E-zeroBatteryZone® -
Battery-Free IoT Network Nodes Powered by Indoor Lighting Energy

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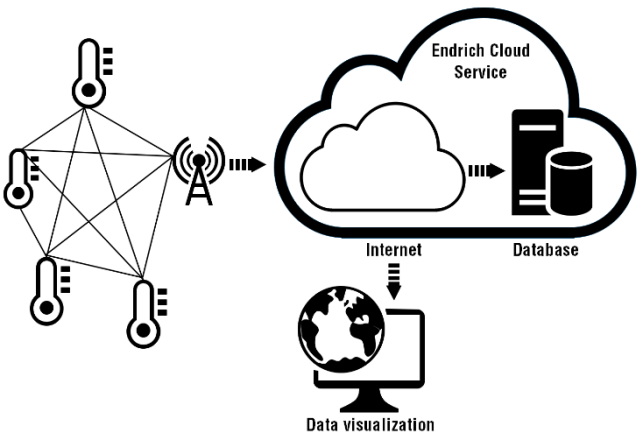
This year, we continue to showcase the smart IoT devices, systems, and state-of-the-art technologies developed by Endrich and its collaborative partners. In this paper we are excited to report on a significant innovation: we have developed — and will be presenting at the Nuremberg EmbeddedWorld 2025 exhibition — a concept for a family of smart sensors that distinguishes itself from competitors not only through its ultra-slim design and compact dimensions, but also through its array of advanced technological solutions.
Believing strongly in the power of collaboration, our development engineers at Endrich have envisioned a product family that was realized through a project characterized by genuine pan-European cooperation with the support of our international partners. The newly developed E-zeroBatteryZone® wireless smart sensors integrate seamlessly into the E-IoT ecosystem, working in perfect harmony with both their battery-powered counterparts and conventional E-IoT Internet gateways, all powered solely by energy harvesting — eliminating the need for batteries.
Endrich's innovation is further bolstered by key components, including the low-power radio module from Denmark's NeoCortec — an integral part of the project from its inception — the specially engineered, hairline-thin, environmentally friendly supercapacitor from Sweden's Ligna Energy, and the unique organic photovoltaic modules (OPV) from France's Dracula Technologies, which are capable of harvesting light energy even under low indoor illumination. These elements combine to make the system both effective and sustainable.

Low-Power Wireless IoT Sensor Networks – Supported by the NeoCortec WLAN Solution



When a relatively large number of smart sensors need to be deployed in a concentrated area and their data is to be offloaded to an Internet cloud service from a single point, an ad-hoc local sensor network solution comprising low-power nodes is typically employed. For example, the NeoCortec NeoMesh wireless radio protocol can be utilized.

A large number of intelligent sensors can be connected to a local network with ultra-low power consumption, where a single data concentrator/gateway with Internet connectivity is responsible for delivering the data to a Cloud database via the mobile network—using cellular protocols such as LTE-M or NB-IoT.

Our engineering team has developed a modular sensor network infrastructure—described in detail within the paper's columns—that offers multipoint-to-point wireless communication through a local mesh network and provides single-point Internet access to the cloud via the LPLAN-LPWAN gateway.

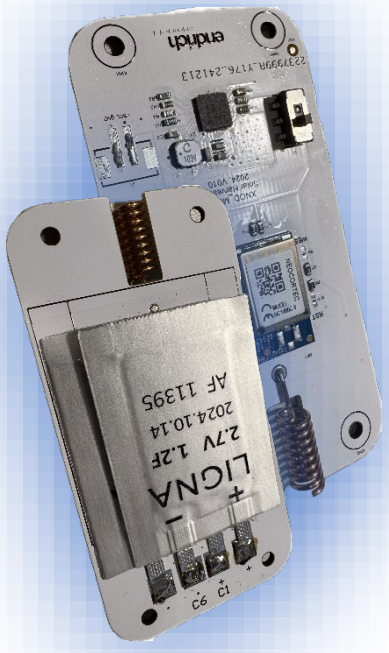
Utilizing the complete E-IoT ecosystem, which comprises the aforementioned intelligent sensor networks, the Cloud database, and the visualization and data processing system, our company can offer an effective solution to transform traditional devices into interconnected "SMART" devices, thereby supporting functions such as predictive maintenance.

