

SYSTEMATISCHE ENTWICKLUNG VON ENERGIEAUTARKEN SENSORLÖSUNGEN FÜR SCHWIERIGE INDUSTRIELLE UMGEBUNGEN

*AM BEISPIEL DER TEMPERATURMESSUNG IN
HOCHSPANNUNGSANWENDUNGEN DER ANTRIEBSTECHNIK*



SiME-Congress

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- 1.2 IIoT – Increasing Connectivity of Systems – Energy Demand & Power Supply

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- 2.2 Conversion Principles for Energy Harvesting
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4. Application Example: Temperature Measurement under High Voltage

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- 4.3 Temperature Measurement on 3 Phases 800V@1000A

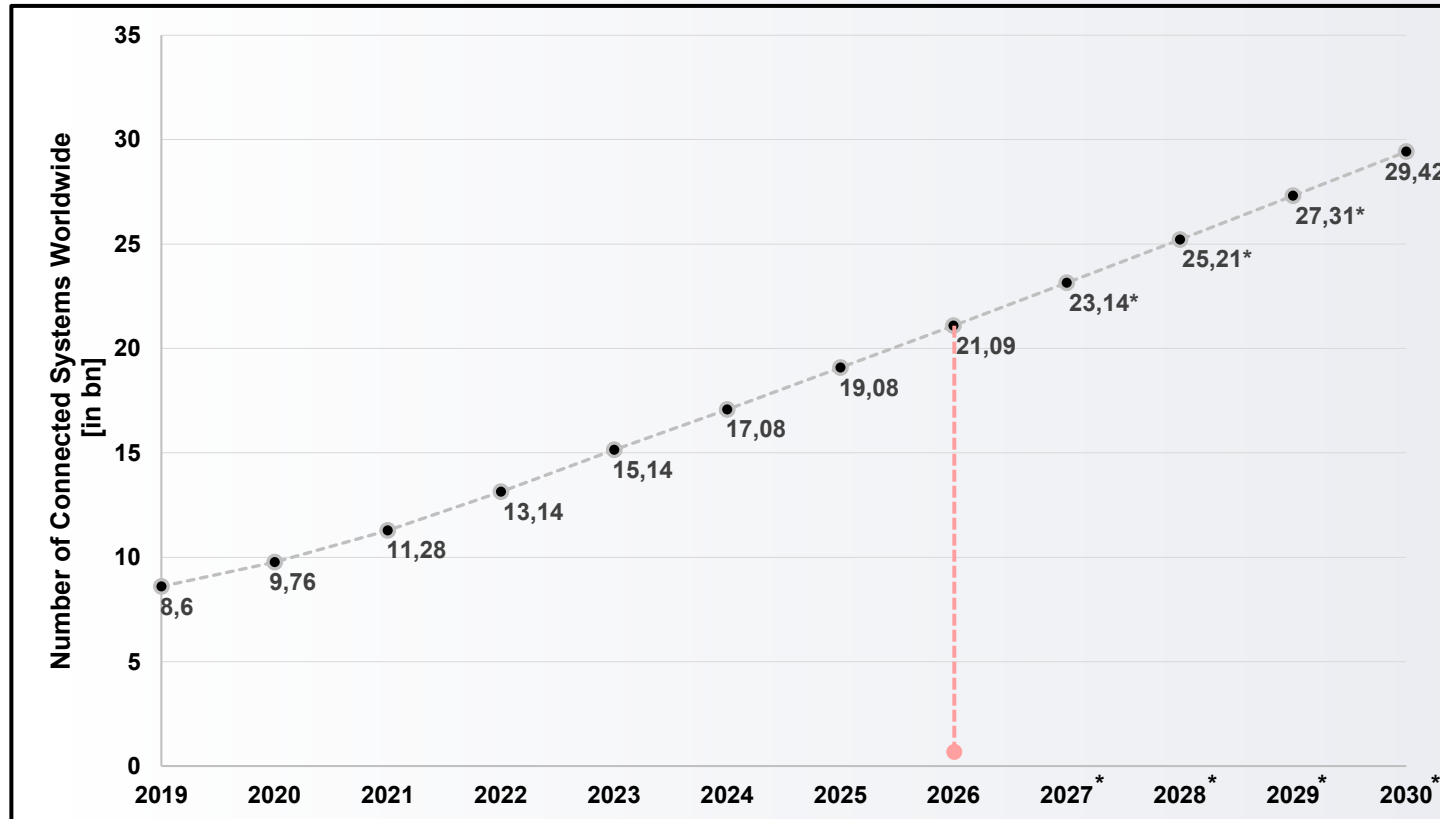
5. Summary and Outlook

PROBLEM STATEMENT AND MOTIVATION

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1. Problem Statement and Motivation

1.1 IIoT – Increasing Connectivity of Systems – Introduction



Source: based on Statista
Number of Internet of Things (IoT) connected devices worldwide from 2019 to 2030

- The digitalization of machines and plants is the key prerequisite for implementing Industry 4.0
- Simple machines and plants are evolving into cyber-physical systems
- Wireless communication for sensor data, control, and tracking is becoming increasingly important
- **IIoT devices are considered key to end-to-end digitalization**
- By 2030, the number of connected systems worldwide is estimated at approx. 30 billion

1. Problem Statement and Motivation

1.2 IIoT – Increasing Connectivity of Systems – Energy Demand & Power Supply

Used in:

- Healthcare, retail, manufacturing, agriculture, smart cities, transport & logistics, energy and utilities

Advantages:

- Automation and networking of processes
- Localization
- Monitoring of a wide range of parameters
 - Temperatures
 - Condition
 - Fill level etc...
- Networking/monitoring of systems in hard-to-access areas

Disadvantages:

- Battery-based power supply is expensive and limits possible uses
- Battery replacement temporarily interrupts operation

Corresponding operating times of the ESP32 with a CR123A battery:

- Lithium Metal
- 3 V at 1600 mAh
- Ø 17 mm, 34.5 mm, 16 g
- Maximum continuous discharge 1000 mA



Source: reichelt elektronik

Sampling Rate	1 x per day	1 x per hour	1 x per minute	1 x per second
Energy Demand	133 mJ	11 J	502 J	30 kJ



Wireless IIoT devices require a continuous and autonomous power supply

TECHNOLOGY FIELD: ENERGY HARVESTING

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2. Technology Field - Energy Harvesting

2.1 Energy Harvesting Fundamentals - What Is Energy Harvesting?

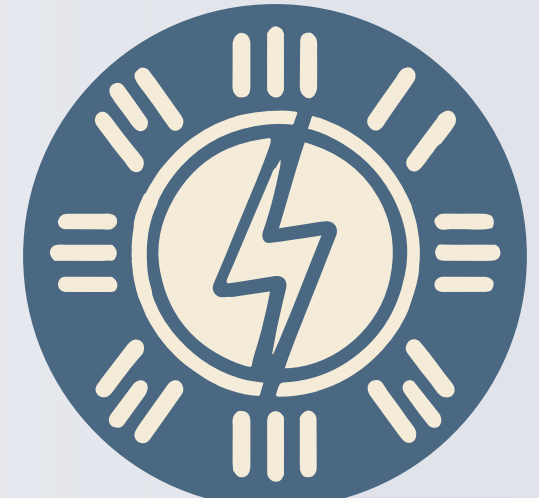
Energy harvesting describes the generation and local use of electrical energy from freely available ambient sources



