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eTag: An Energy-Neutral Ear Tag for Real-Time Body Temperature Monitoring of Dairy Cattle

Madrid, 3rd October 2023

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

Heat Stress in Dairy Cattle

Illnesses and **fatalities** increased by up to **67%**

Cow under heat stress

Acceleration of global climate change

Detecting heat stress for individual cows in real time

$4.4B estimated annual **production losses** in the next 20 years

Conventional cooling requires **56% more energy** compared to precision cooling

Vitali, Andrea, et al. Journal of dairy science, 2009.

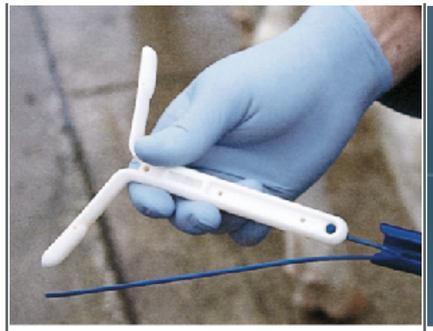
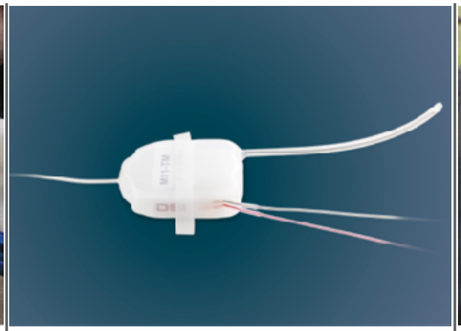
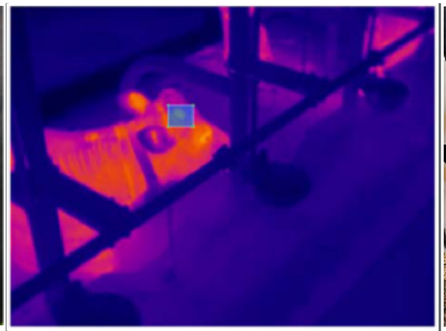
Philip Thornton et al., The Lancet Planetary Health, 2022.

Jung, Seunghyeon, et al. Biosystems Engineering, 2023.

Detecting Heat Stress

- Increase in core body temperature (CBT)
- Increase in respiration rate and heart rate
- Reduction in physical activity
- Reduction in milk yield and feed intake

Previous Approaches to Measuring Body Temperature

	 Temperature logger	 Wireless telemetries	 Wearable RFID scanner	 Infrared camera	 Our ear tag
Accuracy	✓ High	✓ High	✓ High	✓ High	✓ High
Non-invasive	✗ No	✗ No	✓ Yes	✓ Yes	✓ Yes
Real-time	✗ No	✓ Yes	✓ Yes	✓ Yes	✓ Yes
Lifespan	✗ Short	✗ Short	✗ Short	✓ Long	✓ Long
Reliability	✗ Low	✓ High	✓ High	✗ Low	✓ High

Vishal Suthar et al., Journal of Dairy Research, 2013.

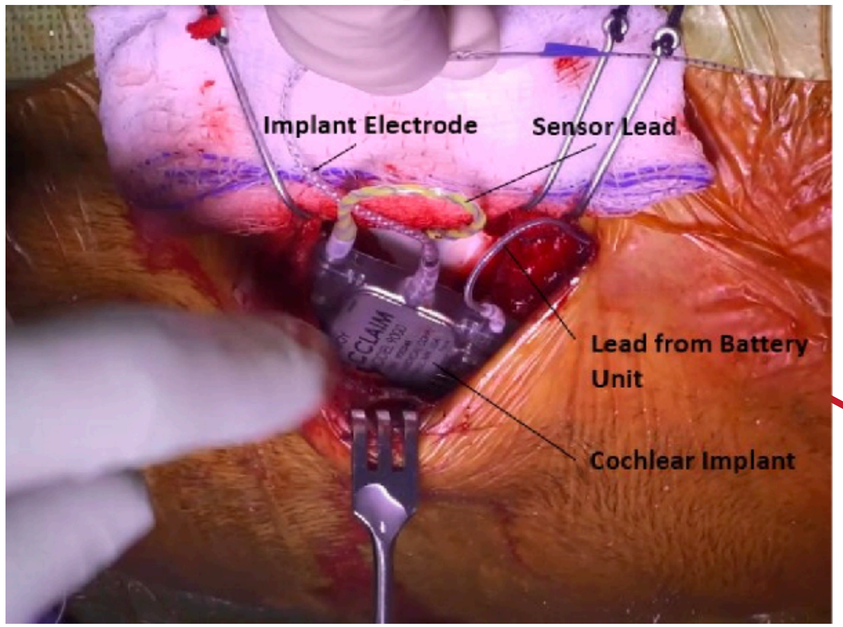
Ninette K A. et al., Journal of Pharmacological and Toxicological Methods, 2017.

Hanwook C. et al., Computers and Electronics in Agriculture, 2020.

Sai Ma et al., IEEE Sensors Journal, 2021.