NeoMesh: A Paradigm Shift in Wireless Mesh Networking

NeoMesh—the wireless mesh networking protocol we employ—represents a paradigm shift compared to traditional network architectures. Unlike conventional solutions that regulate inter-node communication via a central network

controller, this protocol utilizes autonomous intelligent nodes. Each node operates as an independent entity, facilitating direct communication between nodes without centralized authorization. The result is a unified network that functions seamlessly, regardless of its scale or complexity.

As more and more nodes seamlessly join the network, they connect in an ad-hoc manner to existing nodes, forming an extensive, interconnected communication network. This adaptability and scalability are particularly valuable when extending the E-IoT platform to areas requiring coverage by hundreds or even thousands of sensors.



One of the most impressive features of the protocol is its patented routing mechanism. This mechanism ensures that data flows smoothly across the network even when obstacles exist on the radio frequency path or when nodes are in motion within the network. Traditional networks often face performance issues when nodes are blocked or dynamically change positions. However, the NeoMesh Networking Protocol eliminates these concerns and guarantees reliable data transmission. In essence, the network's performance remains unaffected by environmental factors or dynamic changes within the network structure. Whether nodes are added, removed, or relocated, the network stays robust and fully operational, ensuring uninterrupted connectivity for all devices and users. Notably, the protocol can address the weak points of real-world networks; adding an extra node with the proper network identifier results in a seamless integration into the existing network, thereby extending coverage and enhancing overall performance.

An **Integrated Security and Extended Range**

At the heart of NeoMesh technology lies a robust protocol suite featuring integrated security and reliability functions. A key component of this security package is the encryption of wireless communication between nodes using AES128. By employing this encryption, both the valuable data and network communications remain impervious and unobservable to unauthorized entities.

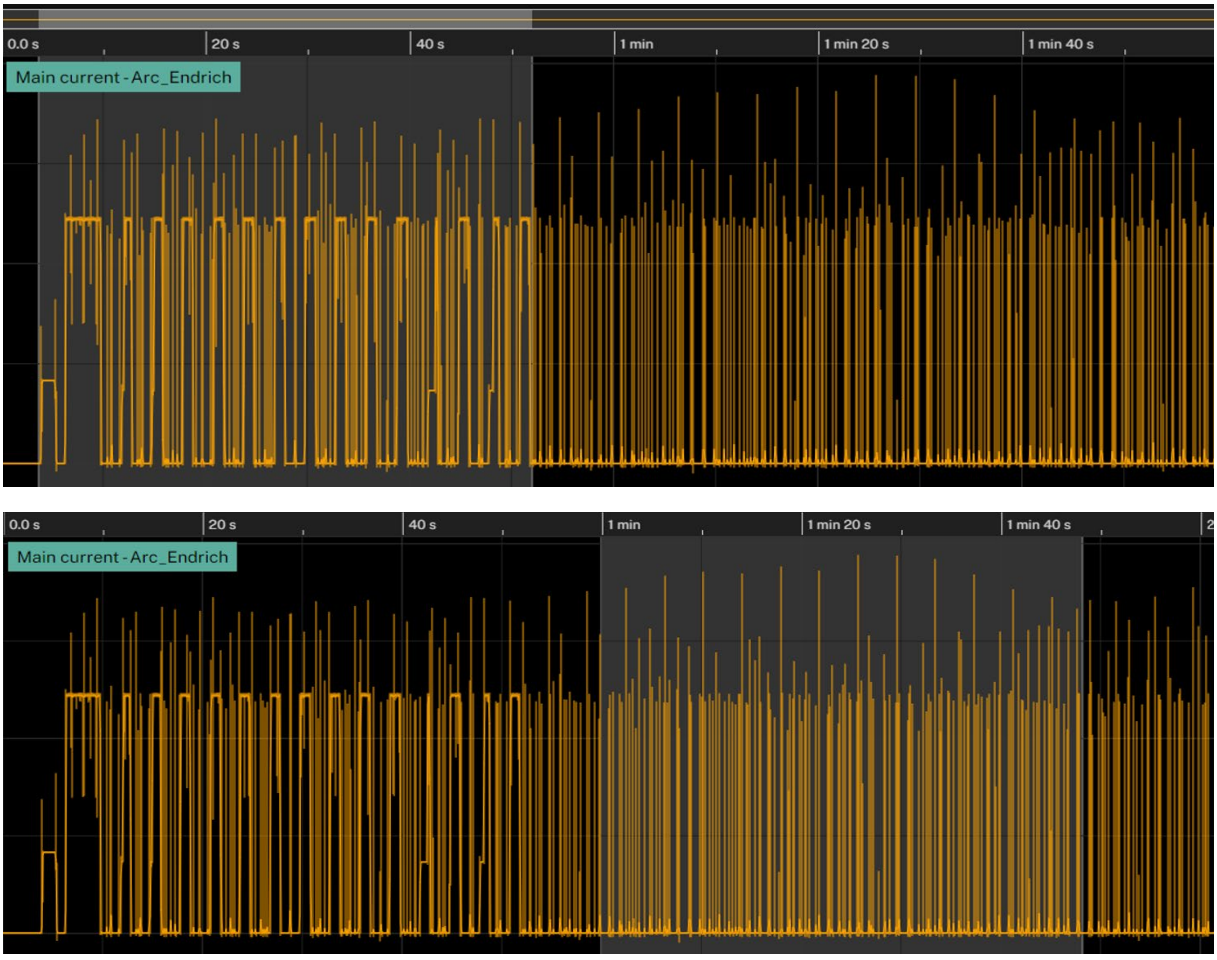
The E-IoT system operates at sub-gigahertz frequencies with the Neo-Mesh local sensor network extension to overcome challenges faced by competing protocols in harsh industrial environments. When comparing a sub-GHz network to WiFi and Bluetooth—using the same antenna and transmission power—it becomes clear that sub-GHz networks offer greater range. This extended range is due to the fact that lower radio frequency waves are not as readily absorbed by physical materials as the 2.4 GHz signals used in WiFi and Bluetooth.

