger, also in an IP67 package. The basic requirements were:

- Secure access control through a fingerprint recognition system in the outdoor area

Technical comparison between linear and switching regulators

Scenario: 24 V ➜ 3.3 V, load 300 mA

Linear regulator (e.g., 78xx)

- Output power: $P_{out} = 3.3\,V \cdot 0.3\,A \approx 1.0\,W$
- Input power (without standby current): $P_{in} = 24\,V \cdot 0.3\,A = 7.2\,W$
- Power loss: $P_{loss} \approx 6.2\,W$
- Efficiency: $\eta \approx 1.0/7.2 \cdot 100\% \approx 13.7\%$ ➜ High heat loss, heat sink usually required

Switching regulator (e.g., R-78K3.3-0.5)

- Output power: 1.0 W
- Input power (measurement/data sheet example): $24\,V \cdot 0.05\,A = 1.2\,W$
- Power loss: 0.2 W
- Efficiency: $\eta \approx 1/1.2 \cdot 100\% \approx 83\%$ ➜ Significantly less heat, no heat sink required (up to ~90 °C ambient temperature)

Standby current comparison (24 V)

- Linear regulator typ. ~8 mA ➜ $P \approx 0.192\,W$ ➜ ~1.68 kWh/year
- R-78K-0.5 typ. ~1 mA ➜ $P \approx 0.024\,W$ ➜ ~0.21 kWh/year

A linear regulator thus wastes over seven times the energy that the load actually consumes. With such low efficiency, even a low load of only 1 W requires a heat sink to dissipate the heat loss.

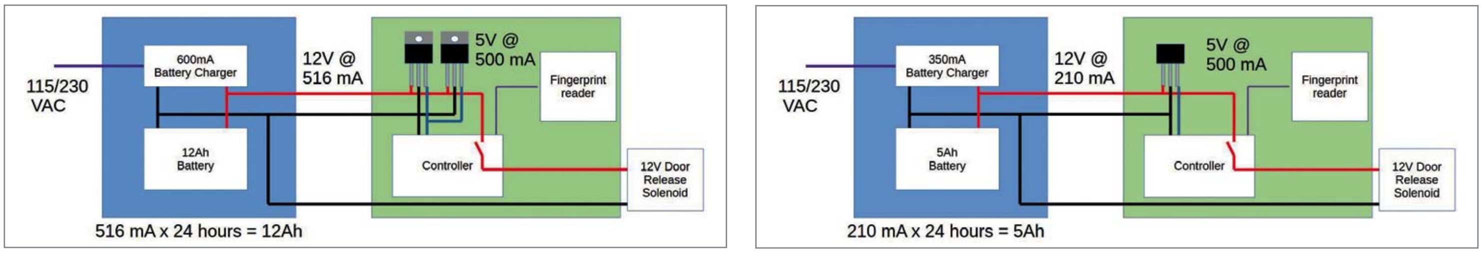


Figure 3: Comparison between door access systems with linear (left) or switching regulator (right).

- Ambient temperatures up to 50 °C and package temperatures up to 65 °C
- 24-hour emergency operation via battery in the event of a power failure
- Minimal costs with high reliability

Below, two solutions are compared: One using linear regulators and the other using switching regulators. The customer's solution (Fig. 3, left) used linear regulators for the 5 V supply. However, at high temperatures, the components overheated, leading to voltage instability. To split the current, two regulators were operated in parallel – a practice that is not Recommended. Although a small heat sink was used, the temperature in the sealed IP67 package continued to rise until the regulators entered thermal shutdown. This made the system unreliable.

Figure 3, right shows an alternative solution using switching regulators, as proposed by Recom. Despite the higher acquisition costs, the input power was reduced by more than half in this case. A smaller battery and charger (5 Ah instead of 12 Ah) could therefore be used. This not only reduced the overall costs but also the weight and volume of the components. Packaging and transportation also became simpler, and the carbon footprint was minimized. Operational reliability was a decisive factor, too: Even at high temperatures, the power supply remained stable, posing no risk to the fingerprint reader and the microcontroller. A comparison demonstrates that, despite the higher unit price of the switching regulator, the overall solution is cheaper, more reliable and more sustainable.

Technical progress and sustainability in harmony

These examples demonstrate that technical progress and sustainability can go hand in hand. Switching regulators minimize losses, reduce material and production costs and enhance reliability. In doing so, they contribute measurably to CO_2 reduction without raising overall costs. With billions of linear regulators used every year, adopting this technology presents significant decarbonization potential. ■

Advertisement

Capacitor technology for modern electronic applications

Polymer capacitors as a clever alternative to MLCC

Ceramic capacitors are everywhere but are quickly reaching their limits as requirements grow. With polymer capacitors, on the other hand, there is hardly any loss in capacitance due to DC bias, and piezoelectric effects are largely eliminated.

By Marc Höferer,
Corporate Product Manager
Capacitors at Rutronik

Multilayer ceramic capacitors (MLCCs) are today the most commonly used capacitors in electronic circuits. They stand out due to their compact design, low equivalent series resistance (ESR) and low equivalent series inductance (ESL). As a result of these properties and their low cost, they are frequently used in input and output filters of DC/DC converters. But they are also the preferred choice in many other designs: These capacitors can be found in almost every electronic device, from consumer electronics to industrial plants.

That said, the weaknesses of MLCCs are increasingly being exposed in complex applications:

- **DC bias effect:** The capacitance of these components varies with the applied DC voltage. In fact, it can lead to a capacitance drop of more than 70% compared to the data sheet specifications, meaning that the originally specified capacitance is often unavailable in real-world scenarios.
- **Inverse piezoelectric effect:** The application of a DC voltage to an MLCC may cause slight static deformation as a result of mechanical stress in the material. However, if high-frequency voltages are applied or certain operating conditions arise, it can lead to vibrations in conjunction with electromagnetic oscillations, which are perceived as an unpleasant screeching noise.
- **Brittleness:** Due to their brittle ceramic structure, MLCCs are susceptible to cracks, for example when bending the printed circuit board. These cracks have a tendency to spread under thermal or mechanical stress. This negatively impacts not only the capacitance but also the electrical parameters ESR (equivalent series resistance) and ESL (equivalent series inductance). Even the smallest of cracks can grow over time and significantly shorten the service life of the component.
- **Large variations in capacitance with respect to frequency and temperature changes:** Capacitance varies significantly depending on environmental factors and can impact system stability.

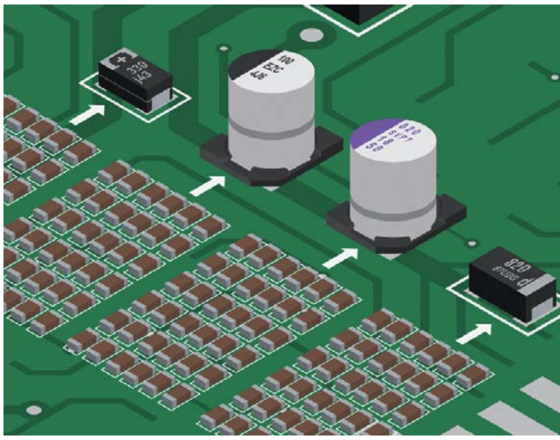
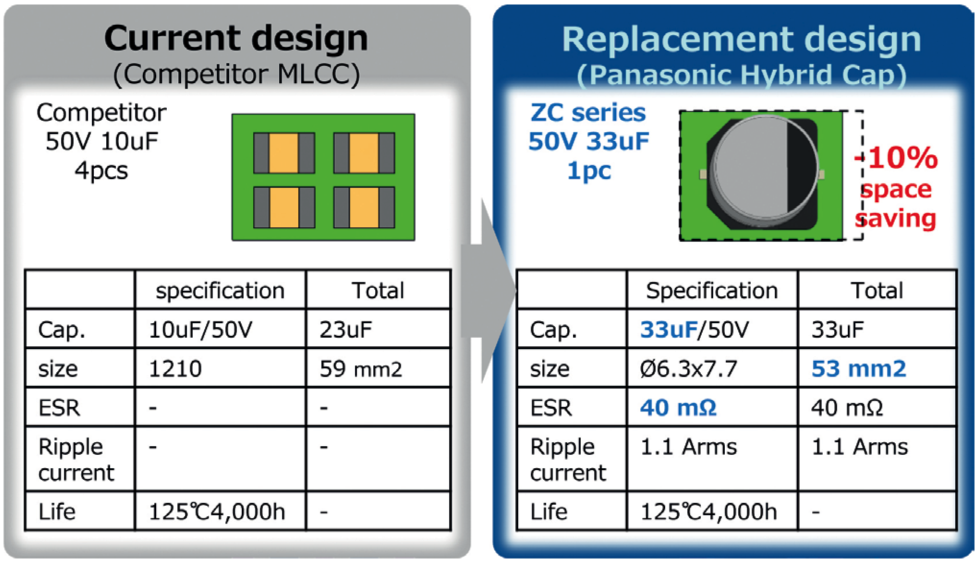


Figure 1: The variety of capacitor types – from MLCCs to polymer solutions – allows for demand-driven combinations or targeted replacements to optimize functions, installation space and efficiency. (Source: Panasonic Industry Europe)

Polymer capacitors – stable capacitance, less faults

Thanks to their special design, conductive polymer capacitors are immune to many of the typical weaknesses of conventional MLCCs (Fig. 2). Instead of a ceramic dielectric, aluminum or tantalum with a thin oxide layer is used and combined with a solid electrolyte made of conductive polymer.



Current design
(Competitor MLCC)

Competitor
50V 10uF
4pcs

	specification	Total
Cap.	10uF/50V	23uF
size	1210	59 mm2
ESR	-	-
Ripple current	-	-
Life	125℃4,000h	-

Replacement design
(Panasonic Hybrid Cap)

ZC series
50V 33uF
1pc

10% space saving

	Specification	Total
Cap.	33uF/50V	33uF
size	Ø6.3x7.7	53 mm2
ESR	40 mΩ	40 mΩ
Ripple current	1.1 Arms	1.1 Arms
Life	125℃4,000h	-

Figure 2: The replacement of MLCCs with polymer capacitors results in more stable light output, greater mechanical reliability and fewer components on the printed circuit board.

This type of design offers significant advantages: Compared to MLCCs, conductive polymer electrolytic capacitors exhibit considerably lower capacitance losses due to DC voltage bias and temperature fluctuations. The DC bias effect is negligible, as the effective capacitance remains stable even under load and circuits can be designed more precisely. Thanks to their high capacitance density, polymer capacitors enable a compact design combined with high effective capacitance. Far fewer components are often needed to ensure the same system performance. This reduces the required installation space and the overall costs – including packaging and assembly. Due to their actual design, polymer capacitors are less sensitive to mechanical and thermal stress. Their low susceptibility to crack formation and high resistance to thermal stress boost reliability.

Since piezoelectric effects do not occur, there is no noise or micro-vibrations – a crucial advantage, especially for sensitive applications. Polymer capacitors offer predictable, extensive operating periods without the aging effects typically associated with conventional electrolytic capacitors. The SMD design allows them to be integrated in a space-saving way and makes them particularly suitable for flat devices, such as sensor modules, display drivers or driver boards for power output stages. They enable automated assembly, reduce the space required on the printed circuit board and simplify the installation processes – especially for large production runs. Further, they have a low ESR across a wide frequency range. This helps smooth out ripple currents, making them the ideal choice for power management circuits.

	Capacitance	Temperature behavior	DC bias	Voltage range	Size	ESR	Ripple
Aluminium Electrolytic Cap. (SP-Cap)	o	+	++	o	+	++	++
Tantalum Solid Cap. (POSCAP)	+	++	++	o	++	++	++
Aluminium Solid Cap. (OS-CON)	++	++	++	+	o	++	++
Hybrid Cap.	++	++	++	+	o	++	++
MLCC	x	o	x	++	++	++	++

Table 1: Comparison of properties of the various capacitor technologies.
Legend: ++: very good, +: good, o: average, x: poor

Table 1 shows: Each type of capacitor has its strengths and weaknesses. To select suitable components, various factors like installation space, costs and aging behavior must be considered in addition to electrical parameters, such as ESR, capacitance and dielectric strength. Due to their high dielectric strength and reverse dielectric strength, MLCCs are ideal for applications with high voltage requirements and extremely low ESR.

Polymer capacitors show their strengths especially in applications with high current demands, space constraints and the need for stable capacitance under load. Their low ESR, high capacitance density and robust behavior under thermal and mechanical stress make them a reliable alternative – especially when multiple MLCCs can be replaced by a single polymer component.

Increase in efficiency for LED applications

In cutting-edge LED driver applications, e.g., in the automotive sector, developers have to come up with capacitors designed for high currents and compact sizes. A real-world example shows how the use of hybrid polymer capacitors can significantly reduce the number of components and the space required on the printed circuit board: Instead of four 10 µF/50 V MLCCs with a total of 23 µF and a footprint of 59 mm^2, a single 33 µF/50 V hybrid capacitor with just 53 mm^2 is sufficient. Besides effectively reducing the space needed by 10%, the hybrid capacitor features a low ESR of 40 mΩ, a high ripple current capacity of 1.1 Arms and a specified service life of 4,000 hours at 125 °C. The use of polymer technology enables stable light output, improved mechanical reliability and simplified installation processes.

Summary

MLCCs remain essential in many applications – especially where compact sizes and low ESR are needed. Nevertheless, their physical limitations make them vulnerable in critical applications. Conductive polymer capacitors offer a robust and capacitance-stable alternative in this case. They enable reliable, space-saving designs with high current carrying capacity and are, therefore, a valuable addition to pioneering electronics development. ■

High-precision positioning in farming

Smart farming with 5G and real-time kinematics

High-precision positioning and IoT technologies are changing farming: Through accurate location data, networked sensors and automated processes, they enable efficient and sustainable smart farming with optimized resource utilization and promise better crop yields.