Design Requirements and Considerations

High accuracy
+



Implanted sensor

Inductive coil

Long lifespan

Wireless power transfer

Autonomous charging

Energy harvesting

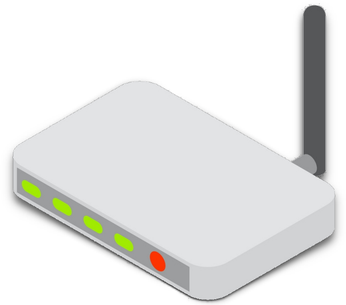
Wearable device

LF RFID

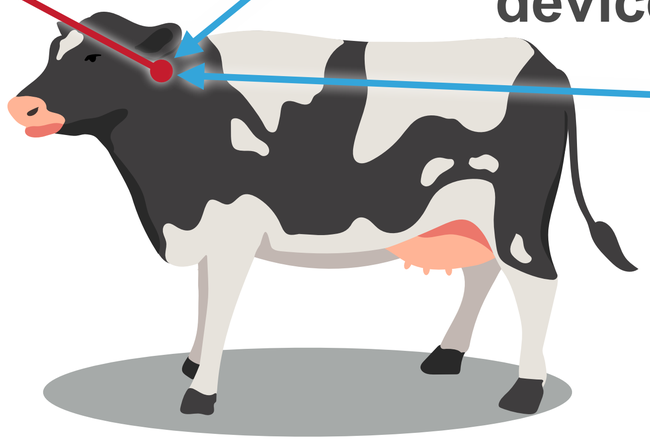
UHF

UHF RFID

Real-time measurement



Transceiver



James R. Dornhoffer et al., Journal of Clinical Medicine, 2023.

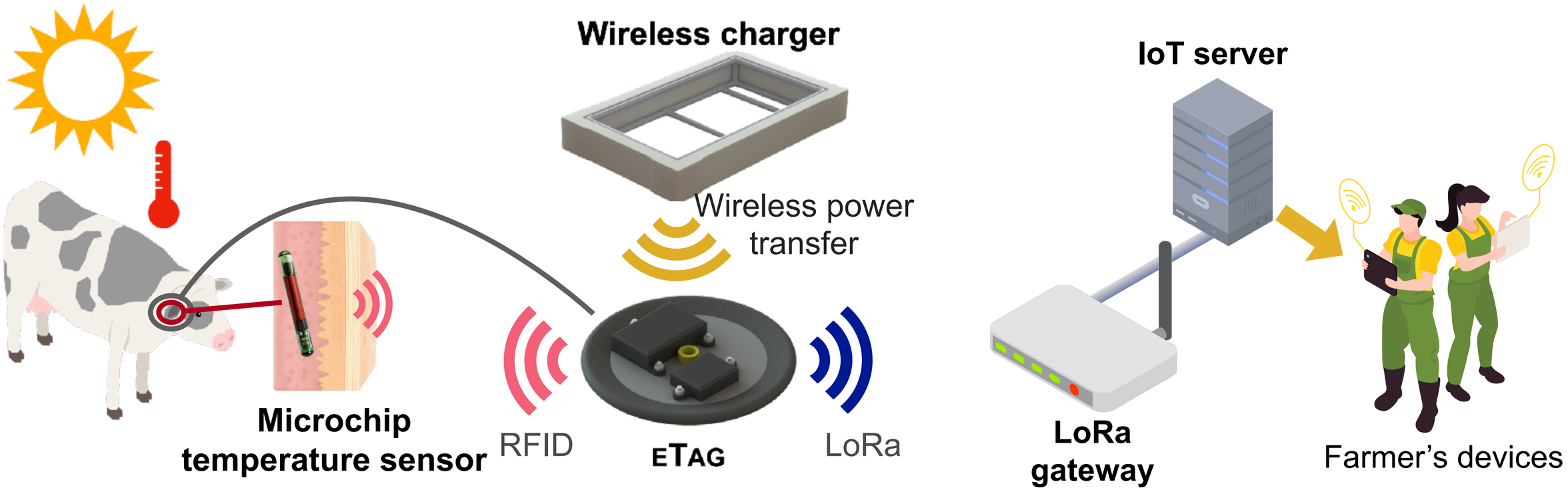
eTag: Energy-neutral Real-time Body Temperature Monitoring

eTag

- Accurate real-time measurement
- Perpetual operation by wireless charging
- Light weight and non-invasive

Wireless charger

- Charges the tag during milking
- Autonomous charging with varying distances
- Safe and scalable



eTag Design Principles

Accurate & reliable: Scan passive RFID temperature sensor

Real-time: Wirelessly send temperature data in real time

Long runtime: Last throughout cow's lifespan without battery replacement

Non-invasive: Small and lightweight

Safety and comfort: to farmers and animals

ISO-11784/5-compatible custom RFID scanner circuit

LoRa low-power communication

Perpetual operation with wireless power transfer (WPT)