These capabilities of the NeoMesh protocol provide an ideal solution for intelligent sensors deployed in large industrial complexes such as factories, buildings, properties, and retail stores.

The system has been optimized for long-term battery operation. Its energy consumption is extremely low, allowing batteries to last for several years. The NeoMesh network employs a time-synchronized protocol in which each node

spends the majority of its time in a sleep state. This architectural approach ensures a highly predictable energy consumption pattern for every node in the network. As a result, all nodes consume nearly identical amounts of energy, enabling each network node to operate effectively for many years.

Although the nodes draw significantly higher power during the first few tens of seconds after startup, once they are synchronized within the network, the average consumption drops to the order of a few tens of microamperes (μA).

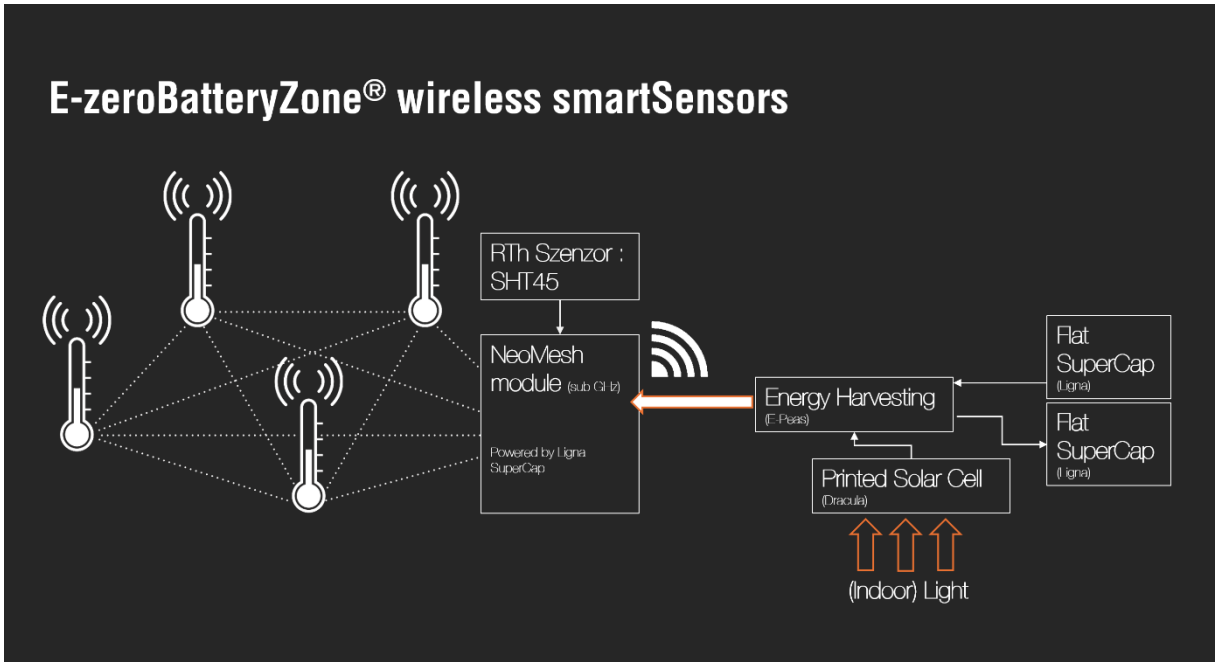


These solutions have been fundamentally designed for long-term, multi-year operation powered by batteries, providing a satisfactory approach in terms of both sustainability and operation for most industrial applications. However, the