Sub-dermal battery-less wireless sensor for the automatic monitoring of cattle fever

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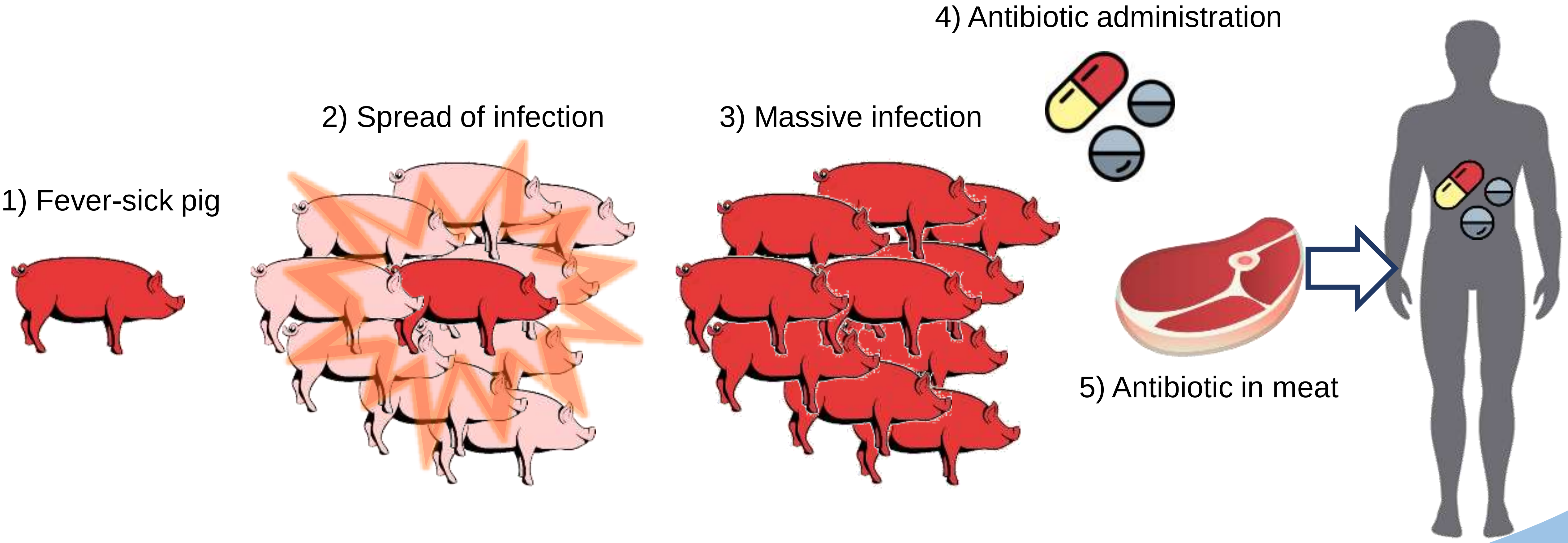
Fever in cattle farm