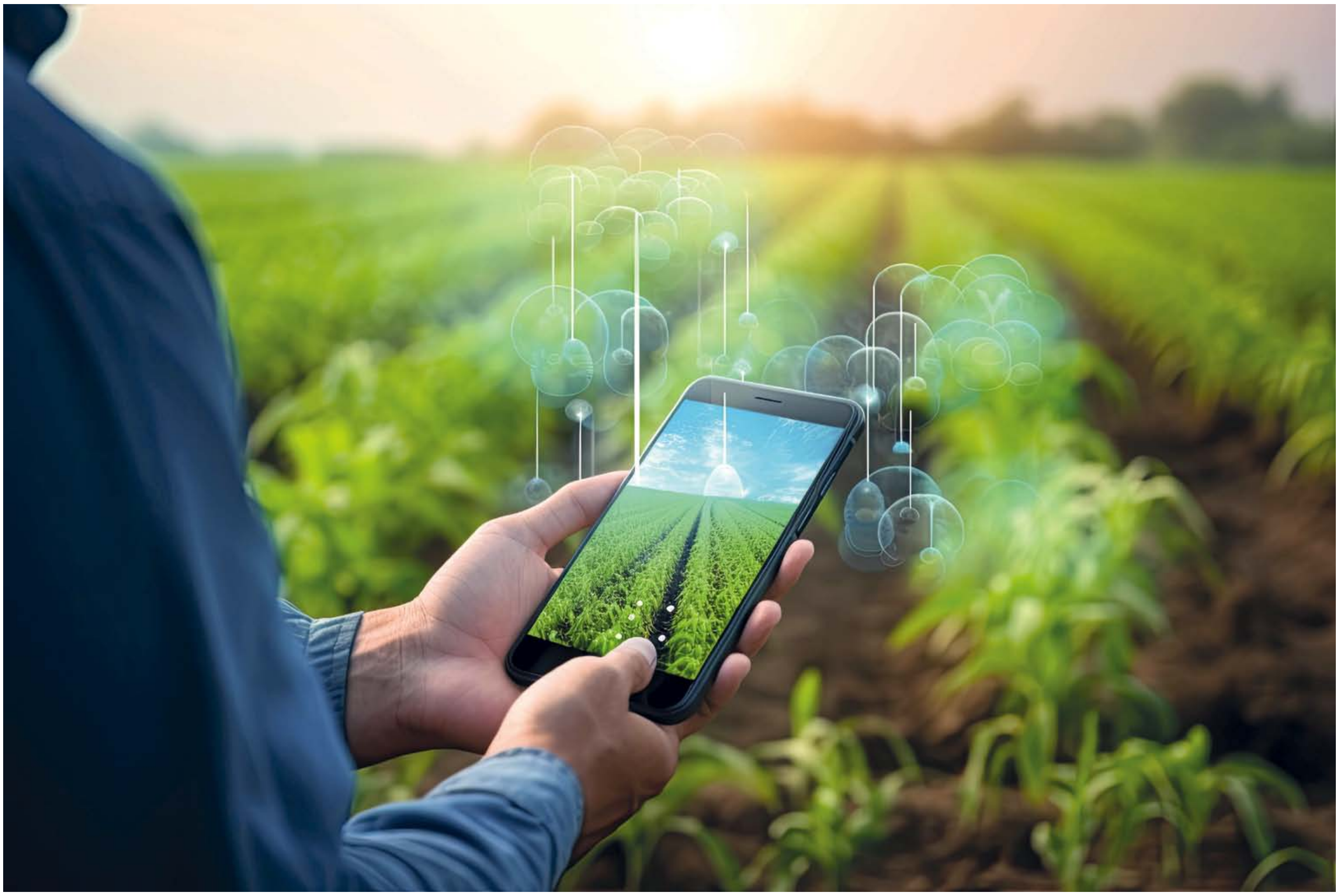


Image: Mayava/stock.adobe.com

By Luisa Letzgus,
Corporate Product Manager Wireless
at Rutronik

Farming in Germany is increasingly exposed to climate risks: Heat waves, droughts, heavy rainfall, storms, sudden cold periods and thus the consequences of climate change have long been a reality. These extreme weather events pose enormous challenges for farms. At the same time, the shortage of skilled workers is intensifying the situation. Artificial intelligence (AI) offers a promising solution to these complex problems. And the market is thus experiencing dynamic growth. According to forecasts, this sector is expected to expand at an average annual growth rate of 25.5% between 2024 and 2030. This is a clear indication of the increasing relevance of smart technologies in the agricultural sector. [1] These intelligent systems can be used in agriculture to promote sustainability, optimize cultivation strategies and improve animal welfare. It is not just

Figure 1: The modular LGA design of the FE990 series enables local data processing and robust 5G connectivity directly in the field. This makes it ideal for environmental monitoring, barn automation and gateway applications. (Source: Telit Cinterion)

about boosting efficiency and economic success but also about relieving farmers of physically demanding and time-consuming tasks.

- **Machine guidance with assistance systems:** Farm machinery, which usually consists of tractors, seed drills and forage harvesters, offers enormous potential for the application of AI. Intelligent control systems enable these machines to work not only more precisely but also to have a more user-friendly design. When paired with drones or autonomous cleaning robots, routine activities can be automated to save valuable working time.

- **AI in animal husbandry:** AI is also opening up brand-new opportunities in livestock farming. Behavior analysis systems can detect abnormalities at an early stage and draw conclusions about the animals' state of health. Simultaneously, AI can be used to enhance feeding – e.g., through demand-based quantity control and automated inventory management. This provides livestock farmers with more time for direct animal care while also improving husbandry conditions.

- **Nurturing and growing crops:** In the case of crop cultivation, AI assists with sorting seeds, detecting weeds and identifying unusable plants. With the aid of image recognition systems, these tasks can be automated and performed with a high level of precision. A key advantage in times of increasing water scarcity is that sensor-based AI solutions can also be used to control demand-based irrigation. [2]

5G and RTK technology for modern farming systems

The demands of modern farming systems in terms of precision, connectivity and availability can only be met with a modular IoT infrastructure. To achieve this objective, Telit Cinterion offers various modules designed for field use that can be scaled from individual sensor units to networked machinery (Fig. 1 to 4). These modules can be used to implement applications ranging from autonomous tractor navigation to networked field monitoring.

- GNSS modules with multifrequency and RTK functionality enable centimeter-level position accuracy for automated tracks and precise field cultivation.

- 5G data cards ensure high transmission rates, e.g., for image transmission from drones, video streams or the connection of stationary systems.

- Compact LGA modules with integrated processing unit and OpenWRT support local data processing, e.g., in sensor stations or mobile routers.

- Cellular radio modules (5G, LTE, LPWA, NB-IoT) enable stable data connections with low latency, also for applications in remote regions.

- Edge and IoT gateways act as an interface between sensors, machine controls and cloud systems for the acquisition, transmission and evaluation of data.

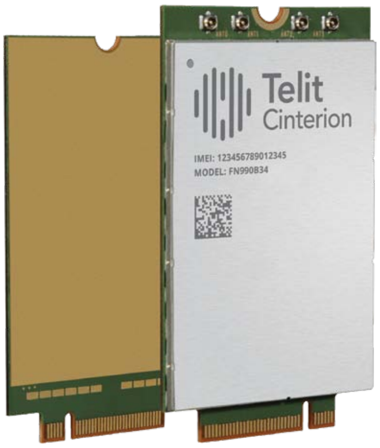


Figure 2: The FN990B34 module supports 5G Sub-6 with GNSS L1+L5 and is suitable for edge applications with increased data traffic, e.g., the real-time control of tractors or drones.

Figure 3: With up to 4.9 Gbps downlink speed, RTK-enabled GNSS and OpenWRT support, the FN990B40 is designed for demanding real-time applications in precision farming.

Figure 4: The SE868K5-RTK module has a compact design with integrated RTK technology for centimeter-level position accuracy via dual-frequency reception (L1/E1 and L5/E5). It is therefore ideal for applications that combine drones and farming.

All the components are designed for demanding fields of use (shock, vibration, temperature range from -40 °C to +85 °C) and can be scaled to a wide variety of devices and applications, from individual sensors to autonomous machinery.

Table 1 provides an overview of how these components interact.

Real-time data for the networked chicken farm

Modern farms increasingly rely on digital technologies to optimize their processes and use the available resources more efficiently. 5G wireless technology offers key advantages, especially where large volumes of data from various sources converge.

A prime example is industrial poultry farming: In such plants, thermostats, automatic feeders and other sensors continuously record operating data. And although each individual sensor only generates small amounts of data, the sum total creates a complex network of information with thousands of data points. That said, connecting each sensor directly to its own 5G line would not be economically viable and would be way too complex from a technical point of view.

The solution is intelligent aggregation: When sensor data is aggregated in locally dimensioned clusters, the resulting data rate corresponds to the performance profile of a mobile 5G broadband connection. This allows the collected information to be efficiently transmitted to the central system via 5G, a process also known as »backhauling«. 5G is thus proving to be the ideal technology for bundling and transmitting data in networked agricultural systems. It enables not only high transmission speeds but also provides a flexible infrastructure that is able to keep up with the demands of modern farming. The 5G Release 17 standard expands the scope of applications: Satellite-based non-terrestrial networks (NTN) allow even remote barns without any cellular network coverage to be integrated into a digital barn monitoring system. Advances in cellular radio standards and chip designs also enable the use of new sensor clas-

Application	Required function(s)	Applied modules/M.2 cards
Autonomous tractors and robotics	High-precision GNSS and reliable 5G/LTE connection for navigation and control	• SE868K5-RTK for centimeter-level position accuracy • FE990B34/40 module for autonomous agricultural machinery that makes decisions directly on site
Precise seeding and distribution of pesticides	Real-time positioning and data synchronization decrease input costs and increase productivity	• SE868K5-RTK to ensure centimeter-level accuracy for GNSS data • FE990B34/40 module for local data processing via OpenWRT
Animal and site monitoring	Energy-efficient modules for wearables and sensors for motion detection and health monitoring	LPWA/NB-IoT-compatible cellular radio modules, combined with SE868K5-RTK for precise location tracking, if required
Environment and soil sensors	Compact, robust modules network field data with cloud dashboards in real time	• FE990B34/40 series for edge computing in the field • FN990B34/40 M.2 card for IoT sensors with cloud connectivity, telemetry and fleet management, as well as remote monitoring and remote maintenance
Mapping and imaging using drones	Lightweight GNSS modules and fast data connection for aerial surveying and analysis	• SE868K5-RTK multiconstellation-compatible GNSS module • FFN990B34/40 M2. card for key image and video data

Table 1: Possible areas of application in smart farming and the applied modules and M.2 cards.

ses that are both more energy-efficient and easier to integrate.

Real-time kinematics for precision farming

The accuracy of conventional GPS systems is often insufficient for automated farming applications. Centimeter-level position accuracy is required, particularly for the guidance of autonomous machines or the precise application of seeds, fertilizers and pesticides. This is achieved using real-time kinematic GPS (RTK-GPS), an extension of GNSS positioning using correction data.

RTK-GPS improves the repeatability and accuracy of mechanized work processes. Tracks can be documented precisely and reused in subsequent seasons. Seeds or fertilizers can also be placed with pinpoint accuracy. Table 2 displays the typical features of RTK.

An RTK system consists of a stationary base station and a mobile rover unit. The base station receives GNSS signals (e.g., GPS, Galileo, GLONASS) and compares them with its known position. Using the difference between the actual position and the satellite signal, it calculates correction data, which is transmitted to the rover in real time. This allows it to adjust its own position with centimeter-level accuracy.

In this application, the SE868K5-RTK module supports multifrequency operation (L1/L5) and various GNSS systems (Fig. 4). It is suitable for machine and drone navigation in RTK applications. Thanks to its compact form factor (11 mm × 11 mm), it can also be integrated into mobile devices with limited installation space.

Characteristics of RTK technology	Result
Centimeter-level position accuracy	• Increased efficiency through fewer overlaps, precise tracks and optimized resource utilization save time, fuel and operating resources • Environmental protection: Precise distribution reduces excessive use and helps to protect resources
Real-time correction data	Time savings and yield gains through faster cultivation, less corrections, improved use of weather windows and land, fewer losses
Multi-GNSS support	• Maximum stability: Automatic steering of machines regardless of the time of day or season • Repeat accuracy: Tracks can be reused exactly over several seasons

Table 2: Advantages of RTK technology in real-world applications.

Summary

IoT technologies have become an established cornerstone of modern, efficient and sustainable farming. Precise GNSS modules, powerful 5G connectivity and robust edge computing components enable smart, data-driven operations, including autonomous agricultural vehicles, connected animal husbandry and environmental monitoring.

The combination of RTK positioning and energy-efficient transmission technologies, such as NB-IoT and LTE-M, ensures reliable, resource-efficient processes, even in areas where conventional networks reach their limits. Expansion of satellite-based 5G networks (NTN) through Release 17 will help to eliminate dead spots and guarantee digitalization even at remote locations.

5G modules of the FN990B34/40 and FE990B series, as well as the GNSS module SE868K5-RTK, are designed for scalability and future proofing. They form the technological basis for automated processes, networked systems and intelligent logistics in tomorrow's world of farming. ■

References

[1] https://www.grandviewresearch.com/industry-analysis/artificial-intelligence-in-agriculture-market#:~:text=The%20global%20artificial%20intelligence%20in%20agriculture%20market%20size,a%20CAGR%20of%2025.5%25%20from%202024%20to%202030
[2] pdf ki-news-impulspapier-landwirtschaft_web_final

Satellite-based IoT networking for remote regions

Global networking with NTN

In many regions, conventional wireless networks are reaching their coverage limits. But new non-terrestrial networks (NTN) are delivering connectivity to areas previously without cellular coverage – using technology that reaches even the most remote locations.