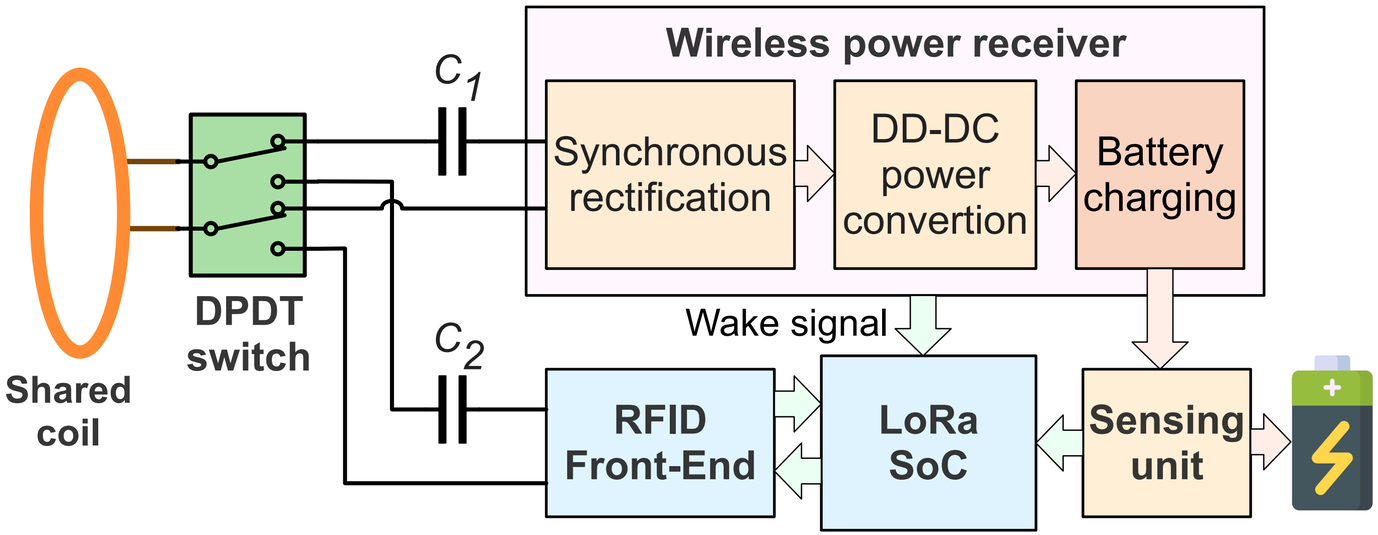
Coil-sharing circuit for RFID scanning and power transfer

Real-time charging control & Ear-mounted wearable device

THE COIL-SHARING DESIGN

Accurate & reliable
Real-time
Long runtime
Non-invasive
Safety and comfort

- **A shared coil for wireless power transfer and RFID scanning**



134.2 kHz for RFID scanning
200 kHz for wireless charging

Block diagram of the coil-sharing circuit

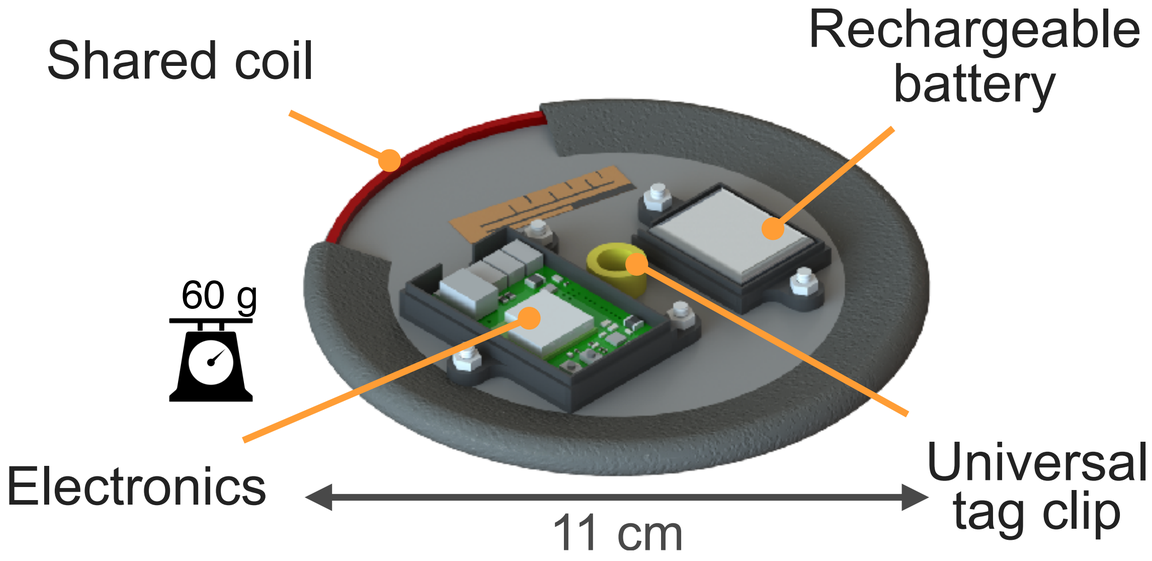
- **Design trade-off:**
  - The lower the ohmic resistance, the better WPT performance
  - The higher the ohmic resistance, the less power consumption during RFID scanning