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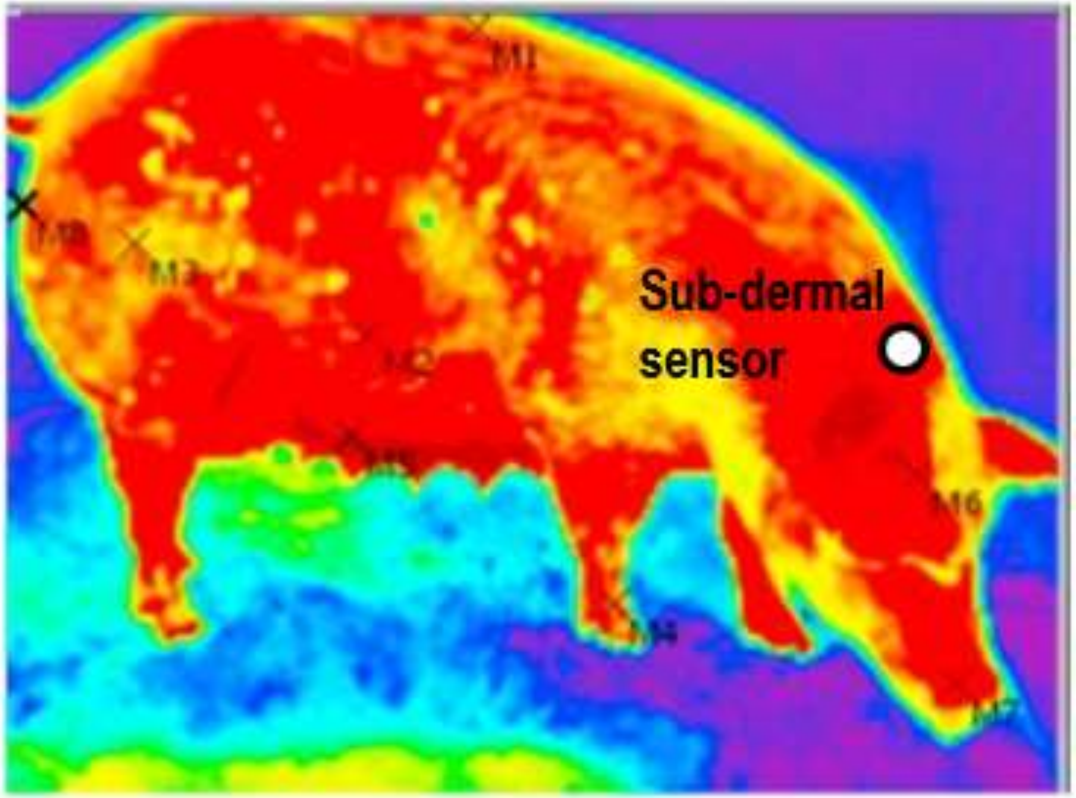
How to measure fever in cattle?

- **Identification** of the sick subject avoiding the massive administration of antibiotics to the whole farm

- The **rectal** thermometer is the standard:
  - **Discrete** measurement
  - **Time** expensive

Implantable temperature sensor



- Wireless communication through-the-body
- Anti-migration system
- Small size

State of the art: implantable antenna

Implanted antenna type	Size	Position	Frequency [MHz]	Gain [dB]	Read distance [m]
Coil IPTT-300 (1)	14 x 4π mm^2	Sub-cutaneous	0.1		0.05-0.08
Copper folded slot (2)	55.2 x 100π mm^2	2÷10 cm from the skin	868		3
Patch antenna (3)	100 x 15 x 0.07 mm^3	1 mm from the skin	918	-12.78	1-2
Hilbert PIFA (4)	25 x 25 x 7.6 mm^3	Under fat tissue	900		2-3

Non-adverse physiological reaction and safe long-term storage

Anchors securely to tissue (Patented anti-migration)

Simple to implant

(1) IPTT-300 by Bio Medic Data Systems
(2) A. Dubok, *et al.*, “Increased Operational Range for Implantable UHF RFID Antennas,” *EuCAP 2014.*
(3) A. M. Chrysler, *et al.*, “Effect of Material Properties on a Subdermal UHF RFID Antenna,” *IEEE Journal of RFID, 2017.*
(4) M. Shahidul Islam, *et al.*, “An Implantable Hilbert PIFA Antenna for RFID based Telemetry,” *2013 ICEAA.*

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Limitations:

- **Size** of the device not compatible with implantation
- **Migration** of the device
- **Read distance** not compatible with automatic and not-cooperative temperature reading

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This work

Design and optimization of a sub-dermal **UHF-RFID** implantable **2D flexible temperature-sensor**:

- **Meshed scaffold** to ease the integration and anti-migration system
- Trade-off between **size** and **communication** performance
- **Prototype** realization and measurements

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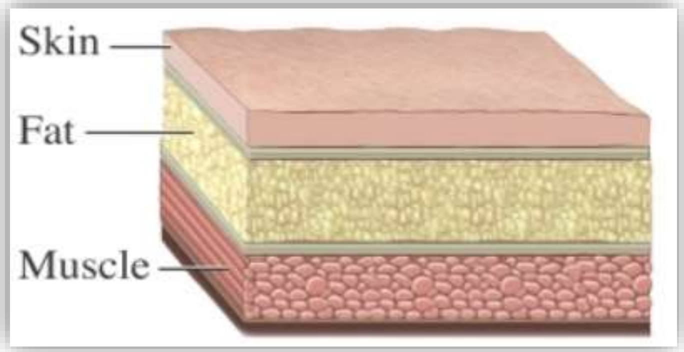
Multi-stratified model

- Site of implant: dorsal region of the neck, where temperature measurements are more correlated with rectal temperatures.
- Dielectric proprieties of the site of implant:

Pig tissues (circa 250 kg)	Relative permittivity ε	Conductivity σ [S/m]
Skin	37.07	0.59
Fat	5.76	0.059
Muscle	55.1	0.93

Thicknesses?