Environment



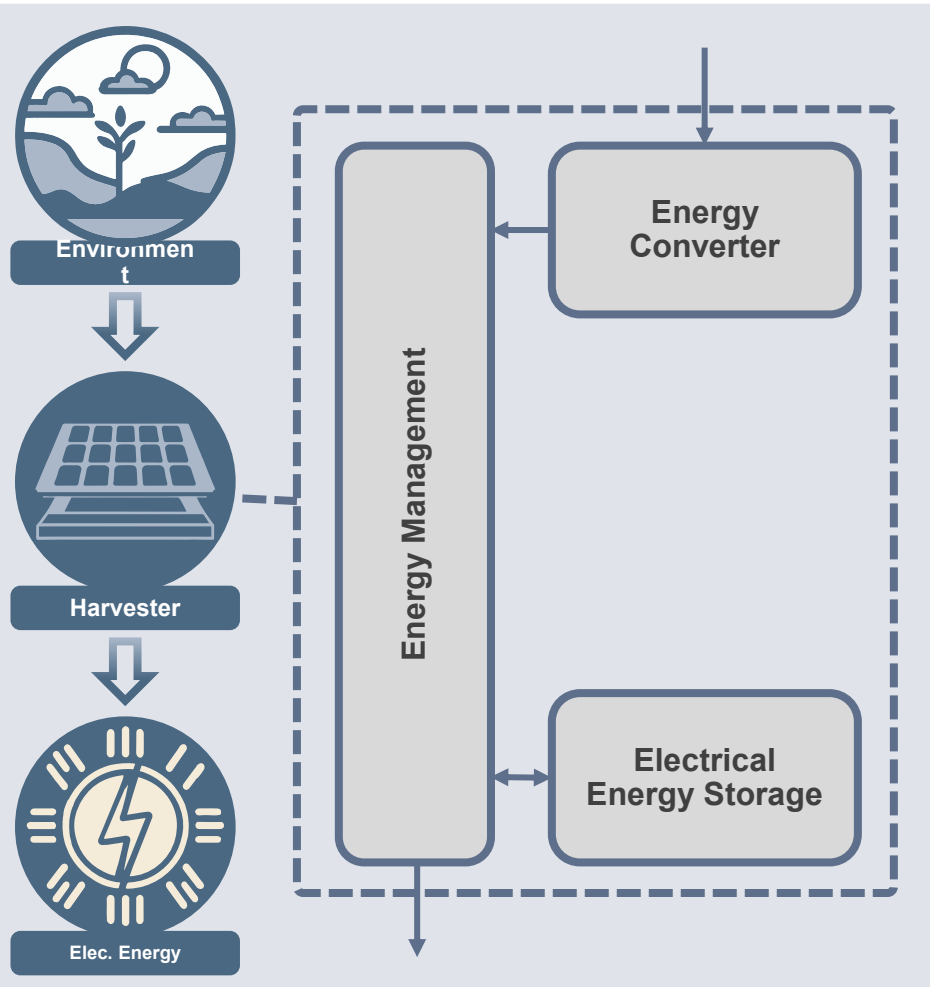
Harvester



Elec. Energy

2. Technology Field - Energy Harvesting

2.1 Energy Harvesting Fundamentals - Basic Structure of an Energy Harvesting System



Energy Converter

The energy converter is often also referred to as an energy harvester, as it converts ambient energy into electrical energy. Energy conversion is based on various physical effects, such as the photoelectric effect. Depending on the application, the energy converter can be arbitrarily complex, e.g., it can consist of different motion-conversion mechanisms.

Energy Management

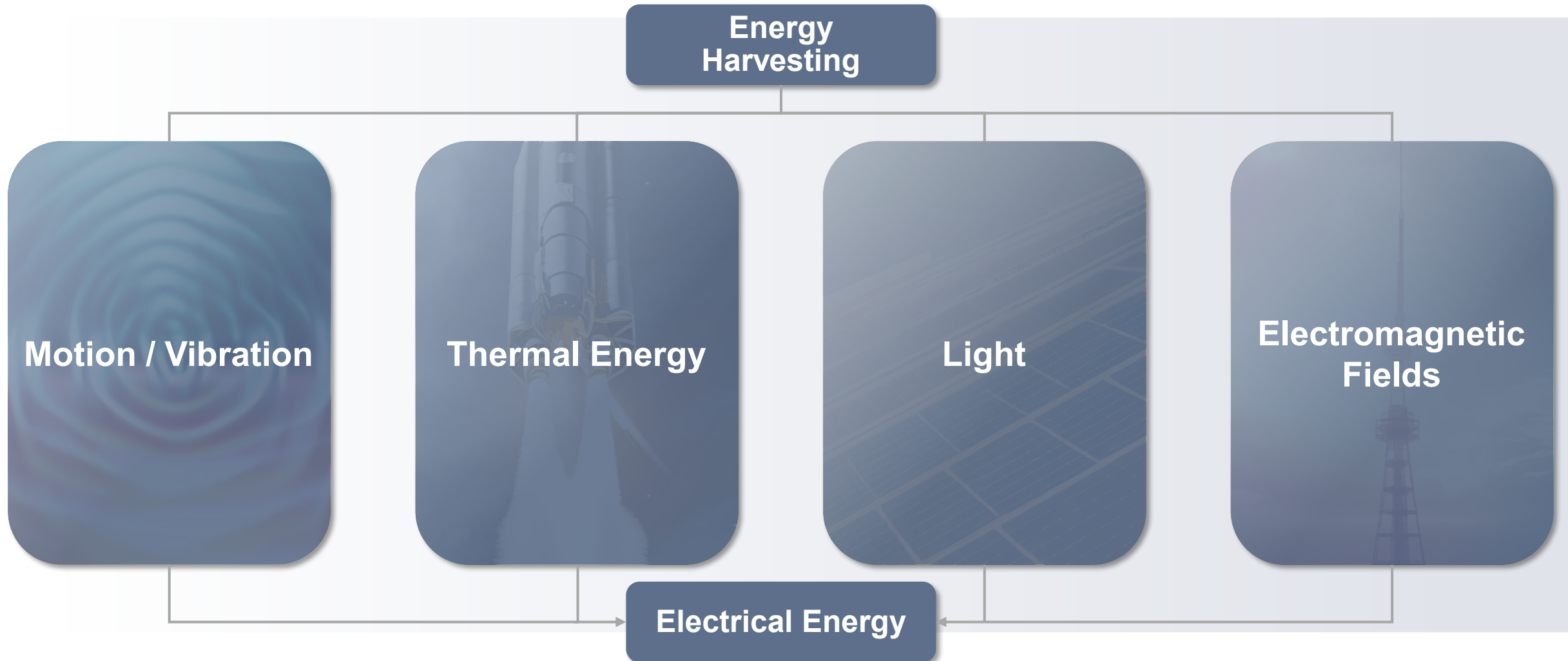
Energy management determines how the harvested energy is used, e.g., converting the energy converter input into output energy usable by the system through level adjustment and conversion for pulsed energy input. It also ensures reliable energy supply to the powered system, e.g., through external energy storage that can be accessed as needed.

Electrical Energy Storage

The energy harvested by the harvesters can be used immediately after conversion. However, fluctuating ambient input energy may cause the powered devices to fail; therefore, some solutions require storage of the harvested energy to enable reliable operation even when the ambient energy yield is low.