➜ Using a low-resistance coil to maximize WPT performance

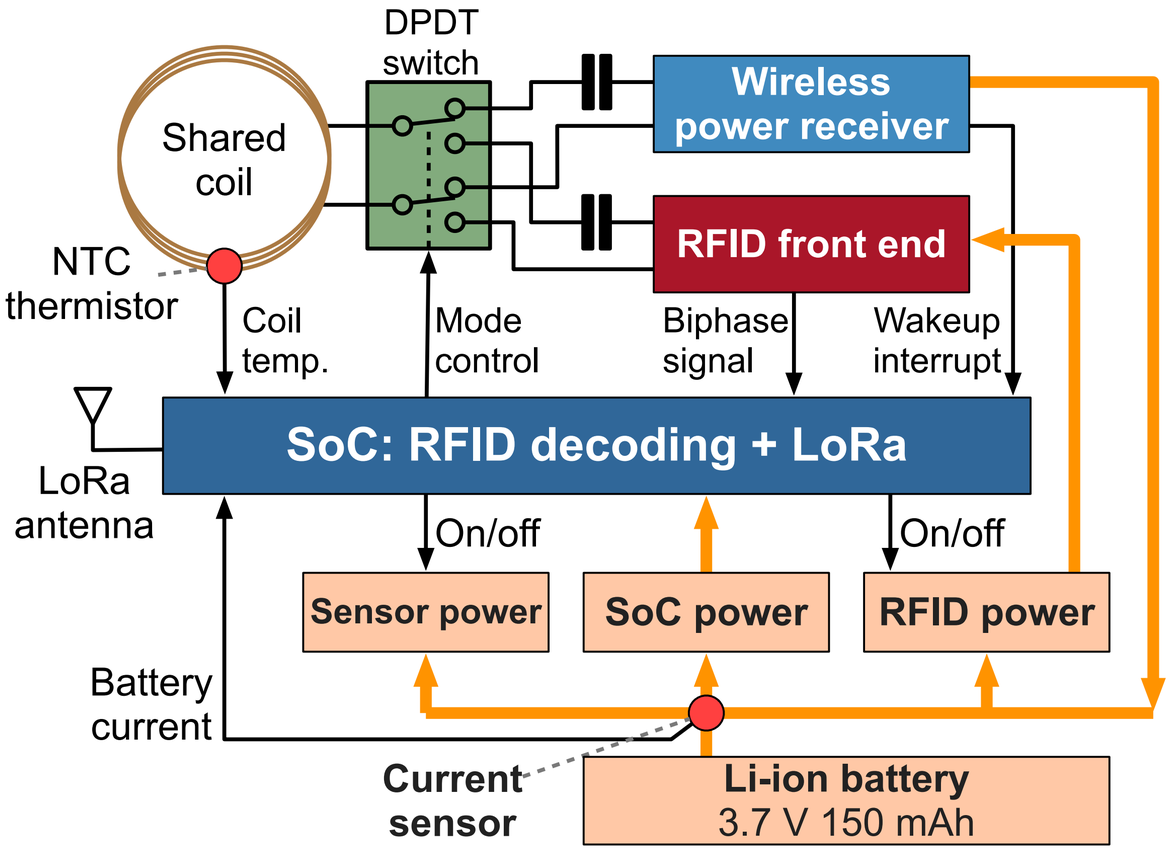
eTag Design

Accurate & reliable
Real-time
Long runtime
Non-invasive
Safety and comfort

- **Optimization for eTag:**
  - Custom RFID decoding: 15x reduction in scanning duration
  - Power gating, measuring very 5 minutes