Realistic thicknesses measurement

Skin

Fat

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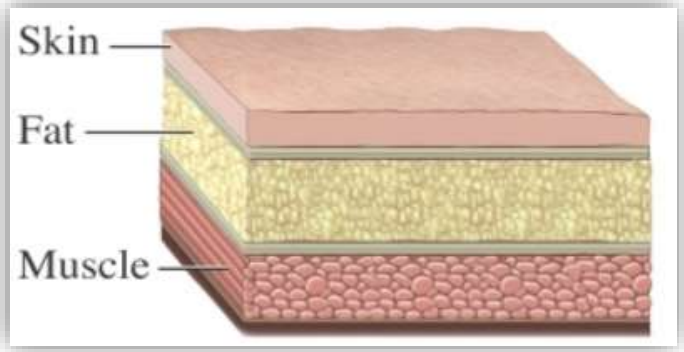
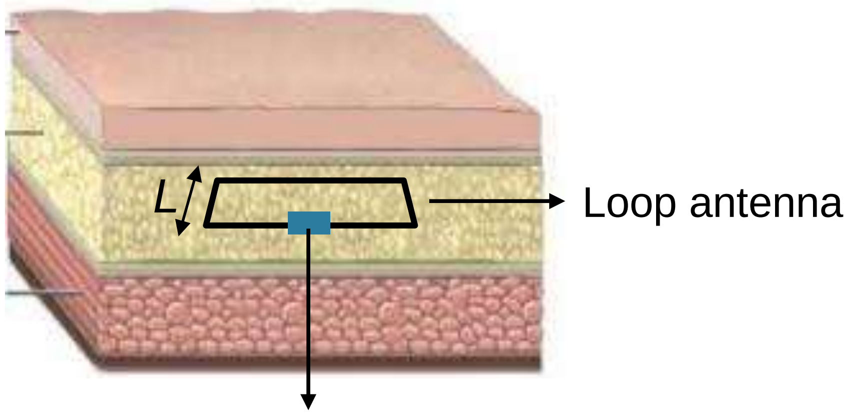
Skin	3,75 mm
Fat	26 mm
Muscle	40 mm



Performance parameters



Power transmission coefficient:

$$\tau = \frac{4R_{chip}R_A}{|Z_A + Z_{chip}|^2}$$

Chip-antenna impedances matching

Se $Z_A = Z^*_{chip}$ → $\tau = 1$

Realized gain:

$$\tilde{G} = G_0\tau$$

G_0: antenna gain

By inverting the *Friis formula* in far field

Maximum read distance:

$$d_{max} = \frac{\lambda}{4\pi}\sqrt{\frac{P_{in}G_R\tilde{G}\eta_P}{p_{chip}}}$$

$P_{in}G_R$: $EIRP$ (Equivalent Isotropic Radiated Power)

p_{chip}: chip sensitivity

η_P: polarization factor

Optimal size and implant depth

Preliminary considerations **without** considering **antenna-chip** impedance **matching**

Depth of implant	Optimal length *L* [mm]	Broadside gain [dBi]	Raed distance [m]	Radiation efficiency [%]
Skin-fat interface	56	-9.8	2.4	6.7
¼ of fat	65	-9.3	2.6	6.0
½ of fat	60	-10.2	2.3	4.9
On-skin	62	-10.1	2.3	6.5

Optimal size and implant depth

- **½ of fat**:
  - Easy implantation
  - Gain stability: maximum variation of 1 dB in the range of loop length 50 mm<*L*<65 mm.
  - Limitation in antenna size due to the proximity of the skin.
- **¼ of fat**:
  - More freedom in the antenna size.
  - Gain stability: maximum variation of 1 dB in the range of loop length 45 mm<*L*<73 mm.
- **Skin-fat interface**:
  - Gain stability: maximum variation of 1 dB in the range of loop length 50 mm<*L*<67 mm.
  - Proximity to the skin that is much vascularized for implantation: risk of infection.
- **On-skin**:
  - There are not particular advantages in terms of antenna gain.
  - The skin temperature is different from the core temperature and it could be influenced by the temperature of external environment. Moreover, the cattle could remove the device placed over the skin.