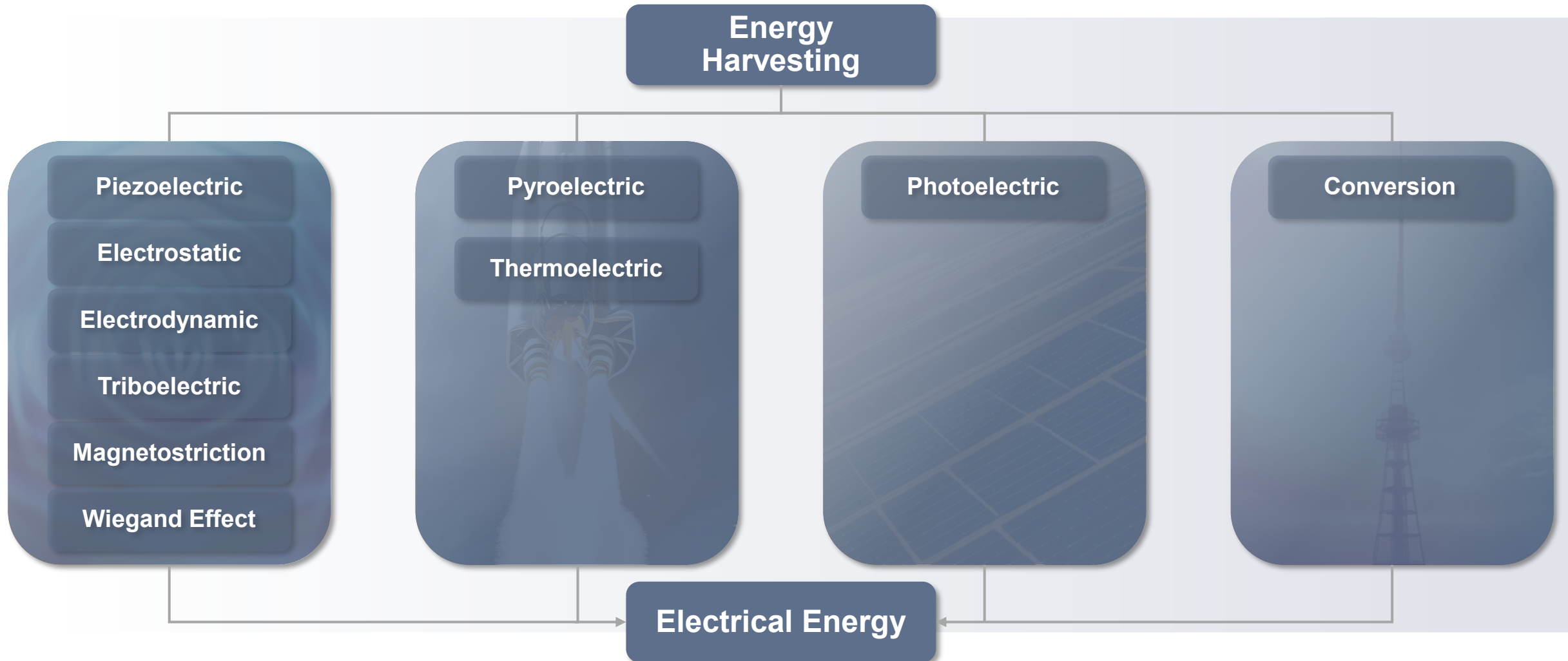
2. Technology Field - Energy Harvesting

2.2 Conversion Principles for Energy Harvesting



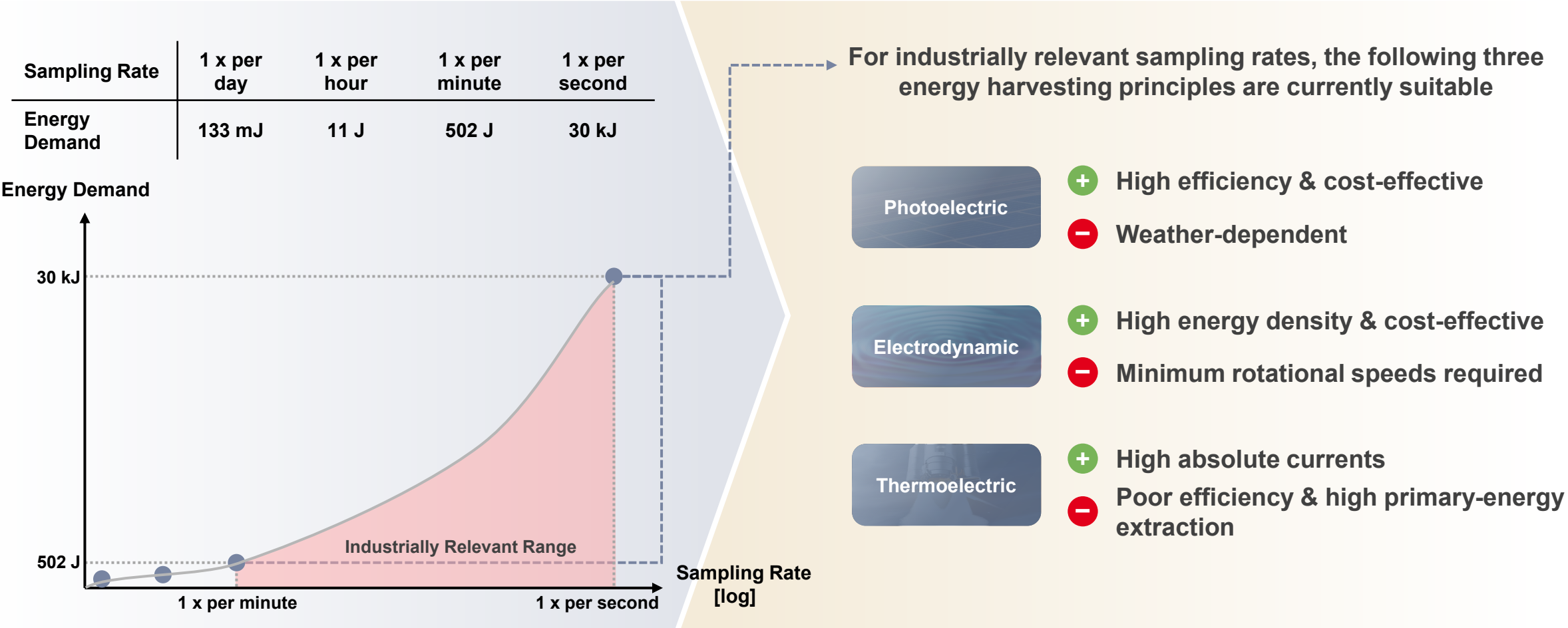
2. Technology Field - Energy Harvesting

2.2 Conversion Principles for Energy Harvesting



2. Technology Field - Energy Harvesting

2.3 Suitability for Industrial Sensor Applications



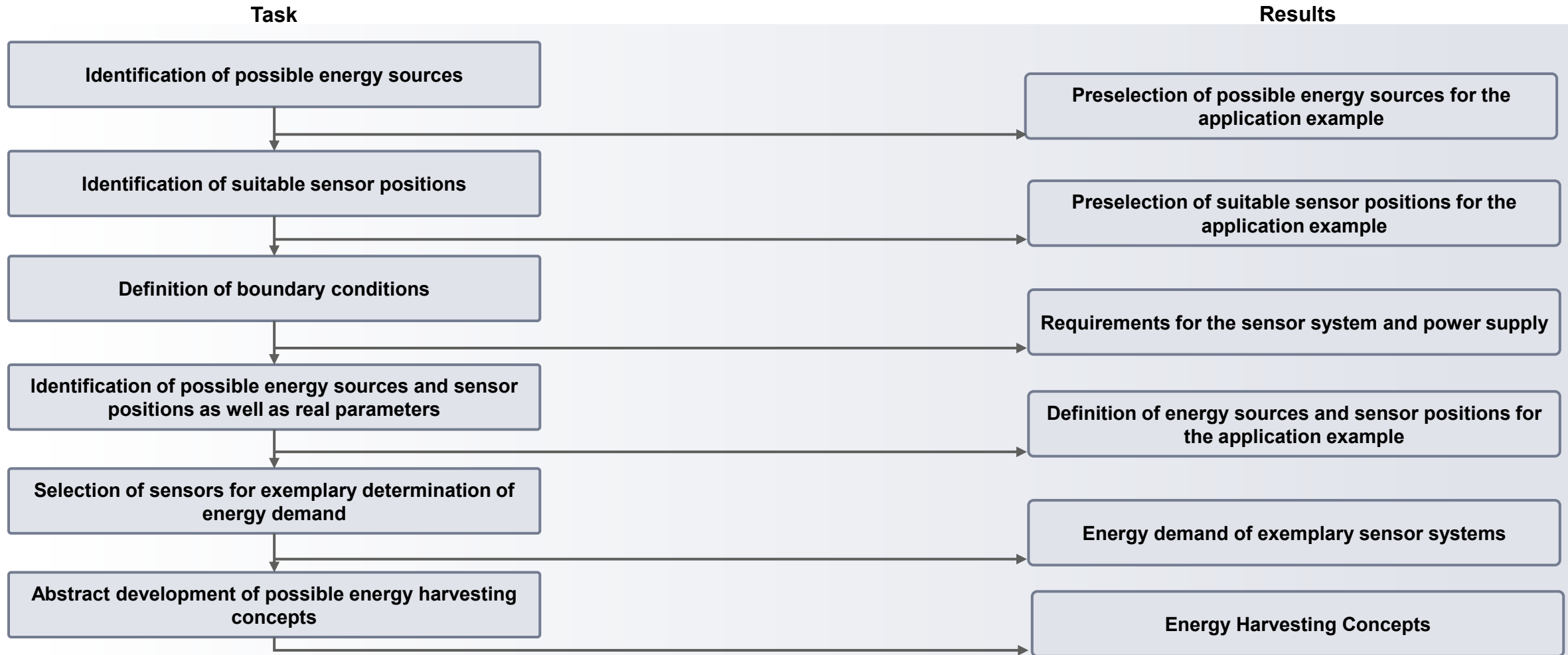
[Energy demand of typical IIoT sensors and their supply via energy harvesting, Mager T., EASS 2024, Dortmund]

METHODOLOGY FOR DEVELOPING EH SENSOR SYSTEMS

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3. Methodology for Developing Energy Harvesting Sensor Systems