By Julian Clauss,
Corporate Product Manager Wireless
at Rutronik

Image: Gorodenkoff/stock.adobe.com

As the Internet of Things (IoT) continues to expand, the demand for seamless, reliable connectivity is rising rapidly. While LTE cellular networks reach roughly 90% of the global population, they cover only about 15% of the Earth's surface. Including 2G and 3G networks raises coverage to 30–35%. As a result, many remote regions remain a challenge for networking. The discontinuation of 2G will further reduce global coverage. Non-terrestrial networks (NTN) are intended to address this challenge by transmitting data directly via satellite systems, bypassing traditional radio masts.

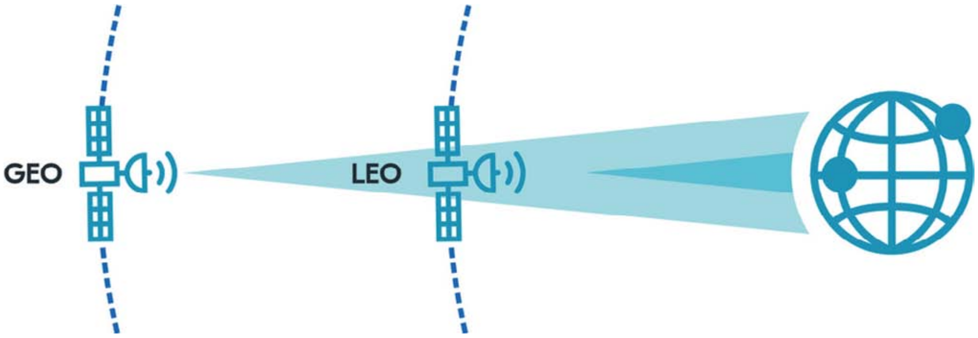


Figure 1: NTN uses LEO and GEO satellite systems to enable the most efficient wireless communication. (Source: Nordic Semiconductor)

NTN enables IoT connectivity via satellites

Non-terrestrial networks (NTN) are radio communication systems that operate far above the Earth's surface. This includes satellites in low (Low Earth Orbit, LEO), medium (Medium Earth Orbit, MEO) and geostationary (GEO) orbits, as well as high-altitude platform stations (HAPS) and drones.

Together, these components provide seamless coverage and also reach remote regions that previously lacked access to conventional cellular networks. Today, end devices can connect either to terrestrial 3GPP networks or to satellites. Users relying on satellite communication therefore require additional hardware beyond their smartphone.

This is about to change with NTN: In the future, all cellular devices will be able to connect seamlessly to both terrestrial and satel-

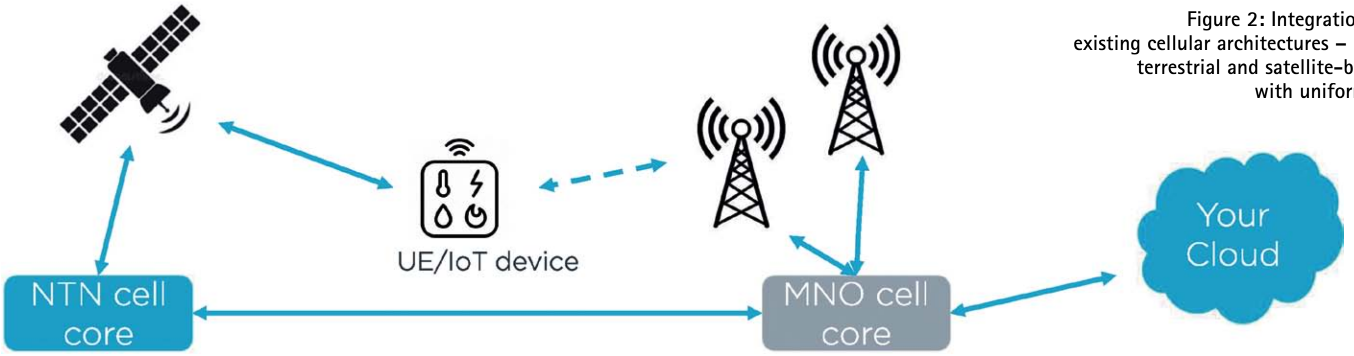


Figure 2: Integration of NTN into existing cellular architectures – parallel use of terrestrial and satellite-based networks with uniform core access.

lite-based networks within the 3GPP ecosystem. With technological advances, satellites are increasingly taking on the role of base stations. In the future, end devices will thus no longer depend on the sometimes limited coverage of stationary 3GPP networks – without any additional hardware. If the terrestrial connection fails, the NTN ensures a seamless transition to the satellite network, which is particularly relevant for critical applications, for instance in agriculture, forestry or the oil and gas industry.

Due to the stationary and larger devices, the introduction of NTN will be straightforward. NTN will be especially important for asset tracking and logistics, though roaming challenges may still arise. However, the first network operators are already developing solutions.

New satellite providers offer cellular core networks in addition to infrastructure in Earth orbit. This enables cellular services to be accessed via satellites. For end devices, this means: End devices can automatically roam into the satellite network using NTN-enabled SIM cards and existing cell phone contracts (MNO/MVNO) or dynamically switch between terrestrial and satellite-based networks when terrestrial coverage is unavailable. NTN is integrated into existing networks using the same APNs and core network structures. The main differences are higher latency and lower bandwidth.

Figure 3: Modern IoT modules like the nRF9151 support both terrestrial and satellite-based communication.

Two satellite types for different requirements

To maximize communication efficiency, NTN employs two satellite systems. Depending on the respective application, GEO and LEO satellites have different advantages and disadvantages.

GEO (Geostationary Earth Orbit):

- Altitude: approx. 36,000 kilometers
- Stationary and permanently accessible above the same region of the Earth
- High latency, elevated power consumption, low data rate (2–4 kbps)

LEO (Low Earth Orbit):

- Altitude: 600–800 kilometers
- Higher data rates (20–40 kbps), lower energy consumption
- As satellites move rapidly, a store-and-forward architecture is essential
- Perfect for routine data collection that does not have to take place in real time

The choice of orbit solution ultimately depends on the requirements of the respective application. GEO networks are ideal for emergency and alarm communications with low data rates, while LEO networks provide efficient, flexible communication for general IoT data with moderate latency requirements. Solutions based on 5G are predominantly operated with LEO systems.

Frequency utilization and antenna design for NTN

NTN has two main bands: n255 (NTN 1.6 GHz or L-band) and n256 (NTN 2 GHz or S-band). These bands partially overlap with terrestrial cellular frequency bands, making it easier to leverage existing antenna designs. L-band applications may require dedicated antenna separation from GNSS.

Initial NTN modules for global IoT connectivity

Nordic Semiconductor's nRF9151 module supports both terrestrial and satellite-based IoT communication (NTN). It is a compact system-in-package (SiP) solution designed for cellular IoT and DECT NR+ applications. Beyond energy-efficient LTE technology, the module includes integrated processing functions, security mechanisms and GNSS for positioning. It supports 3GPP Release 14 LTE-M/NB-IoT as well as DECT NR+.

Full NTN functionality (including GEO/LEO support) has been available since the second half of 2025 (through a firmware update) and enables global connectivity irrespective of cellular network access. Nordic Semiconductor is partnering with providers such as Iridium, Skylo and Myriota to deliver NTN solutions. By the end of the year, Telit will also introduce its first NTN modules to its portfolio.

Summary and outlook

Due to the discontinuation of the 2G/3G networks and the growing demand for global connectivity, NTN is becoming a key technology for the IoT. The combination of modern satellite technology and energy-saving modules opens up new business opportunities and makes previously inaccessible regions accessible.

Precise ranging with Bluetooth

Channel Sounding expands BLE

Bluetooth 6.0 introduces Channel Sounding. This technology enables precise ranging with Bluetooth Low Energy, unlocking new possibilities for positioning, security and interaction – even in domains previously dominated by ultra-wideband.

By Chetan Joshi,
Lead Product Manager at Panasonic Industry Europe GmbH, and Torsten Killinger, Corporate Product Manager Wireless at Rutronik

Device localization has become indispensable in many applications. GPS and cellular networks deliver accurate outdoor data but fall short indoors or when it comes to sub-meter requirements. Although precision can be improved with the help of cellular networks, the added costs and energy consumption make such solutions impractical.

A growing number of applications now focus on short-range devices, i.e., tracking objects in local networks over short distances to generate local position intelligence. This is precisely where various standards and proprietary technologies are seeking to establish themselves. At this point, Bluetooth with Channel Sounding comes into play.

Bluetooth is an established technology, integrated into many areas of modern life. For years, Bluetooth Low Energy (BLE) has served as the workhorse of short-range communication, supporting energy-efficient data transmission across billions of devices. Since its introduction, BLE localization solutions have used the Received Signal Strength Indicator (RSSI) to estimate distances between devices. RSSI is adequate for rough proximity detection, such as determining whether a device is nearby. But not for more precise measurements. Environmental variables, interference and multipath reflections render RSSI an unreliable measure of distance. Companies that contributed to Bluetooth Real-Time Location Services (RTLS) recognized this early on, leading to the introduction of the »Direction Finding« (DF) feature in Bluetooth 5.0. Today, it serves as the backbone for many smart, Bluetooth-based RTLS systems.

The limitations of RSSI-based approaches make Bluetooth unsuitable for industrial RTLS applications. Until now, these applications have been dominated by special ultra-wideband (UWB) solutions. Moreover, while UWB systems deliver distance data in the centimeter range, they demand greater RF design development effort and face additional regulatory requirements. For many applications where sub-meter accuracy is sufficient, UWB systems are thus too complex or too expensive. Channel Soun-

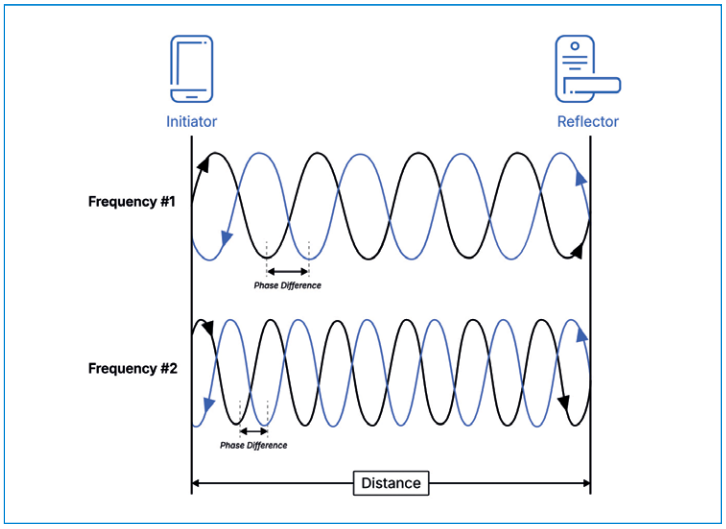


Figure 1: Principle of phase-based ranging (PBR): By comparing the phase shift at various frequencies, the distance between two devices can be calculated.
(Source: Bluetooth SiG)

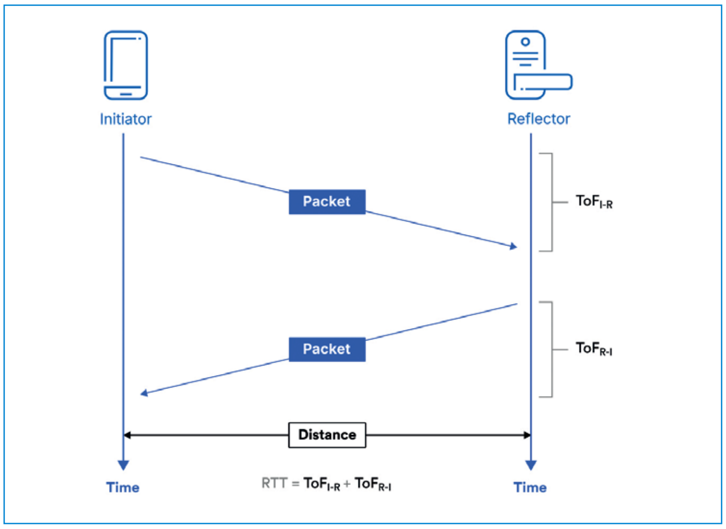


Figure 2: Principle of round-trip time (RTT): The distance is determined using the time difference between sending and receiving data packets.
(Source: Bluetooth SiG)

ding in Bluetooth 6.0 closes this gap. It provides adequate accuracy for many applications without the extensive integration effort demanded by UWB.

BLE-based Channel Sounding enables reliable and precise ranging with cost-effective and easy-to-develop hardware. While earlier Bluetooth generations used RSSI values to roughly estimate the distance between two devices, Channel Sounding now allows direct characterization of the radio channel.

How does Channel Sounding work?

Basically, Channel Sounding is about time and phase. Phase-based ranging (PBR) and round-trip time (RTT) measurements can be used to determine the exact distances between two devices. With PBR, the devices exchange signals across multiple frequencies and compare the resulting phase shifts. This enables precise distance calculation (Fig. 1). RTT works in a similar way to radar: A device sends a packet, the receiving party responds, and the difference in round-trip time provides the distance (Fig. 2). By combining both methods, Bluetooth achieves a level of accuracy that was unattainable with RSSI. The decisive factor here is not only accuracy but also that this further development is based on the same BLE technology that has become a cornerstone of the Internet of Things (IoT).

Although PBR and RTT work reliably in most real-world scenarios, they need additional support to mitigate effects like multipath propagation, interference or attacks such as relay attacks. Bluetooth 6.0 therefore incorporates additional security mechanisms to complement Channel Sounding. Signals can be randomized, encrypted and verified to ensure that the distances determined are not manipulated. Furthermore, devices can use multiple antennas to reduce errors caused by reflections through spatial diversity. This combination of time measurement, phase comparison and cryptographic protection makes Channel Sounding a practical tool for real-world applications.

Hardware base for Channel Sounding

One example of implementation is the new PAN-B611 module family from Panasonic. It provides the Channel Sounding functionality in a compact, pre-certified package. It is based on the nRF54L15 from Nordic Semiconductor, one of the first Bluetooth SoCs that supports precise ranging and angle measurements. The chip integrates a radio subsystem for phase and round-trip analyses, a powerful Cortex-M33 processor and cryptographic protection mechanisms. A separate RISC-V co-processor assumes time-critical tasks. Besides ranging, the support for multiple antennas also enables angle-based positioning and thus more detailed detection in both two and three dimensions.