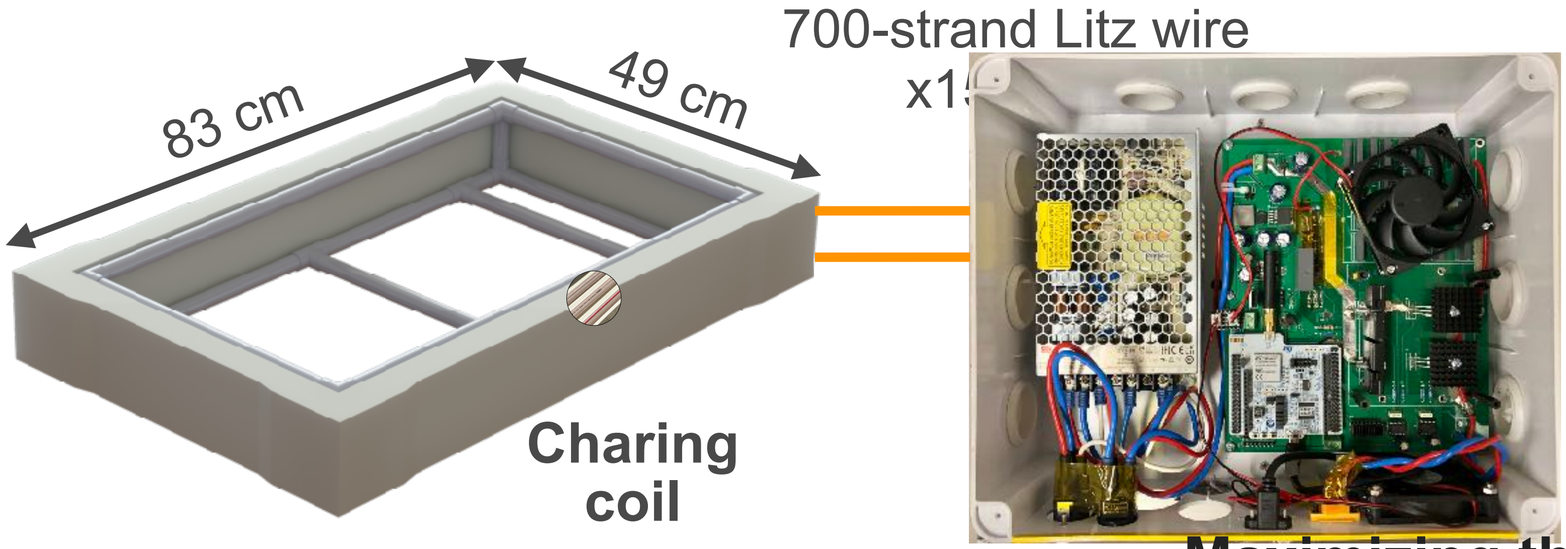
Implementation

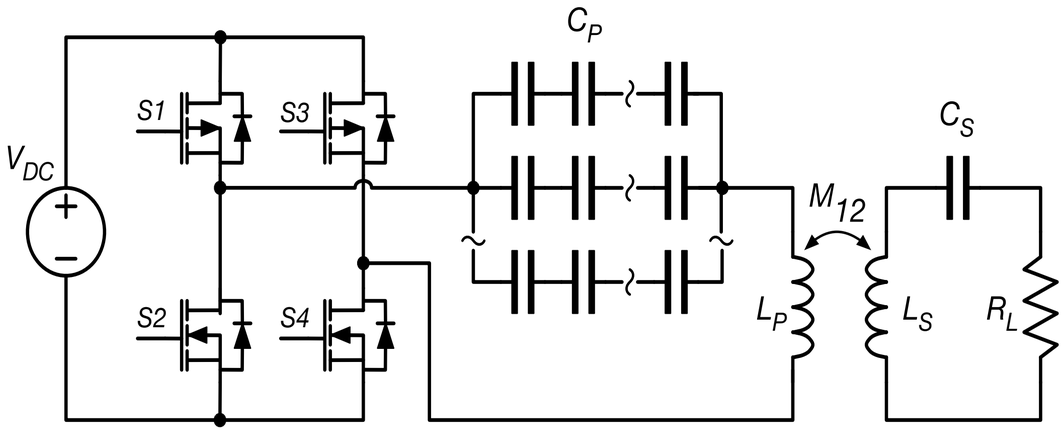


Block diagram

WIRELESS POWER CHARGER

Accurate & reliable
Real-time
Long runtime
Non-invasive
Safety and comfort





Resonant inductive WPT

- **Maximizing the WPT performance:**
  - Use a capacitor array
  - Increase the coil's quality factor:
    - Use Litz wire to minimize the skin effect
    - Proper spacing between adjacent turns
  - Use synchronous converters

WIRELESS POWER CHARGER

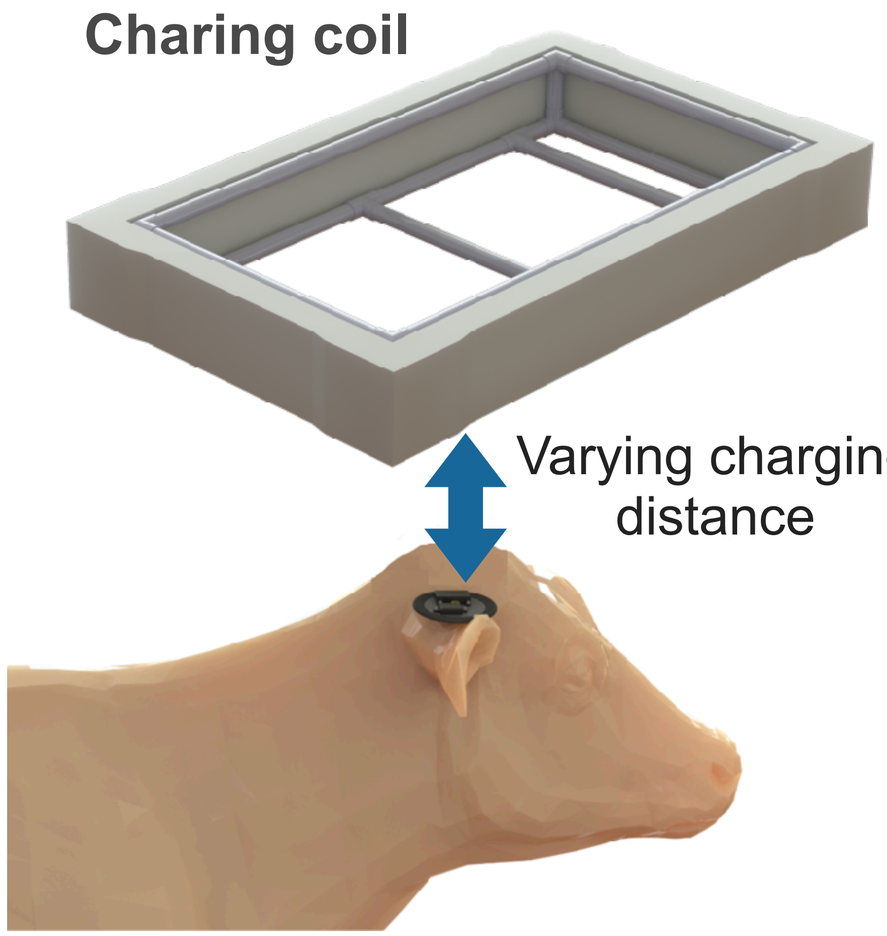
Accurate & reliable

Real-time

Long runtime

Non-invasive

Safety and comfort



A cow under the charing coil

- **Charging control process:**
  - Charging power varies due to the free movement of the cow
  - Using a close-loop control charging process to adjust charging power