Phase-milestone diagram for existing application case

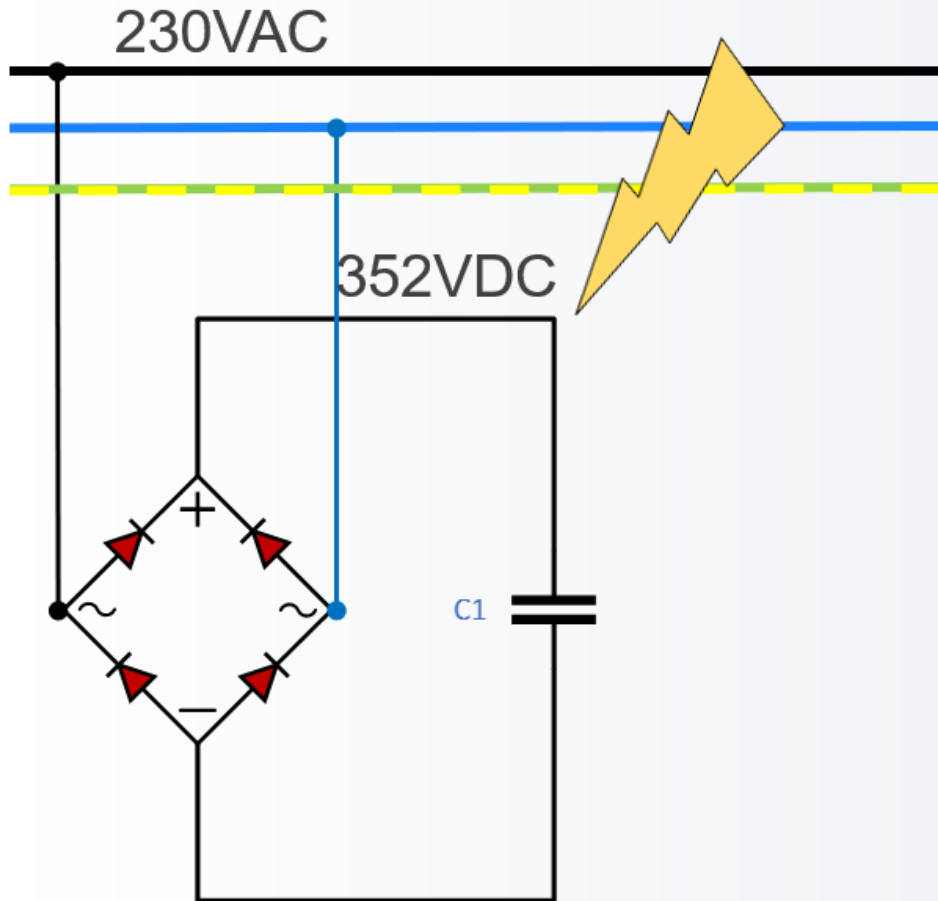


APPLICATION EXAMPLE: TEMPERATURE MEASUREMENT UNDER HIGH VOLTAGE

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4. Application Example: Temperature Measurement under High Voltage

4.1 Problem Description



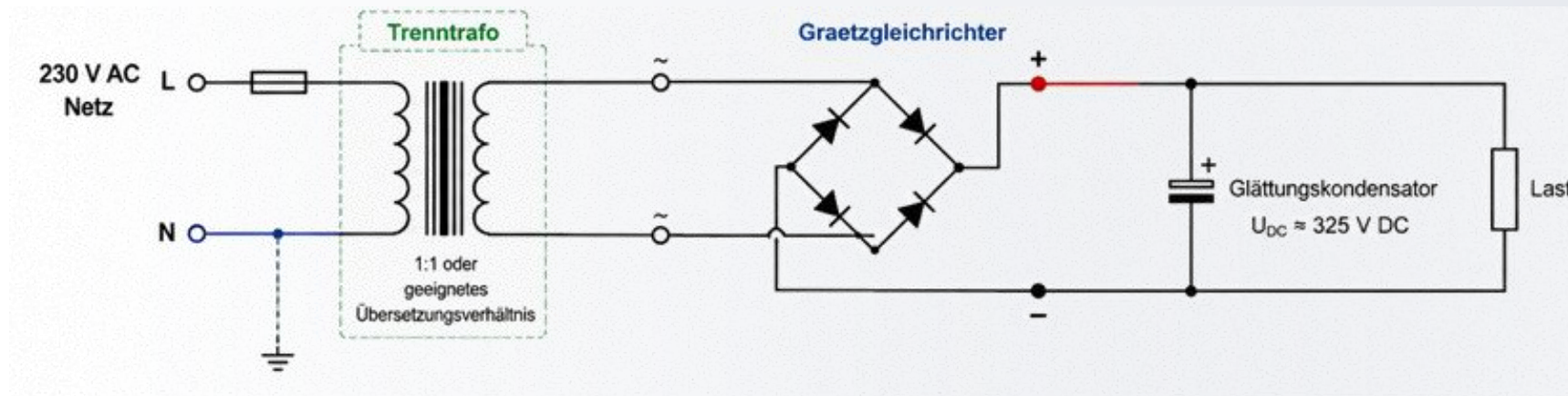
How can the temperature or voltage at the rectifier diodes be measured?

Problem:

- **Personal Safety**
 - Danger due to voltage potential $> 25 \text{ V AC}$ or 60 V DC
 - SELV (Safety Extra Low Voltage) $\leq 50 \text{ V AC RMS}$
 $\leq 120 \text{ V DC ripple-free}$
- **Device Protection**
 - Input-voltage range for grounded measuring instruments
 - Oscilloscope at 50 Ohm input impedance: 5 V RMS
maximum $\pm 30 \text{ V peak}$

4. Application Example: Temperature Measurement under High Voltage

4.1 Problem Description



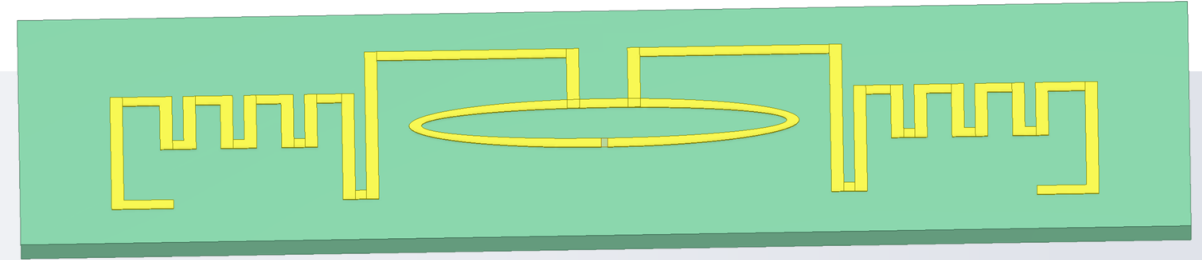
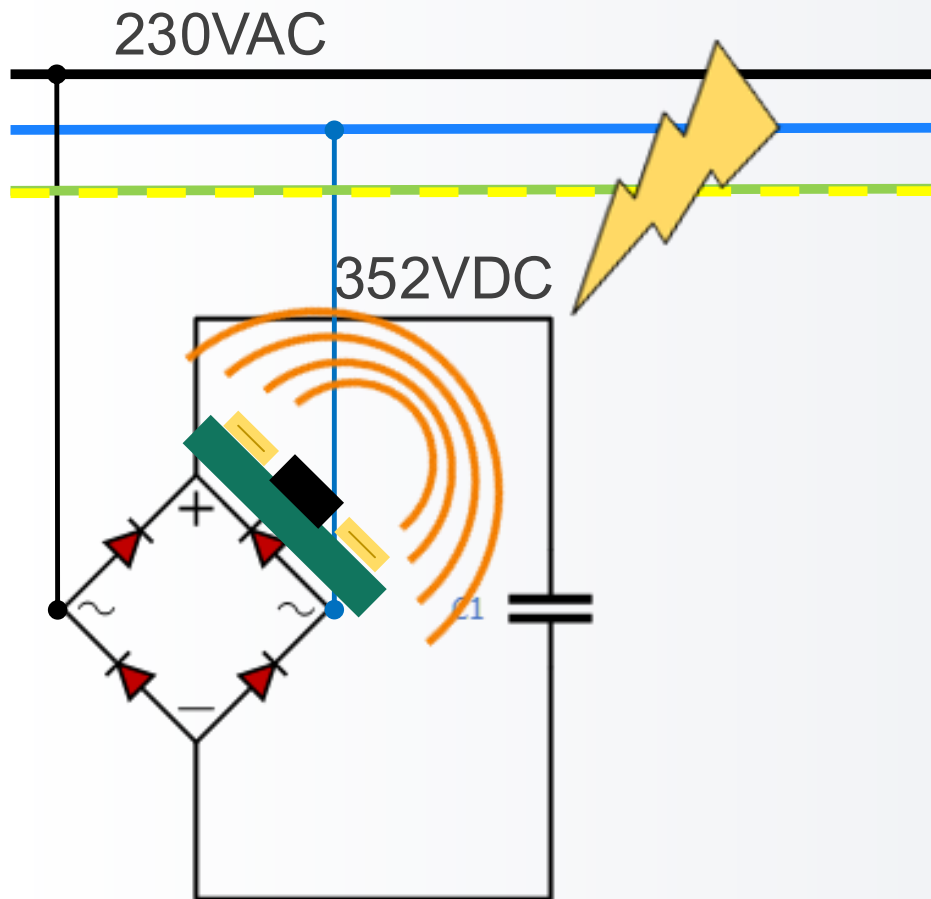
Solution: Isolation transformer