The PAN-B611 routes all pins of the nRF54L15 on a hybrid footprint with castellated edges and LGA pads. Measuring just 10.35 x 9.6 x 1.9 mm, the module is suitable for designs with tight space restrictions. Versions with integrated chip antennas are suitable for compact designs, while models with external antenna connections also allow for multi-antenna setups. All pins of the nRF54L15 are routed out on the PAN-B611-1x modules to ensure that, for example, a PAN-B611-1B can be used for a multi-antenna Channel Sounding setup where an antenna switch is controlled with up to four GPIOs. In many applications, however, use of the integrated antenna in the PAN-B611-1C is sufficient for a rough distance estimate. This eliminates the need for customer-specific antenna adaptations or additional approvals and shortens development cycles.

For memory-intensive applications, Panasonic offers the PAN-B611 module family with an optional and compact 4 MB flash memory chip without changing the form factor. The additional memory allows for measurement data to be stored for further processing, e.g., for cryptographic processes or machine learning algorithms on the edge device. This also helps support the execution of non-time-critical routines directly from the memory (execute-in-place, XiP) as well as the management of larger firmware packages and over-the-air (OTA) updates. Figure 3 shows the PAN-B611 module with an integrated antenna.

The modular approach facilitates integration into existing designs and shortens development times. Developers can focus on the application logic, while certification and RF design are dealt with at module level.

From asset tracking to augmented reality (AR)

Location information creates added value in many areas of life. The possible applications are just as diverse. In healthcare or logistics, cost-effective sub-meter accuracy can significantly help to boost efficiency. Devices can be located immediately, inventories adjusted automatically and processes optimized without human error. In consumer applications, smartphones with Channel Sounding will be able to interact more securely with smart locks or vehicles in the future, as actual physical proximity is verified. In AR and VR systems, precise positioning improves synchronization between the digital and the physical environment. Scenarios based on the exact location data of each family member can also be used in smart homes, for instance the room-specific control of lighting and air conditioning.

Figure 3: PAN-B611 module with integrated antenna. (Source: Panasonic)

One possible example is a smart lock that uses Channel Sounding for distance verification and simultaneously supports a smart home protocol like Matter. This allows for the actual proximity of a Bluetooth key or smartphone to be checked while enabling integration into an interoperable smart home. The optional 4 MB flash memory of the PAN-B611 provides sufficient space for larger firmware packages with protocol stacks, cryptography libraries and OTA functions.

Summary

Channel Sounding is an optional feature of Bluetooth 6.0 but given the growing popularity of new devices is likely to become the standard one. It marks the transition from probabilistic to deterministic ranging and takes Bluetooth to a whole new level: From a simple communication interface to a platform for spatial detection. ■

Fruit Sorting with AI, edge computing and real-time data processing

Food Processing 4.0

The combination of AI, edge computing and image processing allows for real-time automated fruit sorting. Production and quality data is captured directly, classified and made available for analysis. This provides ideal conditions for transparent processes and full traceability.

By Thomas Stanik, Senior Sales & Business Development Manager at Kontron Europe, and Johannes Gasde, Corporate Product Manager Embedded & Wireless at Rutronik

The industrial processing and sorting of food, especially sensitive fresh produce such as fruit, places high demands on precision, speed and flexibility. Conventional sorting systems often operate mechanically or with basic optical sensors. However, they reach their limits when it comes to detecting subtle differences in quality, degree of ripeness or external defects.

Here, modern smart factory concepts come into play, intelligently linking artificial intelligence (AI), machine learning (ML), edge computing and powerful hardware platforms. One possible application would be sorting apples. The aim is to recognize different apple varieties, determine their degree of ripeness (e.g., green, red), and identify quality defects such as bruises, mold or rot. This information could be used for automatic sorting into defined quality classes. In addition, documentation could be created for quality management and traceability.

Possible applications for AI-supported image processing

At the core of this application is the AI system built on the Kontron K4021-Ux mSTX. The integrated NPU (Neural Processing Unit) or AI co-processor enable accelerated processing of

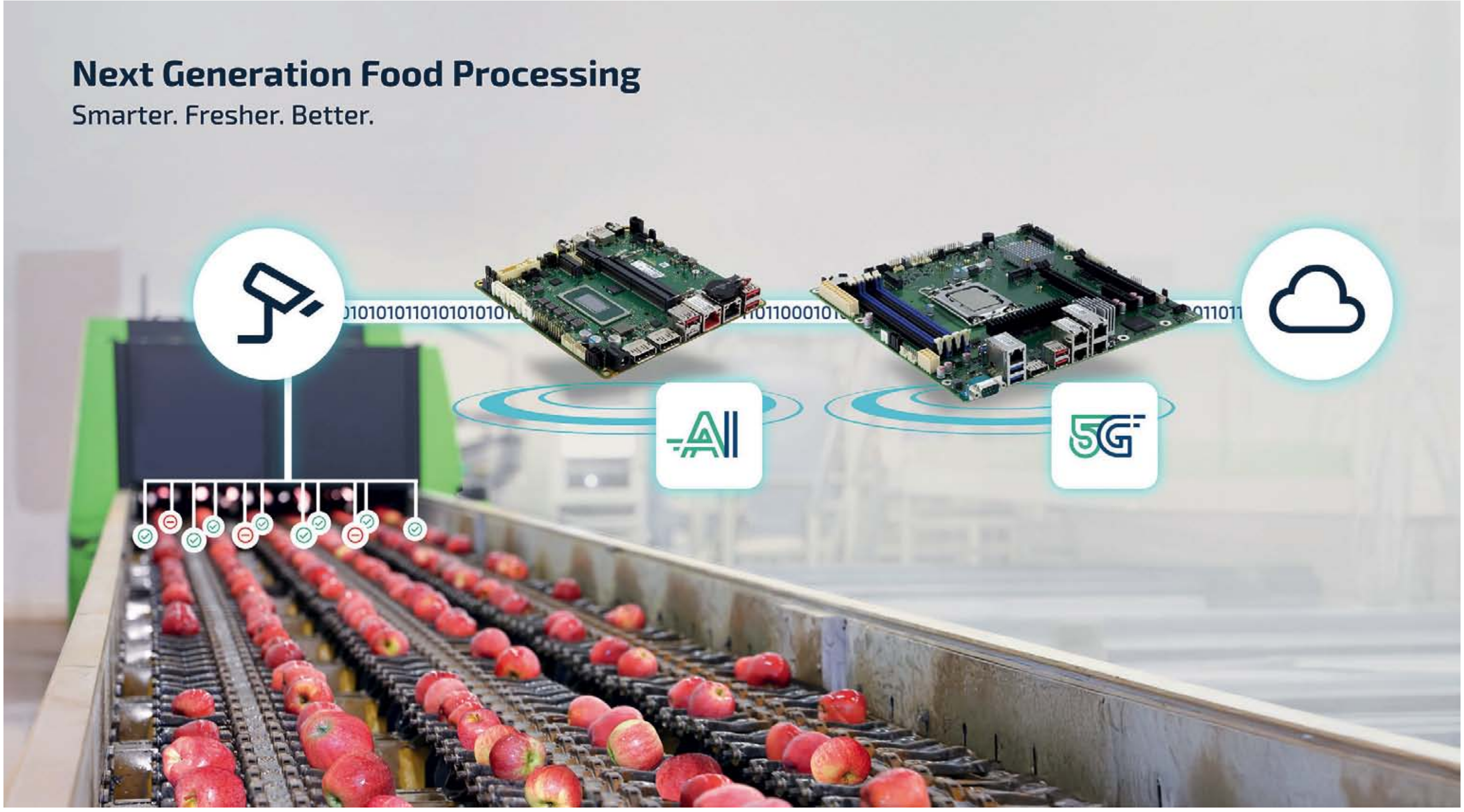


Figure 1: Next-generation food processing thanks to automated fruit sorting. (Source: Kontron)

high-resolution image data captured by a 5GbE IP camera. In a potential application scenario, the camera would capture the apples on the sorting belt in real time and deliver images of each individual product. A specially trained neural network would then evaluate these images. To achieve this, it is pre-trained on datasets containing thousands of images of different apple varieties, stages of ripeness and defects. This is how the system could hypothetically make decisions:

- Is the fruit in perfect condition?
- Is the apple ripe (red) or unripe (green)?
- Is there any external damage or are there any quality defects?
- Which quality or sorting class should the apple be assigned to?

These decisions are made with a speed and precision that would be impossible to achieve with manual methods. At the same time, each individual evaluation result is documented alongside the captured image data and can be used later for quality audits or process optimization.

Compact design for flexible integration

The K4021-Ux mSTX embedded system was designed for applications with limited installation space. It can be integrated either directly or in the SMARTCASE S502 package into existing sorting plants. The system is designed for real-time processing of image and sensor data, enabling process-integrated evaluation of captured characteristics during operation.

Results can be transmitted directly to downstream systems via a dual network interface. Thanks to the long-term hardware availability of at least seven years, an additional Longevity Plus program and BIOS support for up to three years after the end of the product life cycle, the systems can be operated and maintained reliably over several years.

Data consolidation on the edge server

While the K4021-Ux industrial motherboard performs real-time analysis and sorting of apples on the line, all captured quality and process data is continuously transmitted to a central edge server. Here, the K3881-C µATX server motherboard is used and, acting as a local hub, consolidates various data streams from production.

In addition to the sorting results and image data, the server also processes other production-related information. This includes environmental parameters like temperature and humidity, which are integrated via 5G-enabled sensors, as well as machine data for operational monitoring. This information is supplemented by batch indicators such as throughput, quantity distribution and sorting statistics. Product-specific characteristics, e.g. ripeness, sorting classification and documented deviations, are also recorded and evaluated. This delivers a consistent, up-to-date picture of the ongoing process, accessible to downstream systems and analyses.

Powerful infrastructure

The edge system based on the K3881-C µATX is built for continuous industrial operation in demanding conditions. It supports an extended temperature range, ensuring reliable operation even when the temperature changes. Furthermore, it enables both wired 10G connections for high-speed data transfer of large amounts of data to the cloud or to central production control systems and the integration of modern 5G interfaces for flexible connection of mobile units and wireless sensor systems.

Remote management functions and an integrated board management controller (BMC) facilitate central administration and remote maintenance and contribute to reliability. Thanks to the long-term availability of the platform, the system is especially suited for applications with predictable product cycles in production.

The captured and processed data can be integrated into existing cloud infrastructures. There, it is available for various applications, such as analyzing sorting accuracy, investigating the causes of quality deviations or optimizing processes. In addition, this data enables seamless traceability of individual batches, monitoring of compliance with cold chain specifications and predictive maintenance through the analysis of machine-related operating data. The central provision of this information creates the basis for continuous monitoring not only of individual lines but also of entire plants or even across locations.

Fruit sorting 4.0 in practice

In a real-world practical scenario, a modern fruit sorting plant processes several tons of apples every day. Each apple is captured by an IP camera and analyzed by the K4021-Ux system within milliseconds. Automated sorting is performed using switches, wherein classification into different quality classes is based on predefined criteria. At the same time, all sorting results, defect images and sensor data on the environment (temperature, humidity) are transmitted to the K3881-C edge server.

This edge server prepares the data, performs statistical evaluations and continuously monitors compliance with cold chain specifications. The results are stored in a central location and are also available in the cloud as complete batch reports. Both operations managers and quality managers therefore have access to current and historical data at all times.

Summary

The combination of AI, edge computing and networked automation solutions forms the technical foundation for further enhancing quality assurance, traceability and process stability in food processing. Systems like the K4021-Ux mSTX and K3881-C µATX demonstrate that these technologies are already available for practical deployment and can be integrated into existing production environments.

In the fruit processing sector, in particular, this can significantly improve sorting quality, optimize yields and increase customer satisfaction through consistently high product quality. Simultaneously, the fully captured process data offers valuable insights for continuous improvements along the entire value chain.

This shows that data-based production processes in the food industry are already technically feasible and economically viable today. ■

Energy-efficient connectivity for smart health care systems

Smart medical technology with a networked mindset

Rising health care costs and an aging population are driving innovation in medical technology. Networked solutions combined with energy-efficient wireless technology enable mobile, secure and patient-focused applications – from wearables to telemedicine.

Image: partheev/stock.adobe.com

By Julian Clauss,
Corporate Product Manager
Wireless at Rutronik

Health care systems worldwide are facing growing pressure: Populations are aging and the prevalence of chronic conditions like diabetes, heart disease, obesity and cancer is surging – driving health care costs to unprecedented heights. Even with rising investments, health care services often struggle to keep pace. Hospital care remains a cornerstone, but the health care landscape is shifting toward prevention, personalized medicine and empowering patients to take charge of their own health – beyond the guidance of medical staff or family doctors.

Mobile health devices have become an established part of everyday health care. From fitness wristbands and smart rings to medically certified sensors, these devices continuously deliver vital data. They not only aid in the early detection of diseases and in the management of chronic conditions but also promote an active, health-conscious lifestyle through motivation, real-time feedback and personalized recommendations. Reliable, energy-efficient communication is key to making this possible.

Wireless technology as the backbone of digital medicine

Energy-saving wireless solutions lie at the heart of networking. Bluetooth Low Energy (LE), Wi-Fi and cellular IoT technologies deliver scalable, low-latency and secure connections – whether in the home network, on the move or in clinical settings. Combined with on-device intelligence, diagnoses and responses can be accelerated locally without the need for a constant cloud connection.

Nordic Semiconductor is a leading provider of low-power wireless solutions. Key technologies include:

- Bluetooth Low Energy: Basis for energy-efficient networking
- Wi-Fi: Bandwidth-intensive data transfers
- Cellular IoT: Mobile or stationary applications offering extended range, e.g., through LTE-M, NB-IoT or DECT NR+
- Edge AI/ML: On-device local evaluation, classification and pattern recognition

These technologies form the backbone of modern, wirelessly networked health care solutions. However, the requirements on medical IoT solutions are high. In this regard, security, data protection and interoperability are key aspects.