Installation and Deployment

A cow during mounting an eTag

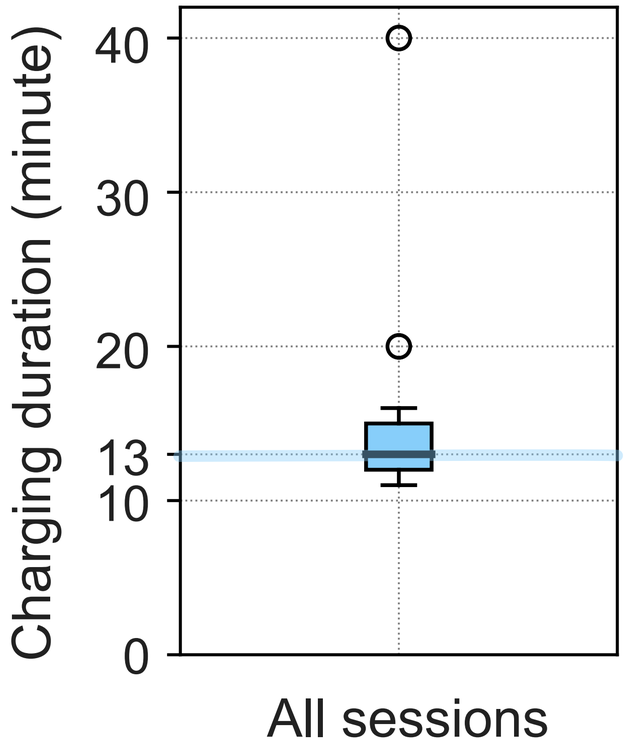
A cow with an eTag being charged during milking

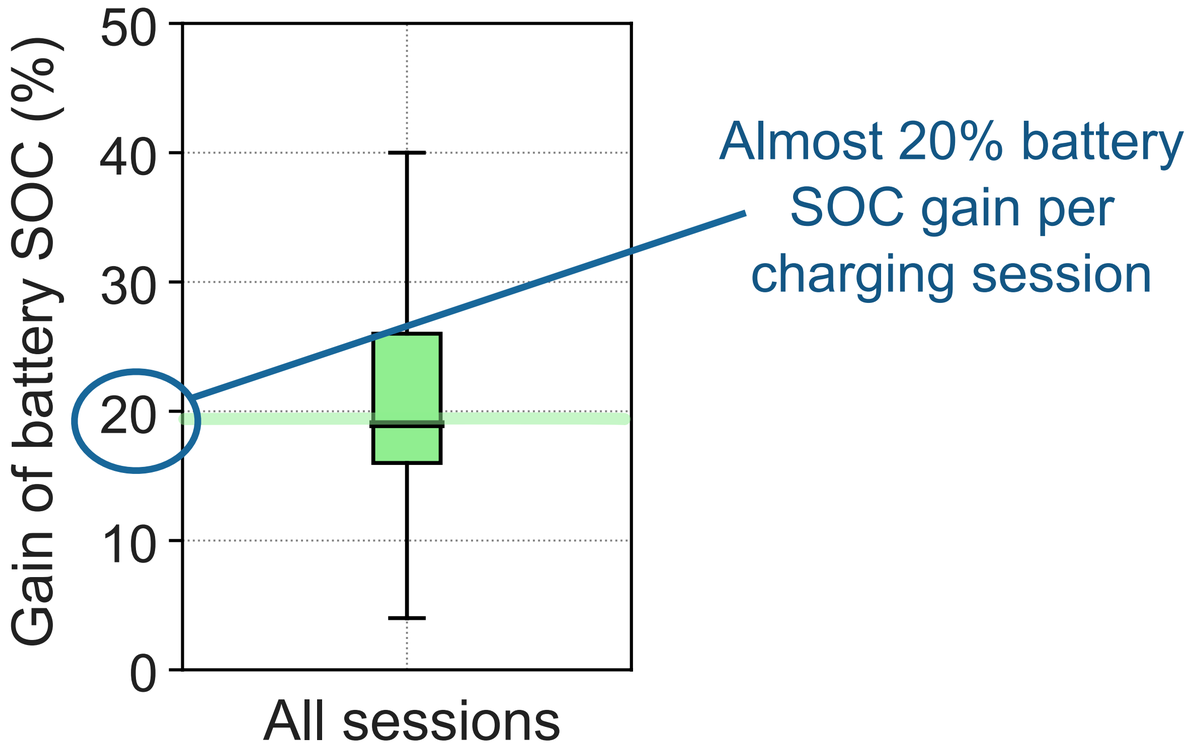
7 cows, 1 wireless charger, and 2 milking sessions per day in 3 weeks

UW-Madison Institutional Animal Care and Use Committee (IACUC) approved (#A006606)