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⇒ The better implant depth is at ¼ of fat with a loop length limited to 40mm to minimize the invasivness

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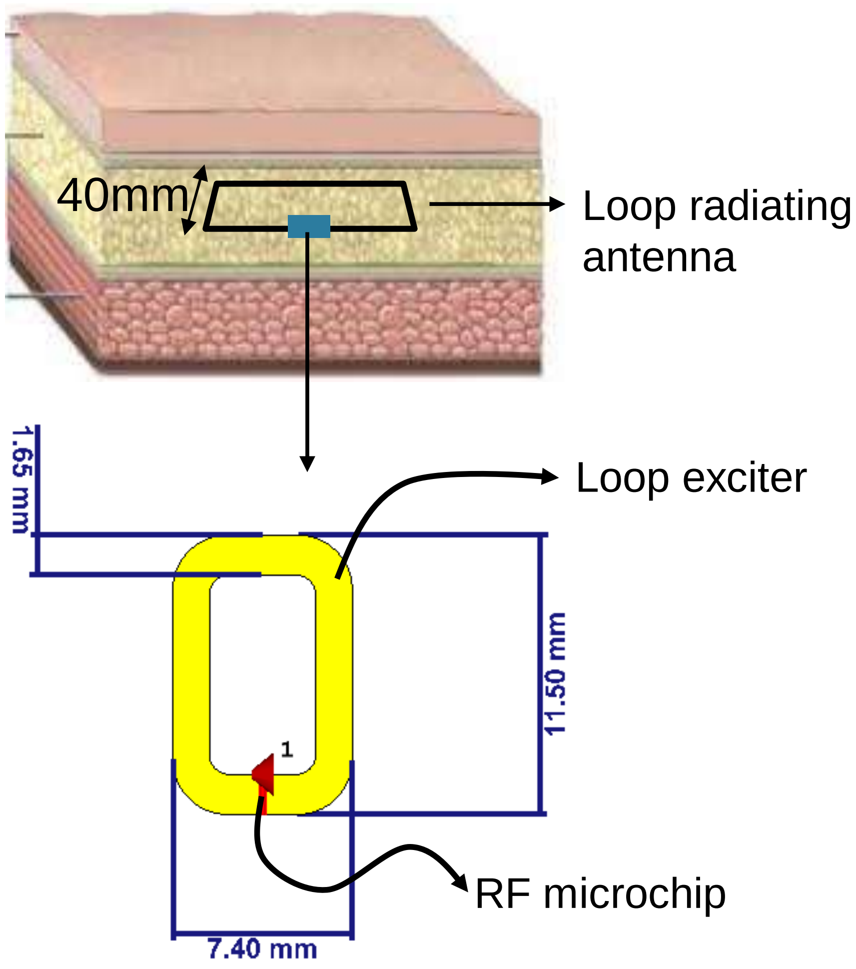
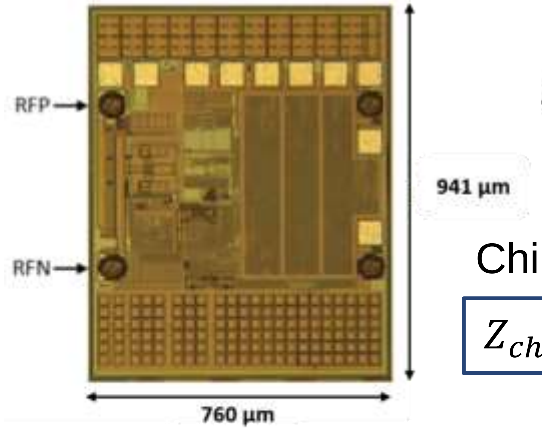
Antenna-chip impedance matching