Problem:

- High weight and high price
- Parasitic coupling between primary and secondary coil, especially in the RF range

4. Application Example: Temperature Measurement under High Voltage

4.2 Solution Approach: Sensor Tag

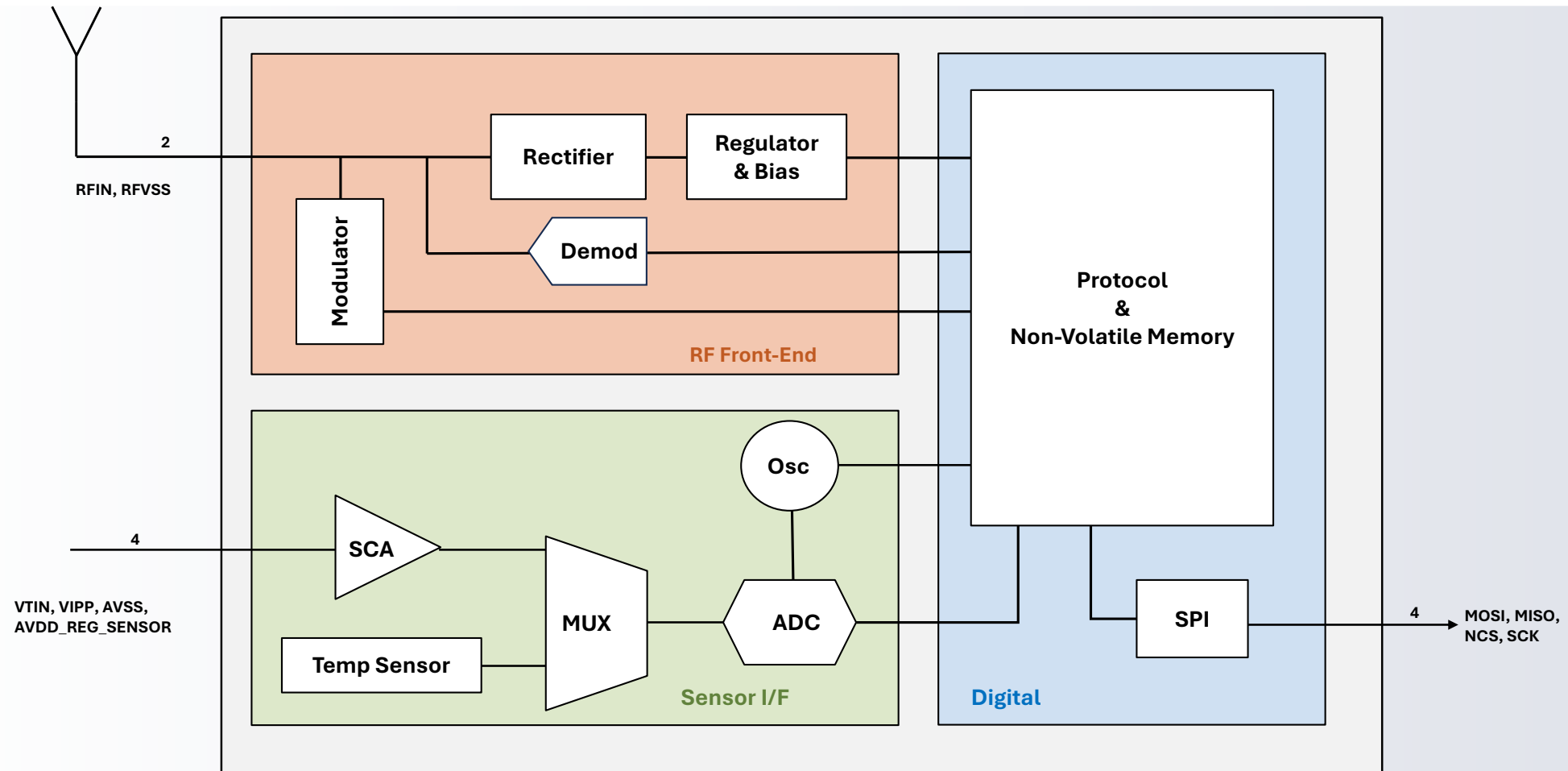


Wireless measurement with a sensor tag offers the following advantages:

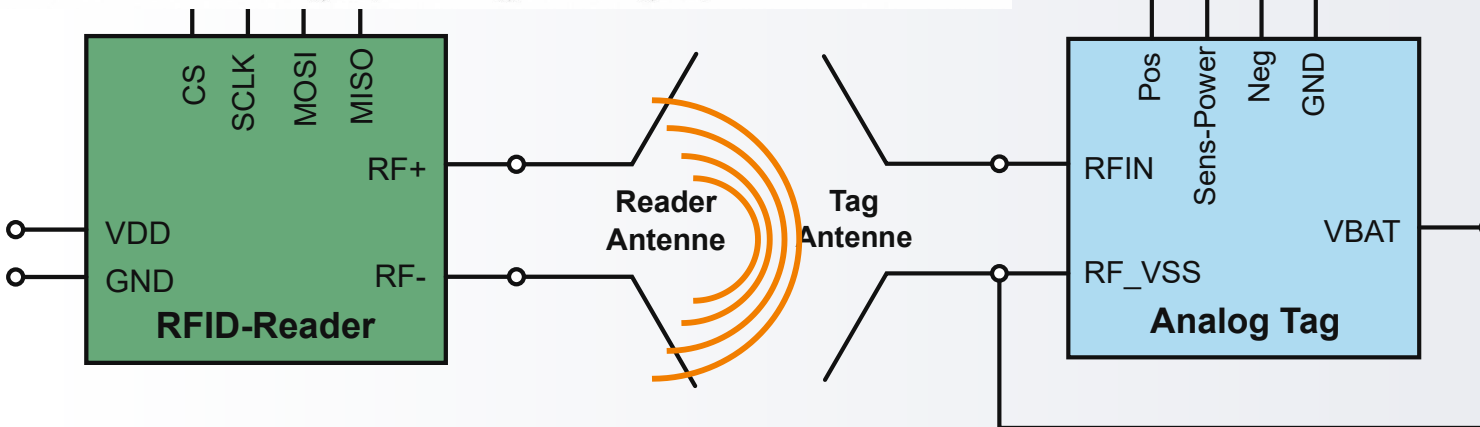
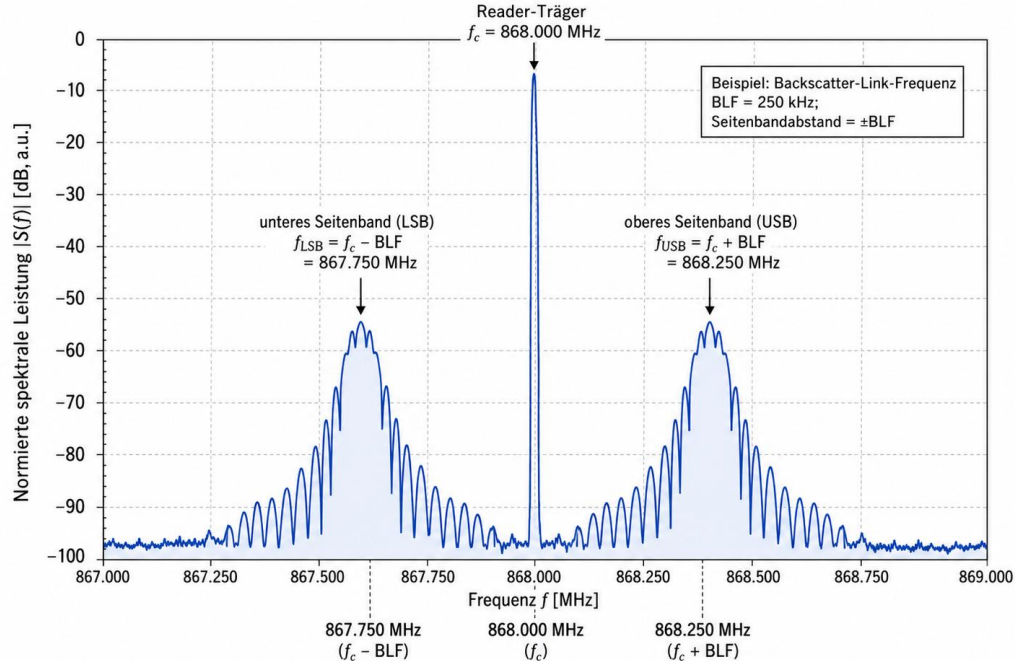
- Potential-free measurement directly at the measurement point
- No elaborate measurement setup
- No risk to personnel or measurement equipment
- Measurement on moving/rotating objects
- No limitation of operating time
 - Power supply via the UHF field
- Highly integrable and encapsulatable (battery-free)