CHARGING PERFORMANCE

- **Results from 17 charging sessions**

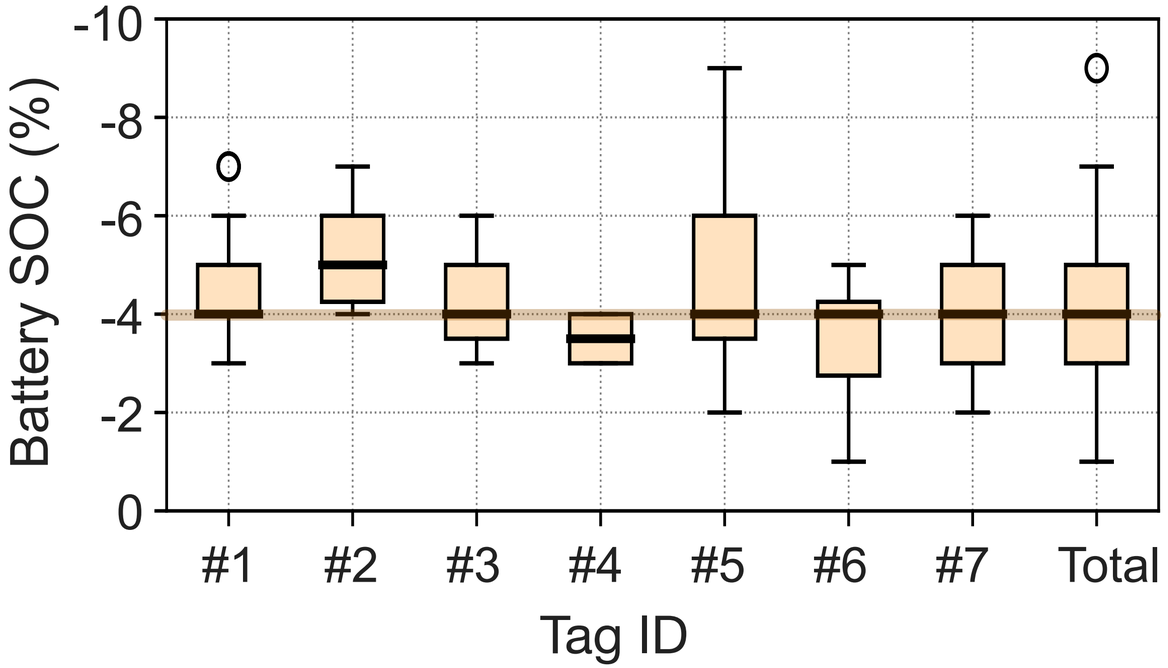




In average, the battery SOC increased by about 20% after 13 minutes of charging

Energy Neutrality Analysis

- **Daily battery level reduction of eTAGs**



- **Runtime from one charging session:**

  20% gain ÷ 4% daily loss = 5 days

- **Number of cows visit one charger during 5 days:**

  2 visits × 3 batches = 6 cows per day

  5 days × 6 cows = 30 cows

Energy-neutral for up to 30 eTAGs using only one charger

CONCLUSIONS

- We proposed eTag, a **light-weight** **energy-neutral** **ear tag** and a wireless charger for **real-time** heat stress monitoring in dairy cattle
- eTag and the wireless charger can be used to enable precision cooling for improving the economic and environmental sustainability

Thank you!

RELIABILITY OF RFID SCANNING

- **The success rate of RFID scanning throughout the experiment**

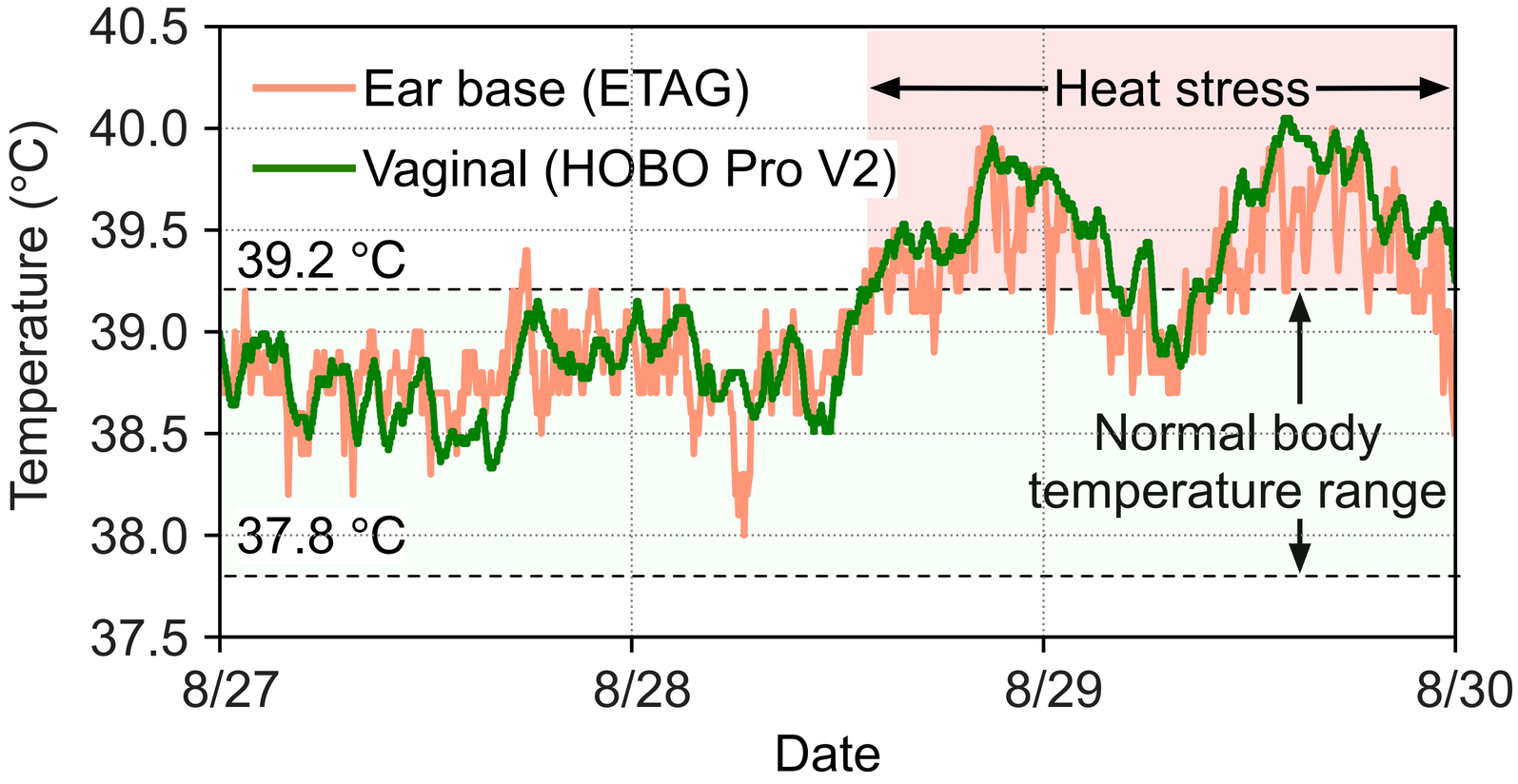
Cow ID	Number of RFID samples	Success rate of RFID scanning
#1	5905	**77.1%**
#2	3217	**94.4%**
#3	3324	**80.0%**
#4	1345	**98.8%**
#5	2272	**37.7%**
#6	4700	**89.3%**
#7	2613	**98.0%**