On top of that, low power consumption, a compact design, high data security and compatibility across diverse systems are in demand. At the same time, users expect devices that are comfortable and virtually invisible. This is where integrated platforms – i.e. hardware and software solutions that combine multiple coordinated functions into a single system – come to the fore, offering everything from radio modules to security features, firmware updates and certification support.

Smart and precise: Networked wearables in use

The range of solutions is constantly growing. Networked insulin pumps, blood pressure monitors, glucose sensors and inhalers with reminder functions already exist. They enhance the quality of health care, ensure comprehensive documentation and seamlessly integrate with higher-level systems like telemedicine platforms. Paired with secure gateways or direct cloud connectivity, they pave the way for new health care models.

The Kaleido insulin management system exemplifies a modern, portable and digitally connected medical product. It combines a compact insulin pump with wireless control, thus enabling flexible, continuous insulin delivery. The system uses Nordic Semiconductor's nRF52840-SoC, which ensures stable Bluetooth LE communication with low power consumption, to connect to the app.

Another key application is portable systems that enhance mobility of Parkinson's patients. These systems deliver tactile signals to improve movement sequences while automatically documenting when and how they were used. Studies show that this can significantly enhance mobility of Parkinson's patients. The portable medical product gaitQ Tempo uses Nordic's energy-efficient nRF5340 for Bluetooth LE connectivity (Figure 1). It records movements, transmits data to an app and thus enables targeted therapy adjustments. Thanks to its low energy consumption, the system can run longer on a small battery.

Designing an intelligent, wireless Bluetooth Low Energy medical device is no small feat – but with today's powerful, highly integrated Systems-on-a-Chip (SoCs) and readily available software and hardware tools, bringing these design innovations to life has never been easier.

Nordic Semiconductor's new nRF54 series is built for IoT applications that place high requirements on processing power, energy efficiency and security. It combines an energy-efficient, multiprotocol wireless solution in the 2.4 GHz band with a multi-core microcontroller based on a 128 MHz Arm Cortex-M33. Compared to its predecessor series, the nRF52, the nRF54 series delivers double the performance and three times the efficiency.

Figure 1: The gaitQ Tempo (left) uses the Bluetooth LE capabilities of Nordic's nRF5340 (right) SoC to connect the remote control and leg-worn devices for manual vibration signals. (Figure: Nordic Semiconductor)

Challenges of market penetration

Beyond technical feasibility, user acceptance and data protection are key to achieving success. The devices must be intuitive, comfortable to wear and reliable in operation. Developers are challenged to deliver cost-effective designs while meeting regulatory requirements.

A key aspect here is ensuring secure and scalable connection of the devices to digital infrastructures. Nordic takes a holistic approach to device security and direct cloud connectivity. This involves the use of security features like Secure Boot, encrypted communication and hardware-based key management – paired with flexible cloud connectivity. This allows efficient and secure implementation of data-intensive applications, remote maintenance and software updates, even in scenarios with limited network connectivity.

Medical technology of tomorrow

IoT empowers health care to do more while using less energy. As a result, health care is set to become one of the largest adopters of artificial intelligence (AI) and machine learning (ML). With the acquisition of Neuton.AI, a specialist in automated TinyML solutions for edge devices, Nordic Semiconductor has strengthened its expertise in Edge AI.

The combination of the nRF54 series with the Neuton framework brings scalable AI to even the most resource-constrained devices – marking a significant leap forward for medical technology. Microcontrollers with integrated AI evaluate biosignals locally, for example for fall detection, arrhythmia analysis or early diagnosis. This keeps data on the device, reduces latency and maximizes energy efficiency.

Long-lasting, reliable battery life is essential, especially for battery-powered medical devices like wearables and fitness trackers. Nordic Semiconductor offers a range of power management ICs (PMICs) for efficient energy management, including the nPM2100 for primary cell applications and the nPM1300 for devices with rechargeable batteries. Features like a boost regulator with just 150 nA standby current, an ultra-efficient 35 nA ship mode, as well as integrated wake-up functions and timers enable a precise energy supply with minimal consumption. The PMICs thus complement the wireless solutions to create a compact, energy-efficient platform for medical end devices.

Wireless technology is also playing an increasingly central role in telemedicine and remote health care for chronically ill patients, especially in regions with limited access to health care. The combination of cellular IoT, cloud integration and interoperable platforms enables a new quality of health care – data driven, personalized and accessible anywhere.

Wireless communication technologies are making health care smarter, more accessible and more effective, thus enhancing the quality of life, cutting costs and expanding health care worldwide. The goal is health care that is efficient, affordable, sustainable and accessible to everyone. ■

Cybersecurity in the quantum age

How to secure tomorrow's data today

Vrom prevention to digital defense: Quantum computers are challenging today's encryption – and our digital security with it. Why Europol calls for action, how German semiconductor suppliers fit in and what your data has to do with my grandmother's wisdom.

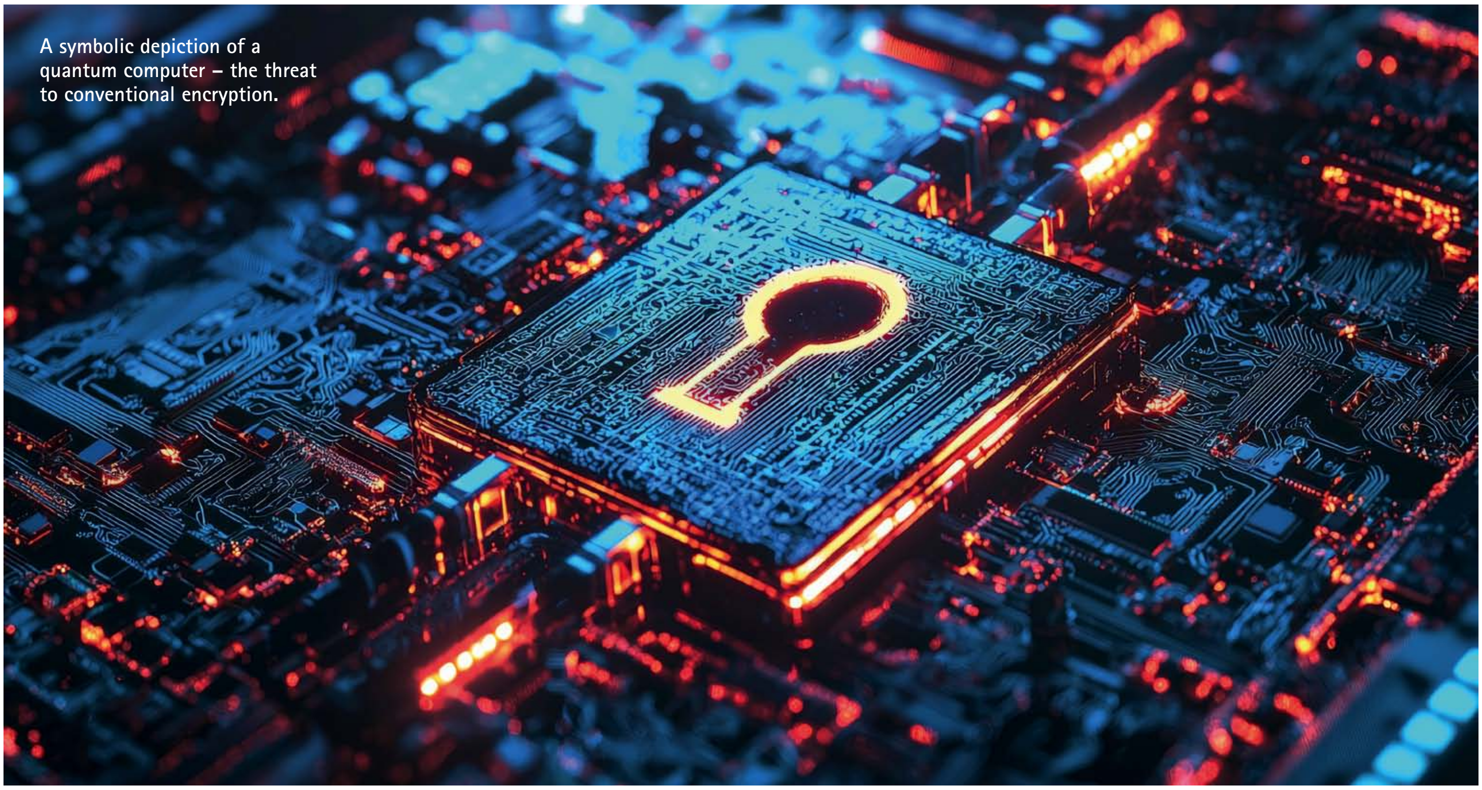
By Bernd Hantsche,
Vice President Technology
Competence Center at Rutronik

Doomsayers never rest. But what does it mean when even the advice of my conservative grandmother, who was shaped by the post-war era, to »make hay while the sun shines« now feels like a call for digital prevention. Because defense today is not about tanks – it is about protecting our data. The threat is real: Europol warns that organized networks are already collecting encrypted data today to decrypt it later with quantum computers for their own purposes. [1] The scenario is called »Store now, decrypt later«.

Quantum computers are fundamentally rewriting the rules of cryptography. Algorithms like RSA (Rivest-Shamir-Adleman), upon which much of our digital communication is based, could soon be cracked by quantum computers. Post-quantum cryptography (PQC) offers the solution: Put simply, new cryptographic methods that will remain effective even against quantum computers.

It is time to act:
The quantum threat looms.

Quantum computing is advancing rapidly. From tech giants and universities to startups, everyone is striving to outshine with achievements. Meanwhile, security research is step-



A symbolic depiction of a quantum computer – the threat to conventional encryption.

Image: Sasint/stock.adobe.com

ping up: The US National Institute of Standards and Technology (NIST) has already designated three algorithms as post-quantum standards: The Federal Information Processing Standards (FIPS) FIPS-203 (ML-KEM), 204 and 205 offer robust key exchange and digital signature mechanisms designed to resist attacks from quantum computers.

The Federal Office for Information Security (BSI) has also weighed in on »Q-Day« – the day quantum computers will be able to break conventional encryption for the first time. The BSI anticipates this to happen around 2030, coinciding with the full-scale production of today's electronic developments. Those who fail to prepare now risk deploying outdated security technology later on.

The Quantum Safe Financial Forum (QSFF), initiated by Europol, also pushes the financial sector, in particular, to use today's tools to defend against tomorrow's technology.

Challenges of transitioning to post-quantum cryptography

Clear though the goal may be, the road to it is anything but easy. Bigger keys and more complex algorithms demand greater processing power – a particular strain on legacy systems. Moreover, since standardization has not yet been fully completed, the algorithms in use may yet change.

And from an organizational standpoint, the transition is far from easy – it requires investment, new mindsets and technical expertise. The key to success therefore lies in what is known as crypto-agility: From the start, systems need to be designed for flexibility, enabling rapid response to emerging findings or threats.

The first steps toward a secure IT infrastructure in the quantum age

Despite these challenges, initial practical implementations show that the transition to post-quantum cryptography is already underway: Infineon, Rutronik's largest franchise partner, established itself early on as a PQC pioneer. Quantum-resistant key exchange was first implemented on a contactless chip back in 2017. [2] At the beginning of 2025, the BSI awarded the world's first EAL6 certification to a security controller featuring ML-KEM technology. [3] Infineon, therefore, focuses particularly on smart card applications.

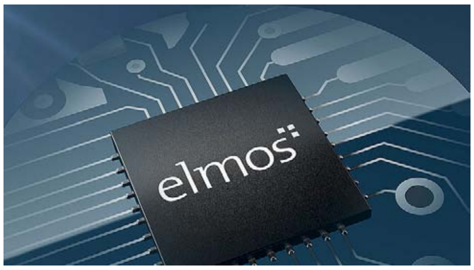


Figure 1: Miniaturized QRNG module from Elmos Semiconductor – true randomness for next-generation networked devices.
(Source: Elmos Semiconductor)

Other German semiconductor suppliers are also driving development forward. Elmos Semiconductor, together with ID Quantique, is introducing a key PQC component: a miniaturized quantum random number generator (QRNG).

All encryption methods start with a random number to generate the key. However, a discrete, logical device struggles to generate genuinely random numbers. HRNGs, or hardware random number generators, have existed for a long time and are available in various technical designs. Conventional generators (TRNGs/PRNGs) are susceptible to manipulation – through physical factors such as light, pressure, temperature, electromagnetic fields or supply voltage, as well as through targeted interventions using artificial intelligence.

QRNGs use genuine quantum effects, like photon emission, to generate truly random numbers. This method is more secure and provides additional hardening for FIPS 203, 204, and 205 compared to keys with conventionally generated numbers. At present, such QRNGs are best known as server expansion cards.

Elmos has now miniaturized the technology into a compact 2×2 mm DFN package (Fig. 1). As a result, Rutronik makes the patented technology available to customers worldwide. Not only the financial sector but also the industrial, medical and automotive sectors are gaining benefits.

Safety is a duty, not a luxury

Since: It is no longer just about banks. Whether industrial plants, medical devices or vehicles with assistance systems – our world is digital, networked and therefore at risk. What if vehicle assistance systems suddenly misinterpret traffic signs, or if cars can be unlocked via ultra-wideband technology and rolling key methods because the key was predictable? Or if medical data is intercepted because the random number generator was not genuine?

The quantum revolution is coming. Perhaps not tomorrow, but certainly sooner than most expect. Those who do not invest today will pay tomorrow. As my late grandmother would have wisely said: »Encrypt your data sensibly today, and you will be safe from tomorrow's quantum cyberattacks.«

The terms at a glance

- **Q-day** – The point in time when quantum computers can crack current encryption systems. The BSI expects this to happen around 2030.

- **QRNG vs. TRNG** – Quantum random number generators produce genuine, non-manipulable random numbers based on quantum physical processes. TRNGs use physical effects but are potentially susceptible to interference.