4. Application Example: Temperature Measurement under High Voltage

4.2 Solution Approach: Sensor Tag – System Architecture



4. Application Example: Temperature Measurement under High Voltage

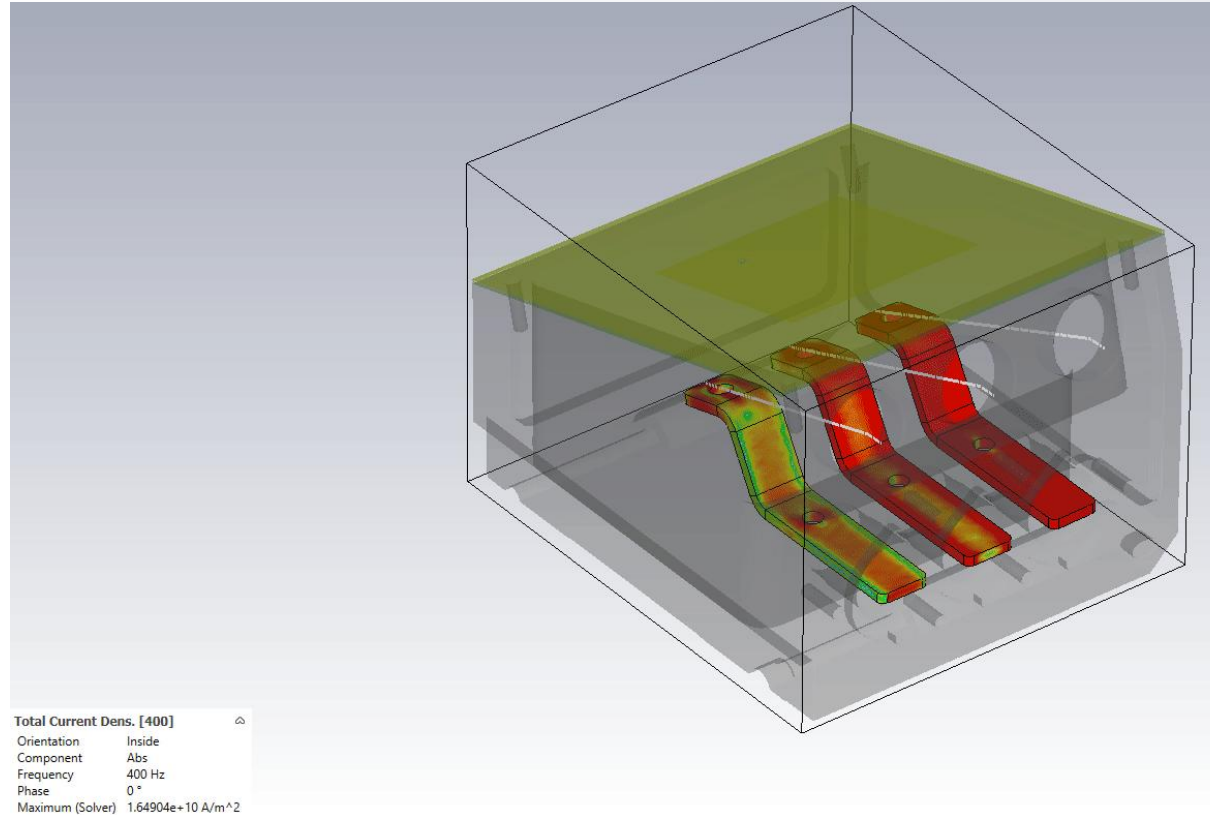


868MHz RFID-Tag EPC Class1 Gen2

- Up to 7 m range
- -40 to 125° Temperature Range
- 10bit ADC
- **Input Range:** 1V@1mV or 2V@2mV
- 1V@1k Ω external sensor supply
- SCA Gain 1 to 20

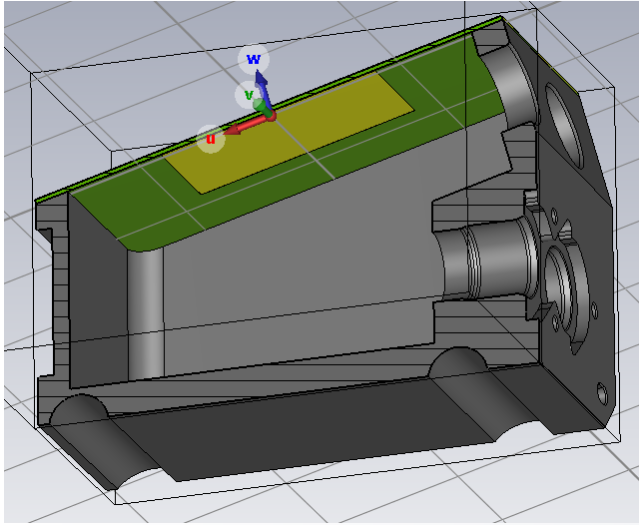
4. Application Example: Temperature Measurement under High Voltage

4.3 Temperature Measurement on 3 Phases 800V@1000A

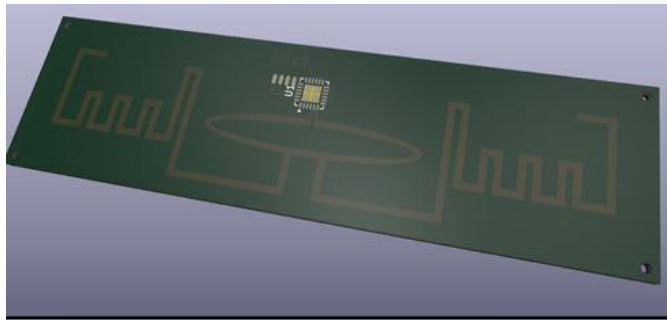


4. Application Example: Temperature Measurement under High Voltage

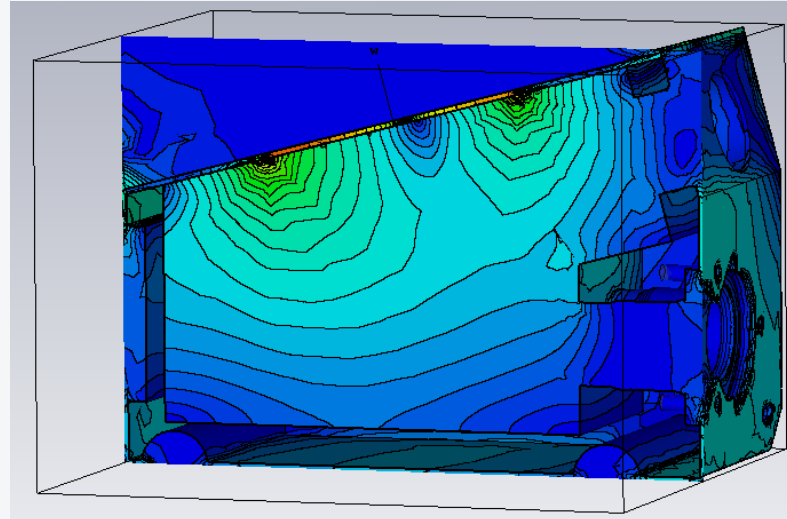
4.3 Temperature Measurement on 3 Phases 800V@1000A