question arises as to whether it is possible to develop a sensor node that, by eliminating battery replacement and the associated operational costs and by utilizing available ambient energy, can operate practically indefinitely. Naturally, this would require optimizing the number of sensors and eliminating all other power consumers—that is, a thorough energy audit and reduction.

Furthermore, in industrial environments we primarily rely on energy harvested from indoor lighting, and we must ensure its collection, temporary storage, and, if necessary, rapid delivery into the circuit—primarily to the communication module—while leaving the smallest possible environmental footprint.

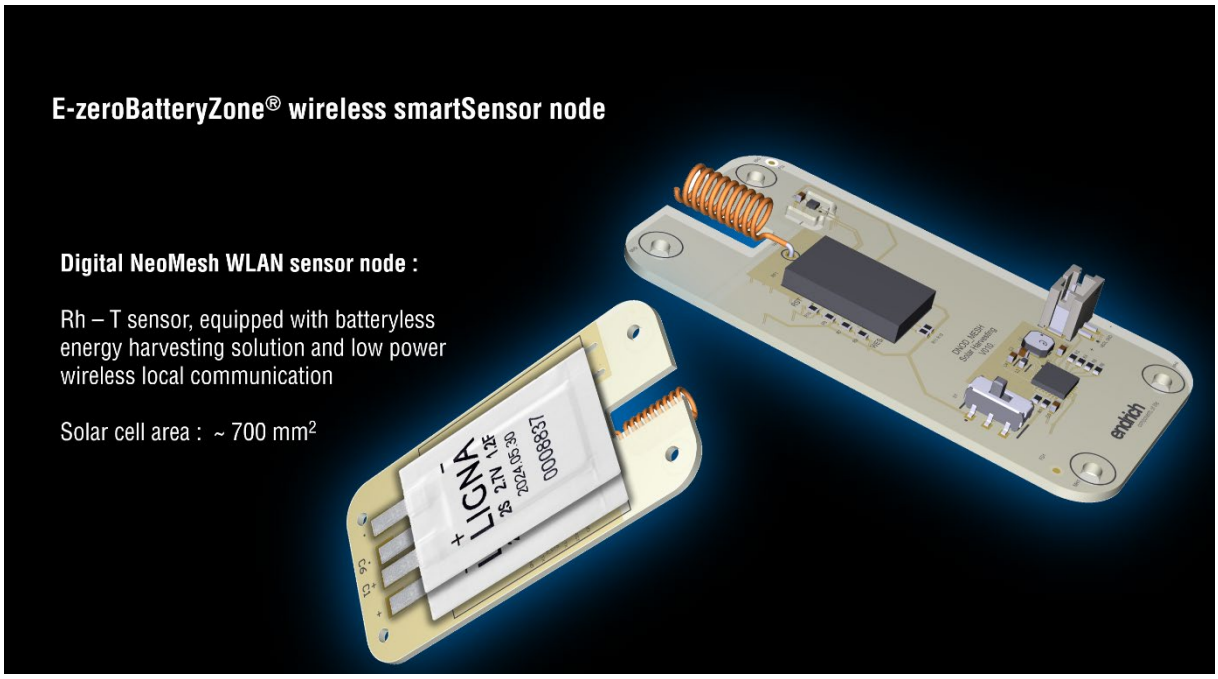
In the case of the E-zeroBatteryZone® wireless smart sensors integrated into the E-IoT system, we aimed to use photovoltaic cells that are capable of generating energy indoors even under low illumination levels. Energy harvesting is managed by an integrated circuit available on the commercial market, and the innovative special energy storage is entrusted to supercapacitors whose geometric dimensions allow for the design of ultra-thin smart sensors made from environmentally friendly materials.