- **FIPS-203/204/205** – Security standards for quantum-secure algorithms (key exchange and digital signatures) published by NIST as the foundation for post-quantum cryptography.

- **ML-KEM** (Module Lattice Key Encapsulation Mechanism) – a key encapsulation mechanism (KEM) standardized by NIST under FIPS 203. It enables two parties to establish a shared secret key that is resistant to conventional and quantum computer attacks

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HMI concepts for two-wheelers, three-wheelers, four-wheelers and watercraft

Modern instrumentation for small vehicles

Modern display and control solutions in the field of micromobility and boats require compact, graphics-capable controllers. A scalable microcontroller platform supports graphical HMI applications – ranging from basic displays to camera-based systems with safety requirements.

By Ralf Hickl,
Product Sales Manager ABU
at Rutronik

Digital display and control concepts are increasingly finding their way into vehicle classes that were traditionally equipped with mechanical or basic LCD instruments – such as two-wheelers, three-wheelers, light commercial vehicles and boats.

Today, the requirements and capabilities of these applications extend far beyond simple speed or fuel indicators: Users expect clear, easy-to-read visualization of safety-related information, personalization options and smartphone integration interfaces.

In the context of software-defined vehicles (SDVs), functions are increasingly being implemented via software and can be adapted or expanded throughout the product life cycle. This applies, in particular, to display units that not only visualize driving data but also integrate safety and comfort functions and can be connected to smartphones or other devices.

The implementation of such systems requires microcontrollers that, in addition to conventional control functionality, can also handle graphics processing and safety functions. At the core of the control electronics are microcontrollers equipped with integrated graphics processing units (GPUs). This category includes Infineon's new 32-bit microcontrollers from the TRAVEO™ T2G Graphics series. Figure 1 shows a possible implementation case.

Figure 1: A possible implementation case with the TRAVEO™ T2G Graphics shows the »speedometer« on the left-hand side with speed and virtual signal or control symbols, as well as the navigation displayed by a smartphone. On the right is the smartphone with a wireless connection to the display unit (Source: Infineon)

Scalable graphics controllers for embedded display applications

The microcontroller family is designed for various display and control solutions in small vehicles and boats. The product selection is based on the specific requirements of the respective application – from basic segment displays to graphics-intensive display units with video output (Fig. 2).

The CYT2CL subfamily is ideal for applications with low graphics requirements, such as basic speedometers with LCD segments or pointer instruments with stepper motors. The modules deliver essential control logic and I/O functionality without requiring a full-fledged graphics engine. The focus is on low power consumption and cost-effective implementation.

Applications with freely configurable graphical user interfaces, such as digital cockpits, scooter displays with navigation overlays or rearview camera systems, can be implemented using the CYT3DL, CYT4DN and CYT4EN subfamilies. These microcontrollers integrate a 2D graphics engine and primarily differ in their RAM configuration and display support.

The target is graphic displays with a WVGA resolution (800 × 480 pixels) or higher:

- **CYT3DL:** internal video RAM (up to 2 MB) for basic 2D graphics at medium resolution
- **CYT4DN:** enhanced rendering with up to 4 MB internal video RAM, supports multiple display layers and warping (Fig. 3)
- **CYT4EN:** external LPDDR4 RAM up to 1 GB for high-resolution displays or larger image buffers

The CYT4EN subfamily is designed for complex systems such as head-up displays, digital rearview mirrors or multi-display concepts with projection or camera-based inputs.

These derivatives combine high graphics performance with low energy consumption, featuring two independent video outputs (e.g., cockpit + HUD), warping for projection surface correction and optional external LPDDR4 memory. They offer the necessary flexibility for future display and assistance functions.

All derivatives of the CYT3 and CYT4 families integrate a sound subsystem and numerous peripheral blocks alongside the graphics engine. The graphics subsystem offers a range of performance features, including the following:

- On-chip video RAM with CYT3DL and CYT4DN. The on-chip video RAM increases the integration of the overall system and eliminates the need for external memory modules. The internal bus connection enables fast access times. With CYT4EN, the up to 1 GB big video RAM is designed as external memory with LPDDR4.
- Graphics processing unit (GPU) for on-the-fly 2D rendering with block image transfer (BLIT), image scaling and rotation, perspective correction for 3D effects (2.5D) and command sequencer.
- Display and composition engine with five graphics layers supporting alpha blending, one of which includes a warping function, e.g. for lens or projection surface correction, and two independent video output signals, e.g. for the main display and head-up display.
- Capture engine for a video stream
- Video I/O interface
- JPEG decoder

The key function is the option to render videos and graphics directly (on-the-fly) to the display via a multi-line buffer, instead of first loading them into a large frame buffer in the RAM. This means that the internal video RAM is sufficient for 720p graphics and BOM costs can be reduced, as the system does not require external DDR RAM. This technique is common for basic sprite graphics but unique in the context of 2D GPUs and demanding operations such as image rotation and perspective correction (2.5D).

Safety functions in display units

In many vehicle applications, display units not only perform a comfort function but also safety-related tasks. This includes displaying warning symbols such as »Airbag deactivated« or »Door open«. To ensure that this content is correct and always visible, specific functional safety measures are required.

A key element is the so-called Signature Driver. It calculates a checksum (CRC) for defined image areas on the microcontroller. This checksum is continuously compared with a reference value. This way, you can see whether safety-related display content is shown as required. These properties also qualify the microcontroller as a Safety Companion MCU for display units that are operated in conjunction with an SoC – such as those running Linux with Android Auto or Apple CarPlay support. In these systems, the microcontroller manages the display of safety-related symbols (e.g., seat belt warning or airbag status), while the main processor handles all other displays. This allows the overall system to secure safety-critical content in accordance with an ASIL classification without requiring the main SoC to meet functional safety requirements.

In addition to functional safety, an integrated hardware security module (HSM) is also available as an option for all modules. This meets the EVITA Full Specification (E-safety Vehicle InTrusion protected Applications) and enables, for instance, secure system startup and hardware-supported execution of cryptographic functions. Compliance with standard ISO/SAE 21434 for cybersecurity in vehicle development is underway, with certification planned by the end of 2025.

Developer tools and evaluation platforms

Drive Core Graphics is an integrated software solution specially tailored to the microcont-

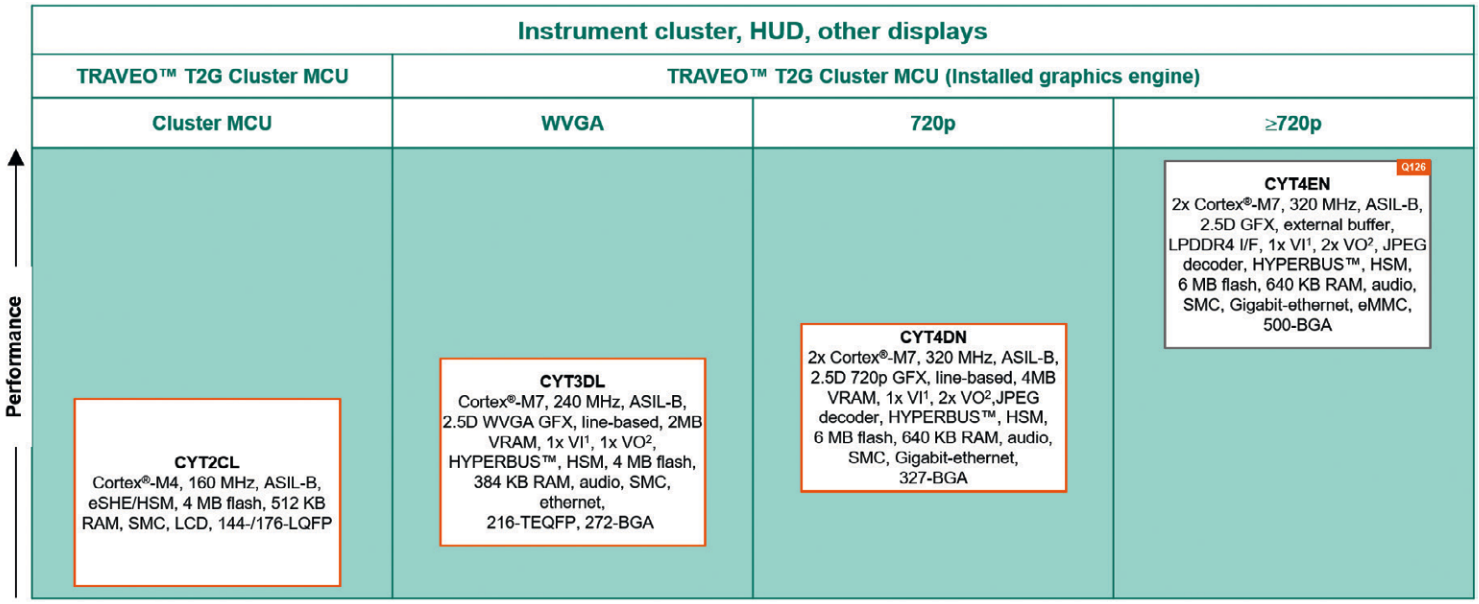

Figure 2: The portfolio of the TRAVEO^{TM} T2G Graphics. (Source: Infineon)

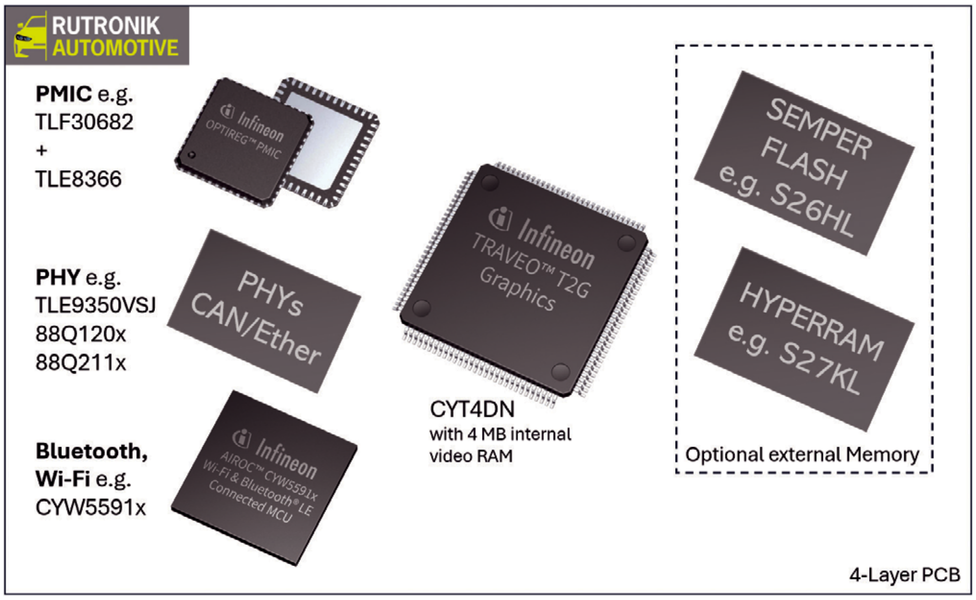

Figure 3: Possible system components for CYT4DN with 4 MB internal video RAM. (Source: Rutronik)

roller family for developing graphics-capable applications. [1] It comprises compilers, debuggers and middleware for hardware abstraction, as well as graphics libraries that utilize the acceleration capabilities of the hardware. Among other things, support is provided for connecting to IAR tools (compilers, debuggers) and using Qt-based graphics development. The evaluation license is available free of charge (limited to three months) and is tied to the hardware purchase.

Various licensing models are available for the AUTOSAR MCAL, Qt Runtime and Infineon graphics package software libraries. With the conventional model, users obtain licenses from the respective software providers and manage them themselves. It is especially suited for high-volume projects but requires upfront investment – typically by the start of series production. In the alternative licensing model, Infineon has already included the licensing costs in the component price. This eliminates the need for a separate advance

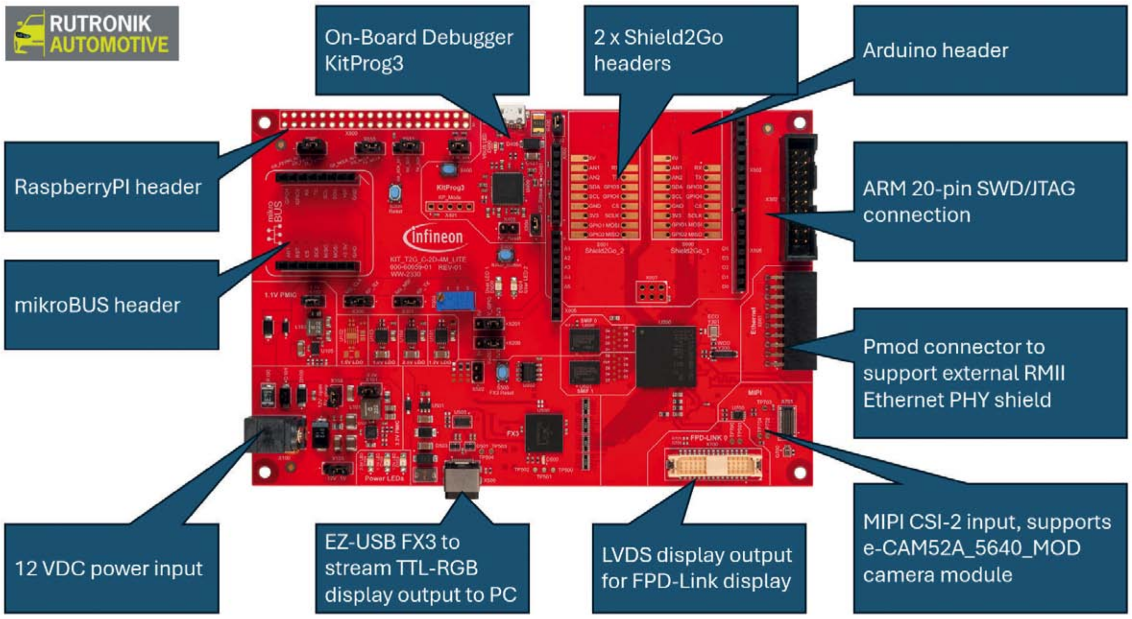

Figure 4:
The KIT_T2G_C-2D-4M_LITE evaluation board based on CYT3DL with 2 MB internal VRAM, external HYPERFLASH (512 Mbit S26HL512T) and 64 Mbit HYPERRAM (S27KL0642).
(Source: Rutronik, with contents from Infineon)

Criterion	CYT2CL	CYT4EN
Area of application	Basic LCD segment displays, pointer instruments with stepper motors	High-resolution graphics-intensive displays, systems with greater memory requirements
Graphics features	No full-fledged GPU, basic control logic	2D GPU with on-the-fly rendering, warping, perspective correction (2.5D), designed for higher resolution and larger image data volumes
Memory configuration	No internal video RAM	External LPDDR4-RAM up to 1 GB, HYPERRAM/FLASH possible
Display support	Basic resolutions (e.g., segment LCDs)	WVGA to HD+, for graphics-intensive interfaces and large frame buffers
Interfaces	Basic I/O (CAN, LIN, SPI)	MIPI-CSI-2 (camera input), LVDS, Ethernet, CAN, SPI, I²C; dual video output possible
Energy efficiency	Optimized for low power consumption	Higher consumption due to external RAM connection, tolerated for performance-critical tasks
Cost focus	Cost efficient, as no external storage is required	Higher costs due to external RAM and high-end graphics functionality

Table 1: Scaling range within the MCU family from minimal to high-end use: CYT2CL vs. CYT4EN.

payment or an additional license agreement with a third-party provider. Use is governed by a clickable end user license agreement (EULA). This model simplifies access to production-ready software for small and medium-sized projects with limited quantities, as are often found in the distribution environment.