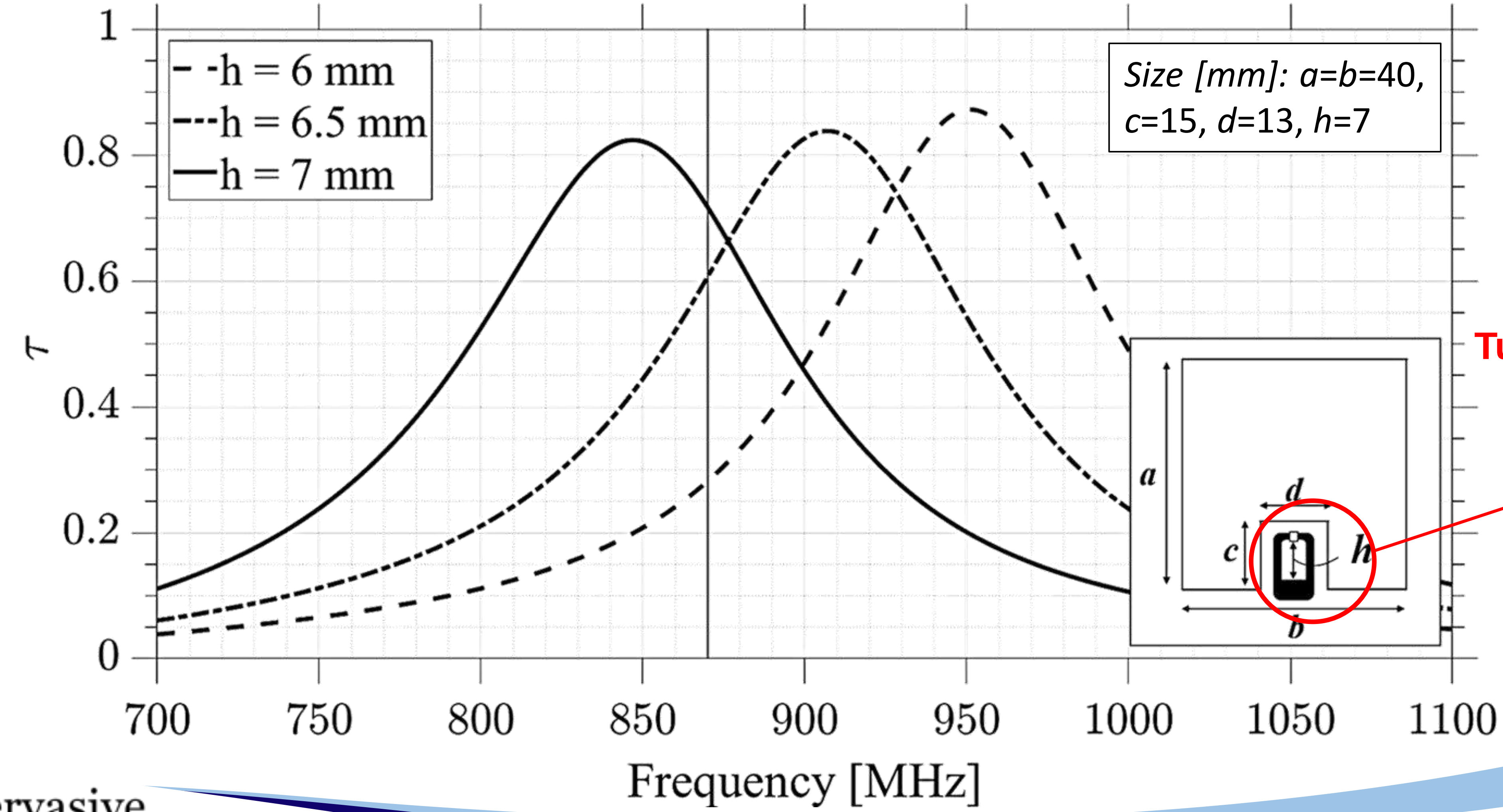


Chip equivalent impedance

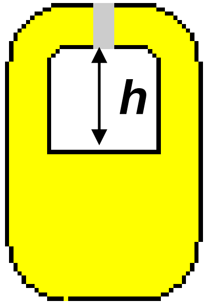
$Z_{chip} = 2.8 - j76\ [\Omega]$ (a 870 MHz)