The block diagram of the system is detailed in the following figure.



The node architecture is very similar whether using various low-power analog or digital sensors. It consists of a sensor—connected either to an ADC pin or an I2C channel of the NeoCortec communication module's internal ARM Cortex M0+ microcontroller—and an energy harvesting unit. The latter primarily comprises a photovoltaic cell capable of operating under low indoor illumination, the energy harvesting IC, and specialized supercapacitor cells.

The light energy utilization efficiency of the employed photovoltaic cell is such that even at 200 lux, a maximum charging current of over 20 µA is available. Since the supercapacitors used have a terminal voltage of 2V, two of these devices are connected in series, enabling them to rapidly discharge the stored energy when the communication device is activated.



About LIGNA Supercapacitors

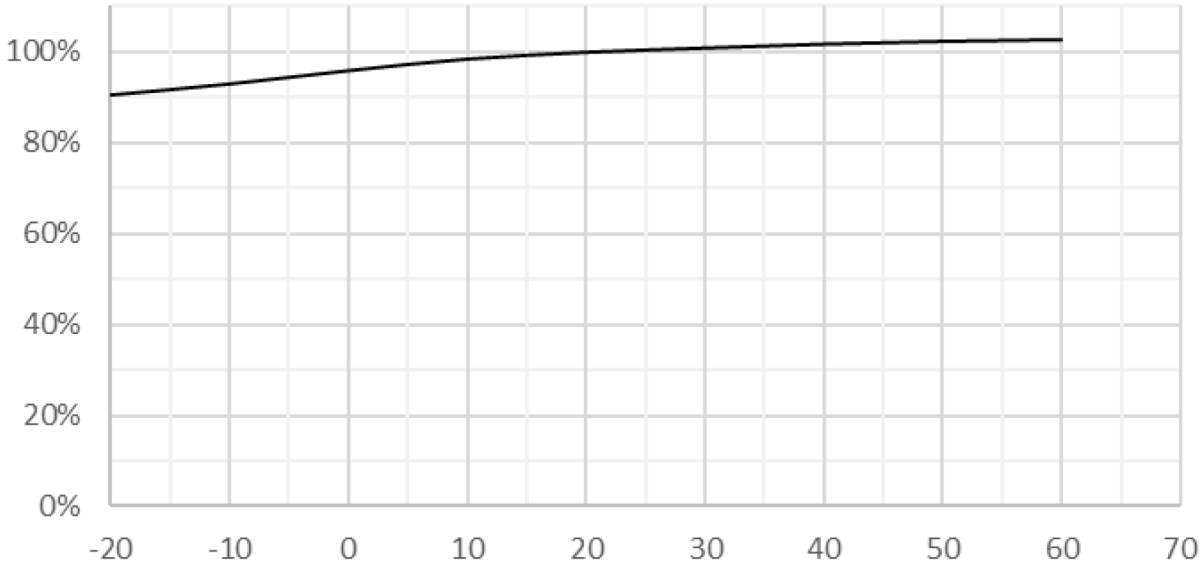
A supercapacitor, also known as an ultracapacitor or electric double-layer capacitor (EDLC), is an energy storage device that bridges the gap between traditional capacitors and batteries. Unlike batteries, which store energy chemically, supercapacitors store energy electrostatically. This enables rapid charging, making them ideal for applications that require swift energy replenishment. However, their energy density is typically lower than that of batteries, limiting their long-term energy storage use.

LIGNA supercapacitors have been developed to meet the growing demand for sustainable energy storage in wireless electronics. They offer the same benefits as conventional supercapacitors but with enhanced safety and a reduced environmental footprint—in a compact form factor. The S-Power series has been designed to integrate seamlessly with energy harvesters, providing an eco-friendly supercapacitor solution for wireless electronics. Thanks to their excellent cyclic endurance and performance capacity, they are well suited for applications that require repeated rapid discharge and charging.

Features:

- EDLC/Supercapacitor
- Non-toxic and environmentally friendly
- Compact and thin
- Low leakage current
- Can be mounted on curved surfaces

Within the operating temperature range of -20 °C to 60 °C, the LIGNA supercapacitor maintains its capacity—similar to that at 20 °C—with only about a 10% loss even at negative temperatures.