the mounting hole is too far away

➜ **eTag can collect ear-base temperature reliably**

Measurement Results

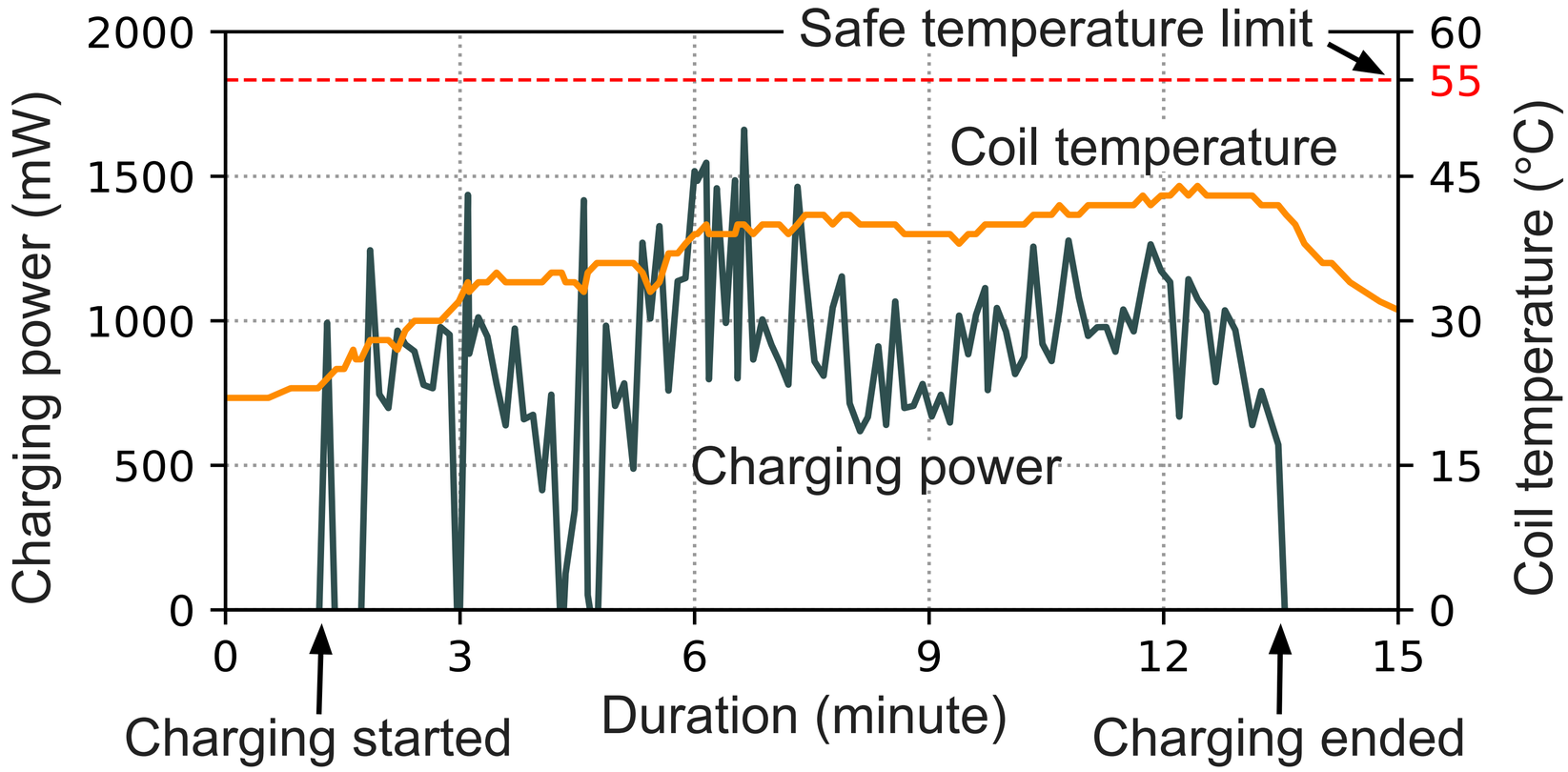
- **Ear-base temperature and vaginal temperature in 3 days:**



➜ eTag can be used to detect heat stress

CHARGING RESULTS

- **A typical charging session:**



APPENDIX A

- **Charging scenarios:**
  - Multi tags, single charger: the charger adjusts power in a conservative manner so that none of the eTags violates the safety limits
  - Multi tags, multiple chargers: chargers advertising their ID through the power channel, where an eTag that is within the charging range receives wireless power and extracts the ID for charge pairing

- **Data usage**
  - eTag can help farmers make timely decisions on cattle management, and will enable focused, precision cooling of individual cows using jet cooling fans

- **Scalability**
  - The lab-prototype eTag, the microchip sensor, and the wireless charger cost USD $43, $12, and $298, respectively
  - LoRa: up to about 100 eTags would be manageable per a single-channel gateway [22]