To fully leverage the potential of graphics-capable microcontrollers, it is crucial that the graphics libraries of software partners actually use the hardware acceleration of the TRAVEO™ T2G. Infineon has tested and approved several libraries for this purpose. The approved libraries include: Altia Design, DeepScreen, Candera CGISTUDIO and Qt for MCUs.

The supplier provides several evaluation platforms for a practical introduction. One example is the KIT_T2G_C-2D-4M_LITE board (Fig. 4), featuring a CYT3DL controller, internal video RAM, as well as external HYPERFLASH and HYPERRAM memory. It enables the development of basic to medium-sized graphical user interfaces and supports typical interfaces such as LVDS, MIPI-CSI-2, Ethernet and CAN.

The reference boards are designed for a wide range of applications – from stand-alone control elements to safety companion roles in more complex system architectures. Extensive connections and interfaces facilitate integration into existing development environments. Rutronik also offers hardware debuggers and flashers from Segger Microcontroller.

Potential in the vehicle display market

The presented microcontroller family is specifically designed for graphic display and control solutions in compact vehicles, watercraft and mobile systems with limited space. The combination of integrated graphics processing, memory options, safety features and a coordinated software package supports a broad spectrum of applications – from basic displays to safety-oriented display units with SoC coupling.

Thanks to the licensing model and the tools available, implementation is also feasible for suppliers with smaller volumes or short development cycles. The more powerful versions will also enable the implementation of head-up displays and camera-based systems in the future. The announced certification in the field of cybersecurity will further broaden the range of possible applications.

Rutronik supports developers in identifying the right solution for their specific application from the available portfolio – from the initial idea to series-production readiness.

Reference

[1] http://www.infineon.com/drivecore

More information about Drive Core Graphics:

BLDC and DC motor controllers for safe automotive applications

More power in less space

Small motors are vital components in modern vehicle architectures – particularly for comfort and thermal management. New control solutions deliver space, safety and EMC advantages while supporting growing functional complexity.

By Martin Kurz,
Field Application Engineer ABU
at Rutronik

In modern-day vehicles, small electric drives perform a wide range of tasks – from cooling the battery and adjusting seats to controlling flaps and blowers (Fig. 1). The number of drives continues to grow steadily, especially in electrified architectures – where space is often limited. Brushless DC motors (BLDC) are becoming increasingly popular, as they take up less space, operate more efficiently and require less maintenance than conventional DC motors. At the same time, ever-more stringent requirements are being placed on functional safety, cybersecurity and electromagnetic compatibility (EMC). There is also a growing demand for compact, robust, and integrated control solutions that are economically viable both during the development stage and full-scale manufacture.

This is where the further developments of Infineon's MOTIX$^{\text{TM}}$ MCU series come to the fore, in particular the B6 bridge driver (TLE995x) and the H bridge driver (TLE994x). They are designed for use in an array of small to medium-sized motor applications in vehicles where compact design, cost efficiency and functional safety are top priorities.

Functional integration for decentralized control

A special area of application is the thermal management of electric and hybrid vehicles. Several smaller pumps and blowers are needed to regulate the temperature of the battery, power electronics and vehicle interior.

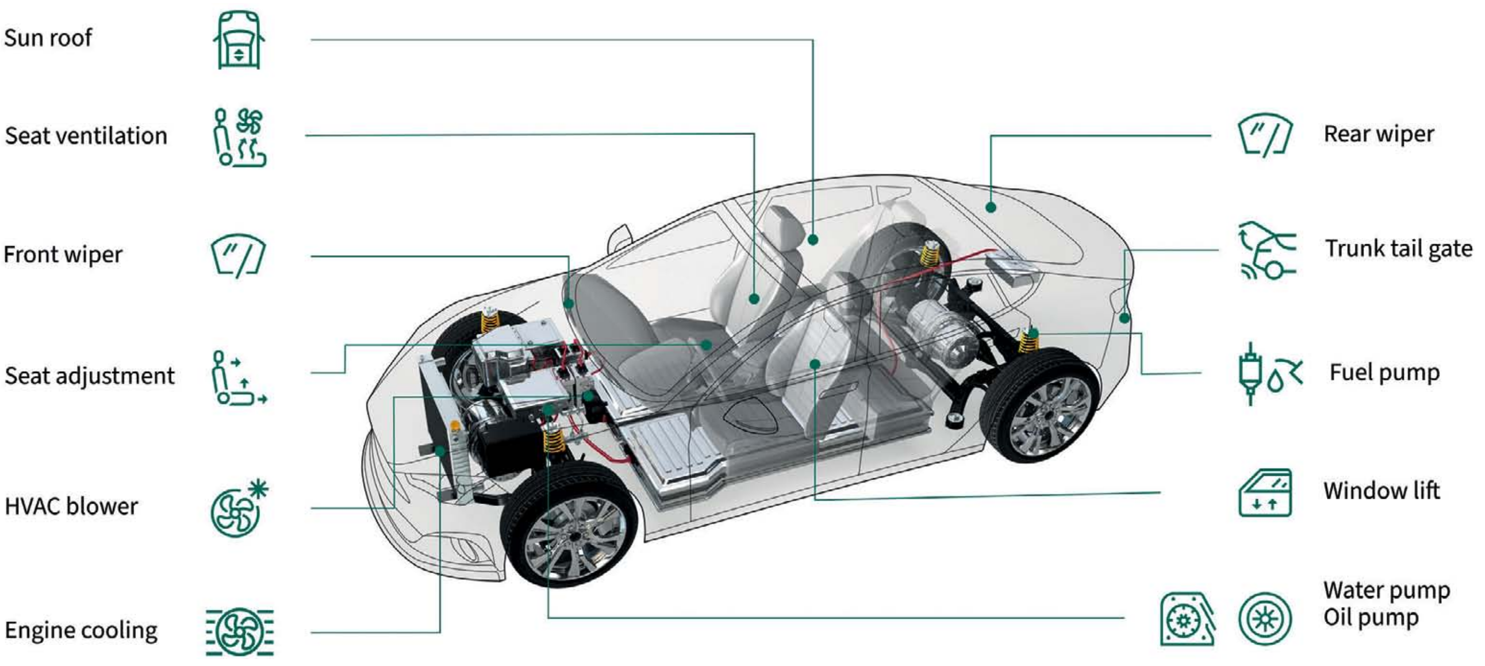

Figure 1: Typical applications for the Motix$^{\text{TM}}$ MCU motor controller in the automotive sector. (Source: Infineon)

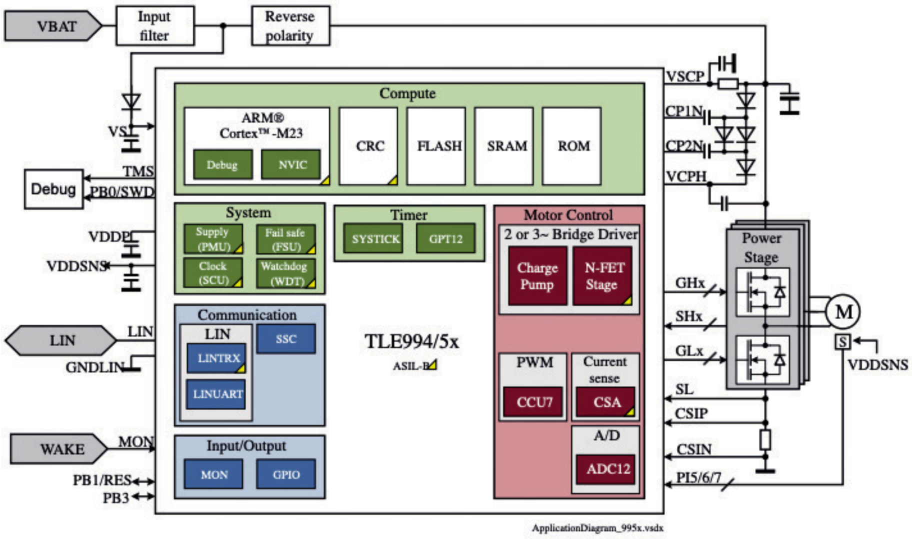

Figure 2: Block diagram of the TELE995x/4x controller.

These systems are typically installed in areas where space is limited, often close to heat sources or in humid environments. This demands compact, robust and reliable control units. The TLE995x series offers the ideal platform to meet these priority needs: Based on a 32-bit Arm Cortex-M23 core (40 MHz, 0.98 DMIPS/MHz, supported by 72 kB Flash and 6 kB RAM), it integrates not only the motor driver stage but also the power supply and a LIN communication interface in a TSDSO-32 package with good thermal properties and a footprint measuring just 6 mm × 9 mm (Fig. 2).

Comfort functions, such as electrically adjustable seats, window lifts, sun roofs and cargo bed covers, require cost-sensitive solutions that need to incorporate protection and diagnostic functions. This is the only way to ensure blockage detection, current limits or error communication via LIN.

The fully integrated LIN interface and diagnostic functions facilitate system integration into existing vehicle architectures. Despite its lower core power compared to the predecessor model (TLE987x), the TLE995x meets the high demands placed on modern motor controls. This is supported by efficient algorithms, such as field-oriented control (FoC) in dual-cycle operation, which are provided by software partners (Tab. 1).

Focus on safety functions

The primary innovation focuses on integrated safety and protective mechanisms. The architecture was developed in accordance with ISO 26262 and meets requirements up to ASIL B. The ARM core supports safe computing, thereby enabling the implementation of safe communication, and has a safety shutdown path for the output stage. When it comes to cybersecurity, ARM TrustZone technology is applied. It ensures that sensitive data and processes that are critical to system security are executed in a protected zone shielded from manipulation and unauthorized access.

Further properties:

- Peripherals for the motor control: The CCU7 Advanced Timer Unit supports symmetrical and asymmetrical PWM generation and is directly connected to the bridge driver. This driver features a three-step sequencer and a high-speed sequencer for VDS slope timing. As such, the rise and fall times can be set and controlled, for example. The dual-stage charge pump supports a 100% duty cycle and can switch on the reverse polarity protection FET.
- The current sense amplifier enables differential voltage measurements via an external shunt and is directly connected to the ADC. The voltage range can be adjusted, and the current sense amplifier offers a high level of accuracy and low gain drift. An overcurrent shutdown feature is also integrated.
- The controller delivers comprehensive diagnostic and protection functions, which are integrated into the MOTIX^{TM} 32-bit motor control system-on-chip. They include adjustable overvoltage and undervoltage detection and shutdown, overcurrent detection and shutdown for external MOSFETs and OFF-state open load detection.
- The 12-bit SAR ADC offers complex post-processing functions, such as averaging and thresholds, and can independently detect the back EMF and make it available internally.

System-in-package offers advantages to developers

The TLE9954QSW40-33 system-in-package solution is available for applications with higher power requirements. It combines the TLE9954 motor controller with six OptiMOS 7 MOSFETs in a single package, making it the first fully integrated 12 V automotive solution for motor applications up to approx. 150 W.

Direct integration of the power semiconductors with the bridge driver offers several technical advantages:

- Reduced line inductances between driver and MOSFETs cut switching losses and minimize downtime.

Characteristic	TLE987x	TLE995x
CPU	ARM Cortex-M3, 40 MHz	ARM Cortex-M23, 40 MHz
Memory	up to 128 kB Flash, 6 kB RAM	72 kB Flash, 6 kB RAM
Safety/Security	Basic functions	ISO 26262, ASIL B, TrustZone
Communication	LIN	LIN
Current measurement	integrated CSA + ADC	integrated CSA + ADC
Application	Generic BLDC control	Cost-optimized generic BLDC control for “low-end” applications with less complex requirements

Tabelle 1: TLE987x vs. TLE995x.

- Less EMC emissions, as the length of the conductor is minimized.
- Reduction of external components, especially for gate triggering and the protective design.
- More compact design, which enables the use of smaller control units.

The package measures 9.5 mm × 9.5 mm and is designed for applications in a power range up to approx. 150 W, depending on the general thermal conditions. The thermal connection of the SiP (system-in-package) in this highly integrated approach is crucial for the overall performance of the system.