The device is characterized by a capacitance of 1.2 F and a terminal voltage of 2.7 V. It stands out not only for its impressively small mechanical dimensions (0.6 g weight, <0.5 mm thickness) but also for its flexibility, making it an ideal energy storage solution for our E-zeroBatteryZone devices.

Dracula Technologies' Indoor Organic Photovoltaic Modules

Dracula Technologies harvests the light emitted by backlighting to generate energy using special, highly efficient organic materials that absorb both natural and artificial light. Even under low-light conditions, their OPV devices achieve high energy conversion efficiency. Hence, the company's name is quite fitting—just as Count Dracula is an exemplary vampire, the solar panel brand bearing his name performs reliably even in the poor lighting conditions of dawn.

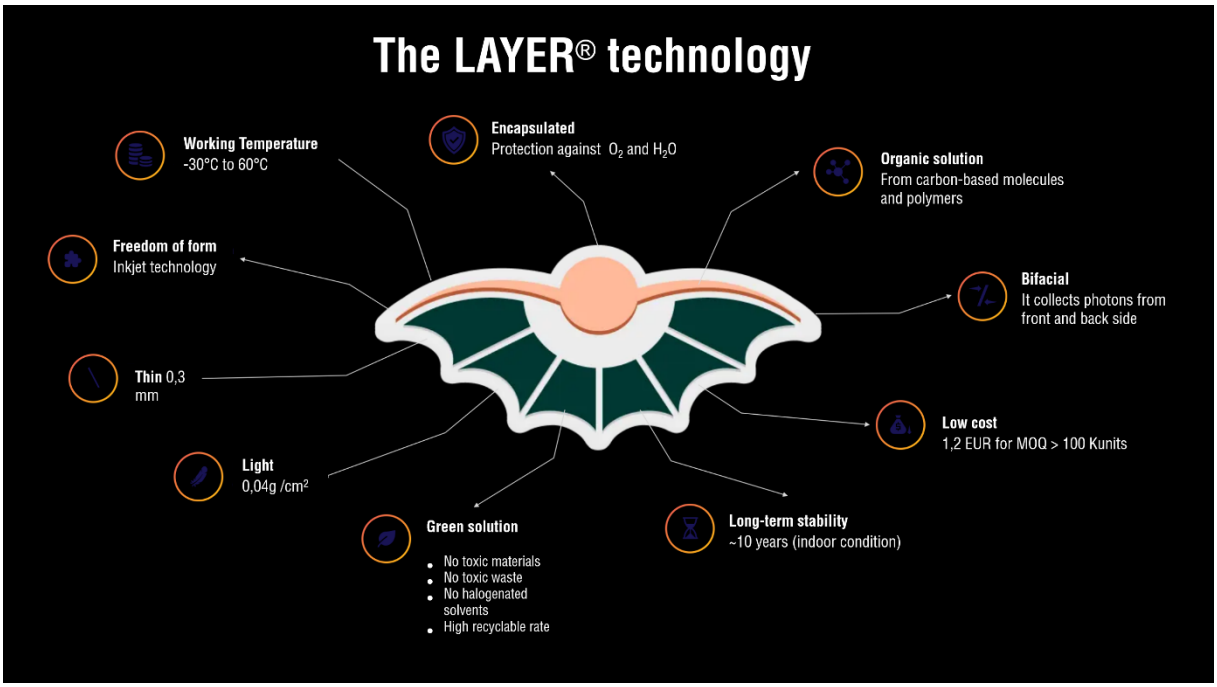


Image source: https://dracula-technologies.com/products/

In addition to the above NeoMesh-based device, the E-zeroBatteryZone® product family will soon be expanded with a new member: the LoRaMesh-based sensor module, which implements a version of the NeoMesh protocol adapted for LoRa modulation. At Endrich, we are delighted to complement our E-IoT sensor family with such a versatile, wide-reaching local wireless networking solution powered by energy harvesting and entirely battery-free technology. We will report on this device soon; in the meantime, we warmly invite our esteemed readers to visit our stand at the EmbeddedWorld25 exhibition in Nuremberg, where we will also have a few complimentary copies of the book on Endrich's "E-IoT" concept, published at the end of last year.