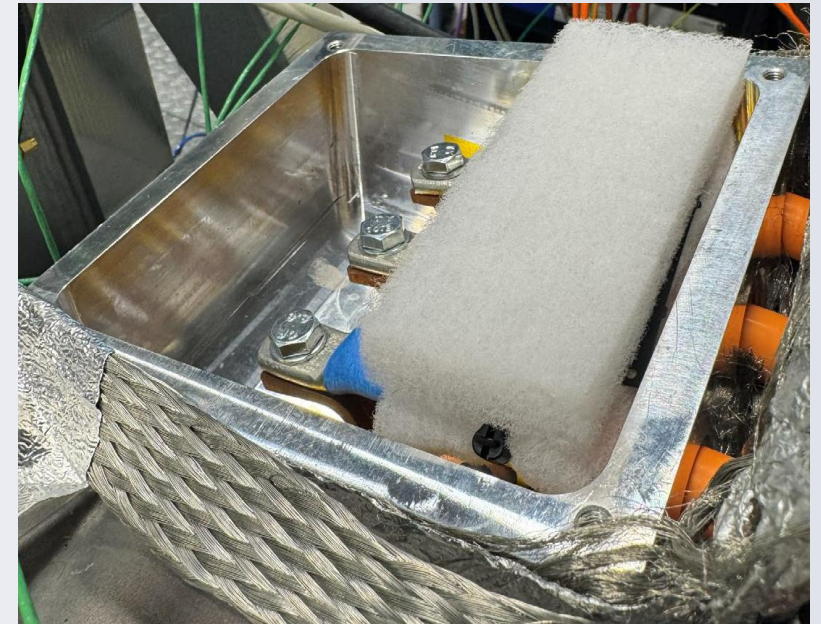
Reader antenna in the switch cabinet



Sensor Tag



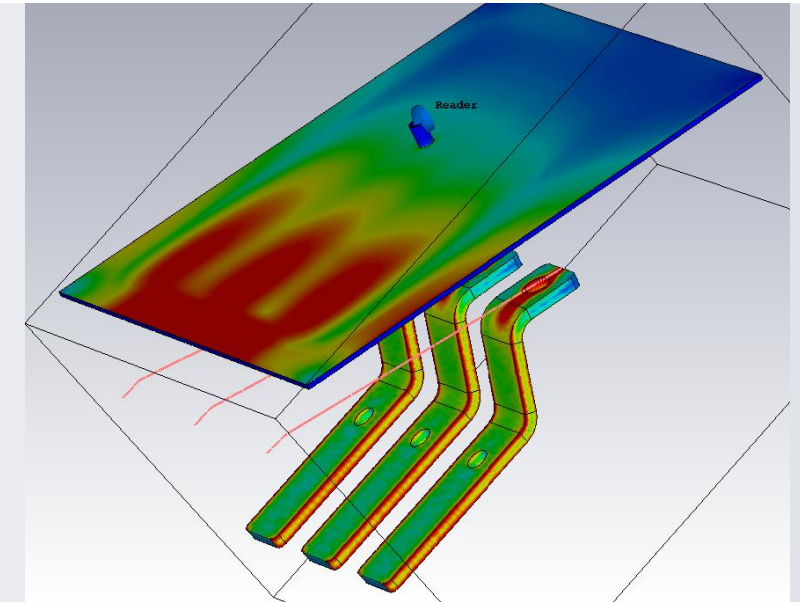
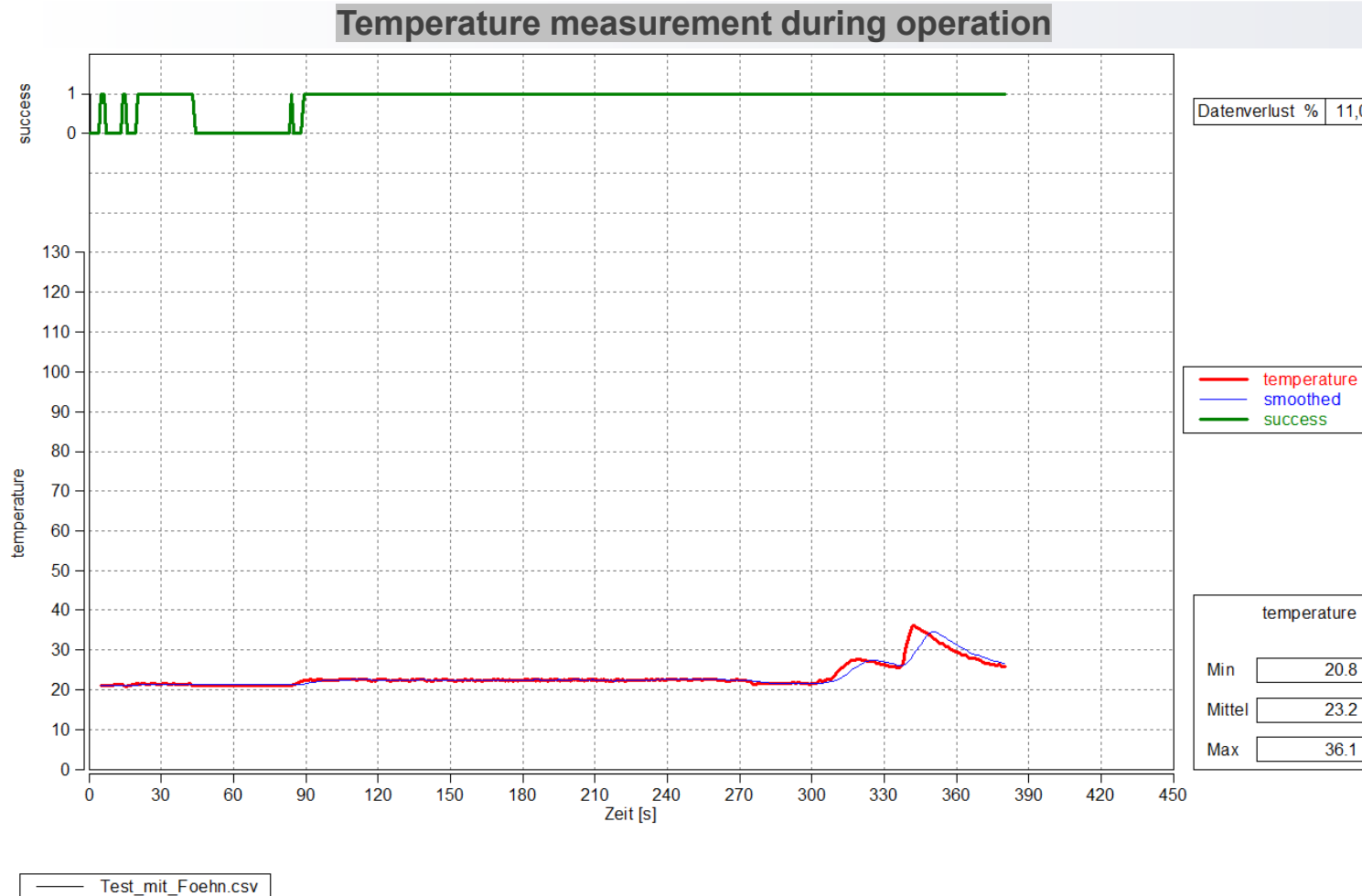
E-field of the reader antenna