Software and development support

An extensive software package is available for the TLE995x series. This includes ASPICE and MISRA-compliant components, peripheral drivers, sample applications and reference projects. Access is via the Infineon Developer Center. Commercial software solutions are available from partners for integration in applications. MOTEON and EONAS offer field-oriented control (FOC) algorithms and other motor control software. ihr GmbH provides a LIN stack optimized for the TLE995x. This tool and software support simplifies the development of robust control units that comply with relevant standards. The SiP variant TLE9954QSW40-33 is in the sampling phase, with initial test samples already being used by customers. Serial production is planned for mid-2026. The variants TLE995x and TLE994X have been in production since June. Appropriate design guidelines and reference PCBs are available for evaluation.

Looking to the future, it is to be assumed that requirements for functional safety, energy efficiency and networking will continue to rise. Infineon is, therefore, already planning to expand its portfolio to include industrial applications (IFX995x, IFX994x). The solutions are aimed at developers looking for space and cost-efficient small drive controls without compromising on safety, diagnostics and EMC. ■

Drive technology and urban mobility of the future

48 V systems for modern low-speed electric vehicles

Light electric vehicles (LEVs) are seen as a key element of sustainable urban mobility. Practical system voltages of 48 V enable the implementation of compact, efficient drive and charging solutions.

By Uwe Rahn,
Senior Director Automotive
Business Unit at Rutronik

Densely populated cities, limited traffic space and ambitious climate goals are driving the push for more sustainable transportation and mobility. In addition to emissions, factors like land use, noise pollution and quality of life are increasingly in focus.

Low-speed electric vehicles – also known as light electric vehicles (LEVs) – are considered a key technology in this context. They combine compact vehicle concepts with locally emission-free mobility.

If LEVs were to gain a significant share of private and commercial transport, they could make a substantial contribution to climate protection. Due to their low weight and limited maximum speed, they consume considerably less energy during operation. The resource requirements for their production are also lower than those of high-voltage topologies. [1]

Dynamic market for urban electric mobility

The market for LEVs offers strong global growth potential. Dynamic growth in distribution can be observed particularly in Asia, the ASEAN region, Latin America and Eastern Europe. Beyond private customers, LEVs are increasingly targeting urban commercial transport, for example for courier, express and parcel services or last-mile deliveries.

Current forecasts project the global LEV market to grow from USD 81.23 billion in 2022 to approximately USD 205.76 billion by 2032, reflecting an average annual growth rate of 9.74% over the forecast period. This growth is driven by advances in battery and drive technology, along with government incentives for sustainable mobility.

LEVs are easy to use, affordable and require minimal maintenance. This increases demand

and creates enormous growth opportunities for market players. LEVs occupy less traffic and parking space than conventional cars and can be flexibly integrated into existing mobility and logistics concepts. These properties make them a sustainable solution for urban areas with limited space, for example for short commutes, errands and other daily activities.

48 V systems for LEVs

In the low-speed electric vehicle segment, 48 V electrical systems have become a widely adopted practical standard. They enable compact and cost-efficient implementation of electric drive and charging systems without the complexity of conventional high-voltage technology. This provides an ideal balance of performance, safety and energy efficiency – particularly for L7e-class vehicles and smaller.

For applications such as electric scooters, compact commercial vehicles or last-mile delivery vehicles, 48 V systems reliably provide power up to approximately 15 kW. At the same time, the system architecture remains lean, benefiting both development and subsequent vehicle design.

Reference designs for charging and drive units

Rutronik is focusing on two practical reference designs for implementing efficient 48 V systems for low-speed electric vehicles: an on-board charger (OBC) and a universal traction inverter. Both designs target cost-efficient series applications in the urban mobility environment and allow developers to quickly begin functional validation.

48 V on-board charger (3.3 kW): The reference design (Fig. 1 and Fig. 2) is based on a half-bridge LLC resonant converter topology with an upstream PFC stage and is implemented entirely with silicon-based semiconductors. The choice of switching frequency and transformer was specifically tailored to achieve an optimal price-to-performance ratio.

Rectification on the input side is performed by a thyristor-controlled diode bridge, while Schottky diodes are used on the output side. The resonance circuit components – especially the RF transformer and power modules used – are precisely matched to each other, thereby ensuring high efficiency of the overall circuit. The design supports communication in accordance with the CCS standard, making it suitable for use in modern wall charging stations. The goal is to deliver a cost-effective solution for 48 V charging applications in LEVs that is both functional and cost optimized.

Figure 1: Micromobility vehicle from Rutronik's Automotive Business Unit. (Source: Rutronik)

48 V traction inverter (10 kW continuous power/15 kW peak power): The universal traction inverter (Fig. 3 and Fig. 4) is designed for continuous currents up to 350 A (or 600 A for 60 s). With its CAN interface and analog and digital I/Os, the system can be controlled flexibly. All electronics are located on a compact PCB featuring state-of-the-art MOSFETs and a top-side cooling concept. Therefore, the MOSFETs do not need to be cooled by the PCB but can be connected directly to a heat sink, such as the base plate, using a thermal interface material (TIM).

The thermal resistance between the MOSFET package and the base plate is thus lower than with heat dissipation through the PCB. This contributes to the thermal performance and high power density of the overall system. The single PCB design reduces the complexity of the overall system. This eliminates the need for error-prone connectors between PCBs. Potential target applications include electric powertrains in L7e-class low-speed electric vehicles, such as golf carts, LEV scooters and light urban transport vehicles.

The two reference designs not only demonstrate the technical feasibility of the topologies but also serve as guidance for selecting suitable power semiconductors, components and system architectures. Automotive developers benefit from complete bills of materials (BOMs), circuit diagrams and thermomechanical concepts, all available through Rutronik's technical sales department. This reduces development time and significantly speeds up the time-to-market for new mobility solutions.

Rutronik Automotive

Rutronik's Automotive Business Unit (ABU) is a dedicated business segment of Rutronik specializing in the automotive sector. It collaborates with specially selected suppliers from this field. In this role, ABU serves as a consultant and interface for electronic component suppliers, Tier 1 companies and OEMs.

The primary goal of the ABU team is to anticipate the future challenges facing customers and to provide them with relevant information, component recommendations and reference topologies.

A key part of showcasing the reference designs in recent months has been ABU's presence at trade fairs and its contributions to presentations and panel discussions at trade fairs and congresses such as Future Mobility Asia, ASEAN Automotive Supply Chain in Thailand and electronica India in Bangalore. Furthermore, Rutronik's experts also provide advice on the functionality and performance characteristics of the 48 V reference designs, with a particular focus on regions that show great promise for this technology, such as Asia, India and EMEA.

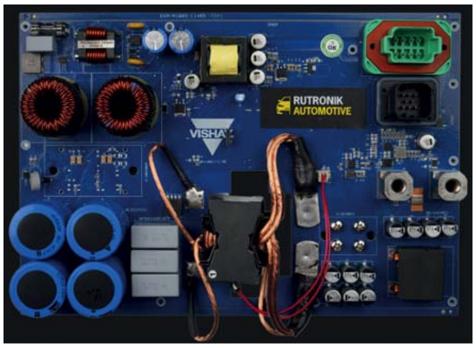

Figure 2: Prototype of the unidirectional on-board charger.

Collaboration with prospects

The shift toward electric mobility is creating new technological, geopolitical and economic challenges for suppliers, subcontractors and system partners worldwide. Especially in times of global uncertainty, strategic alliances, market-driven product approaches and reliable supply chains are crucial for developing sustainable micromobility solutions.

Against this backdrop, the close partnership between Rutronik and Vishay takes on a particularly important role. Ever since the establishment of the Automotive Business Unit in 2014, Vishay, as a key supplier, has been closely involved in developments, especially in developing 48 V system solutions for light electric vehicles.

One example of this successful collaboration is the joint development of the efficiency-optimized reference designs for charging and drive units in the 48 V range presented here. These solutions enable urban mobility requirements to be addressed with technically mature, practical and economically viable systems.

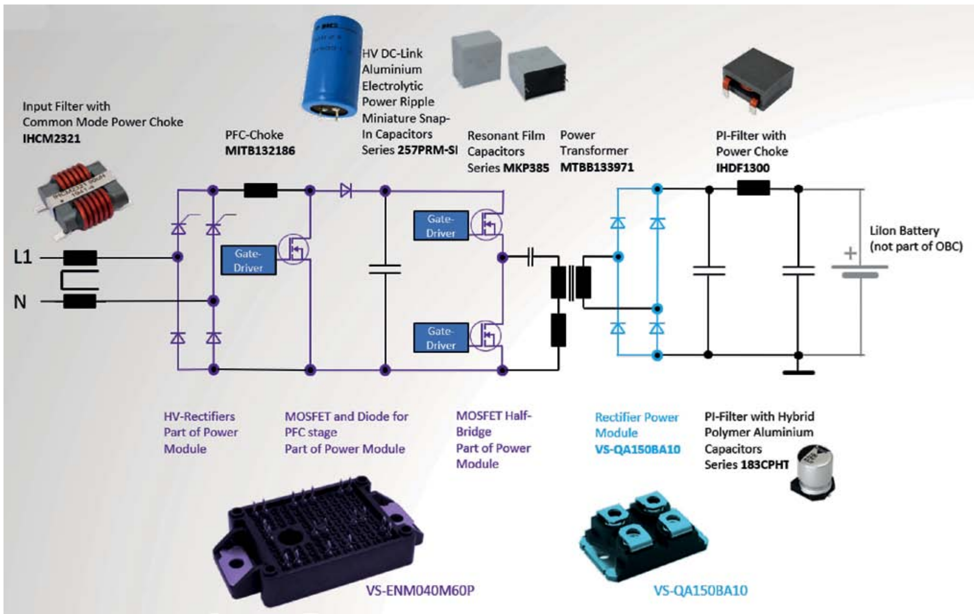

Figure 3: Key components from Vishay were used for the reference design of the on-board charger.

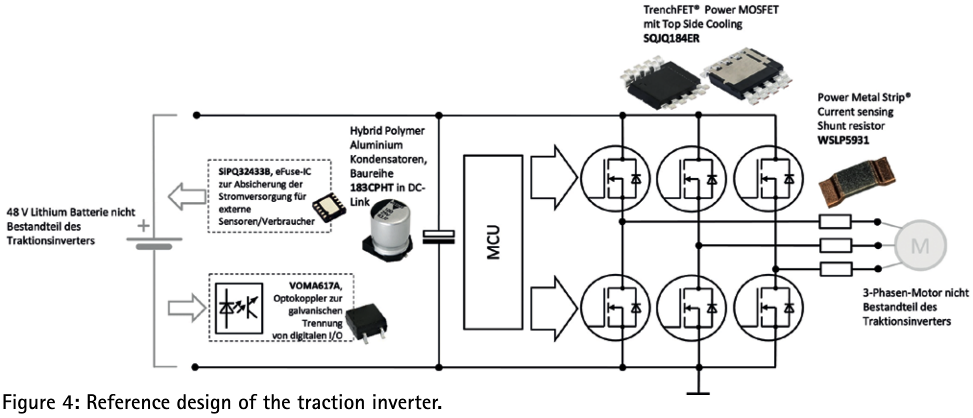

Figure 4: Reference design of the traction inverter.

Reference
[1] https://www.e-mobilbw.de/fileadmin/media/e-mobilbw/Publikationen/Studien/LEV_e-mobil_BW_Leichtfahrzeug_Studie.pdf

Additional information on 48 V micromobility and the corresponding Rutronik ABU reference designs is available here.

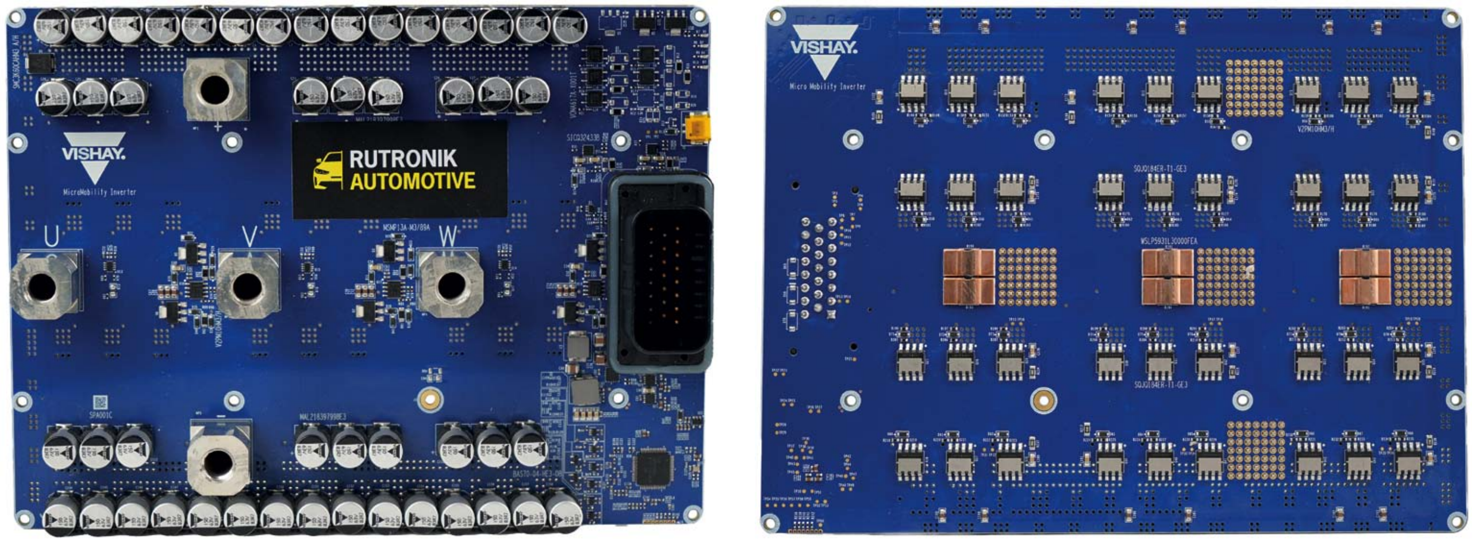

Figure 5: Prototype of the traction.

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