Sensor tag on the busbars

4. Application Example: Temperature Measurement under High Voltage

Temperature Measurement on 3 Phases 800V@1000A

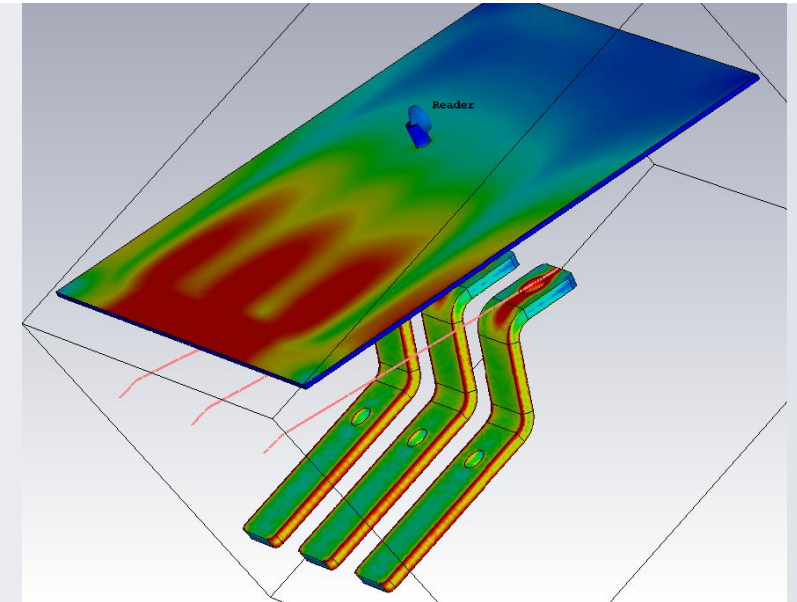
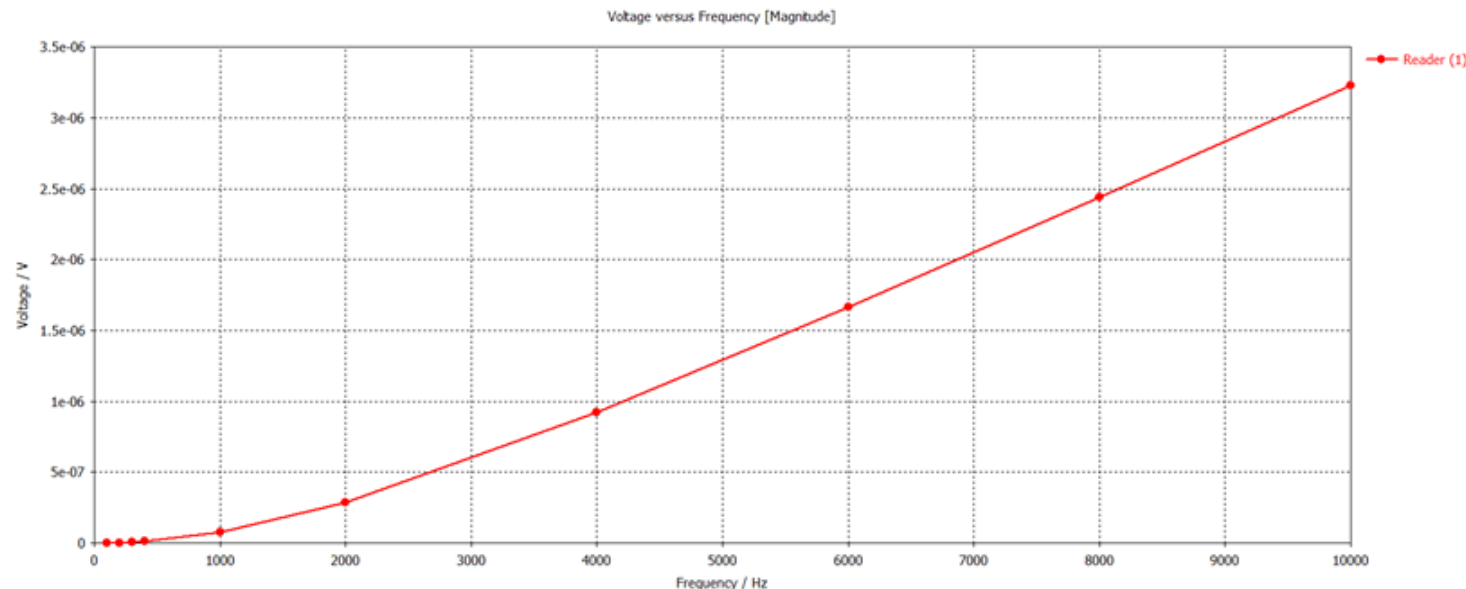


Current density distribution during operation with 800VAC@10kHz and 1000A

4. Application Example: Temperature Measurement under High Voltage

Temperature Measurement on 3 Phases 800V@1000A

Coupled interference voltage at antenna connector $<10\mu\text{V}$



Current density distribution during operation with 800VAC@10kHz and 1000A

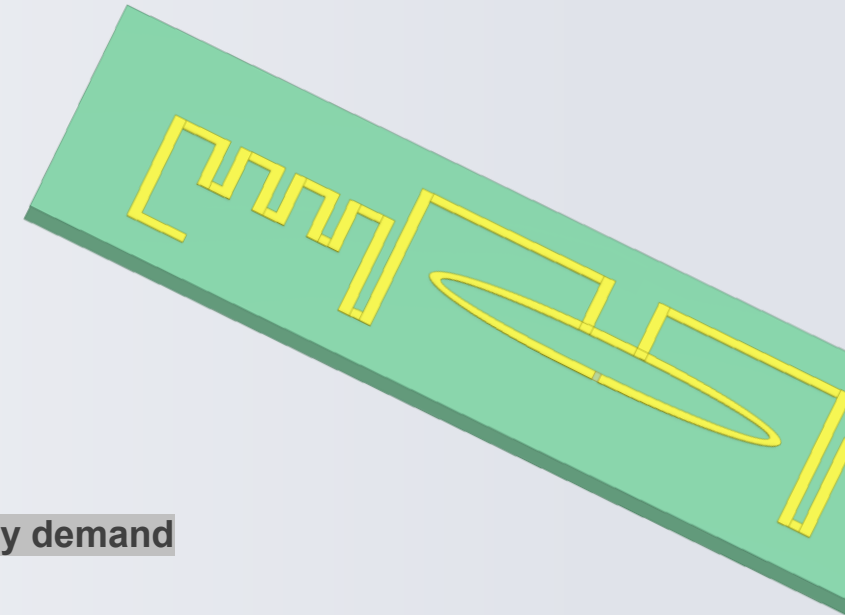
SUMMARY AND OUTLOOK

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5. Summary & Outlook

Summary

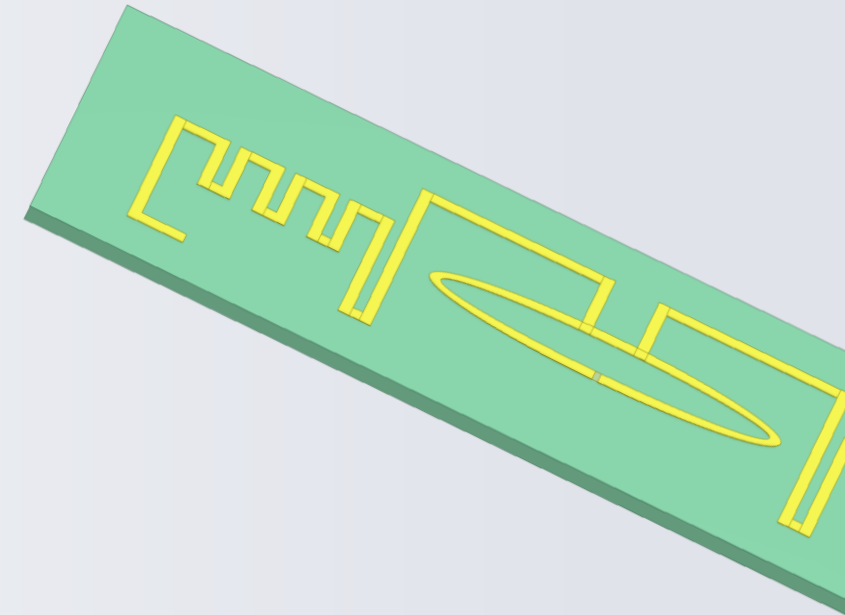
- **I4.0 requirements and AI solutions in production require continuous data supply**
 - Battery-powered devices must trade off sampling rate and operating life
- **Energy harvesting is a solution for permanent, continuous IIoT supply**
 - Batteries reduce operating life
 - They limit the operating temperature
 - They make hermetic encapsulation of IIoT systems in plants and devices more difficult
- **Electrodynamic converters offer the highest energy yield relative to volume and cost**
 - They require a rapidly changing magnetic flux $\Delta\Phi$, achievable via microgears
- **Sensor RFID tags are an interesting special solution for sensor systems with low energy demand**
 - Easy integration in moving or rotating applications
 - High integration density, low weight, and good read range (~7m)
 - Potential-free measurement under high voltage, measurements inside liquids, etc.



5. Summary & Outlook

Outlook

- **Development of an in-house portfolio of IIoT energy harvesters based on the electromagnetic principle**
 - Funding applied for
 - Seeking interesting use cases with companies that we can implement
- **Collaboration with international R&D partners for microgear production**
- **Development of a low-cost RDIF reader and corresponding sensor tags**
 - First demonstrator planned with FVA for the end of October
 - Building in-house expertise in tag-reader software “Made in Germany”
- **Independence from system integrators**
 - Hardware and software design in-house
 - Feasibility of custom solutions



Thank you for your attention.



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