- Battery-free
- UHF-RFID working frequency 860-960 MHz (transponder EPC Gen2)
- Chip sensitivity $p_{chip} = -16.6\ \mathrm{dBm}$
- Internal memory
- Self-tuning capabilities
- Integrated temperature sensor (range -40-85 °C)

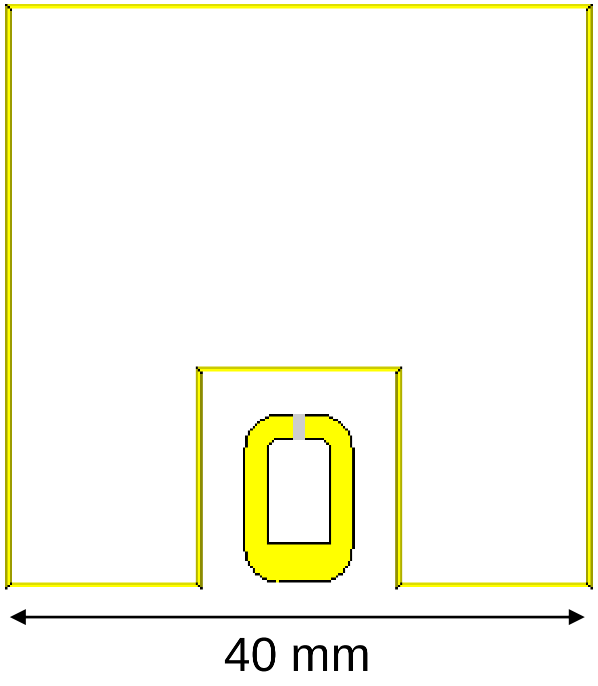
Power transmission coefficient

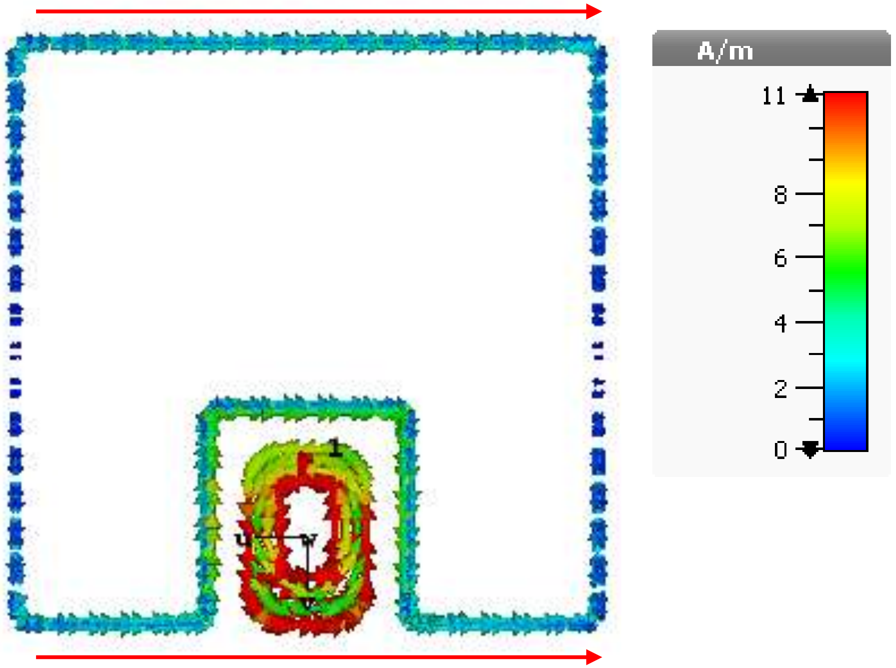


Tuning parameter



Final layout





In-phase currents over two opposite side → as an array of 2 dipoles

Parameter	Value
Size [mm^2]	40 x 40
Im(Z) [Ω]	74.7
Re(Z) [Ω]	6.6
Tau	0.8
Gain broadside [dB]	-11.9
Realized Gain [dB]	-12.8
Read distance max [m]	1.7
Radiation efficiency	4.2%

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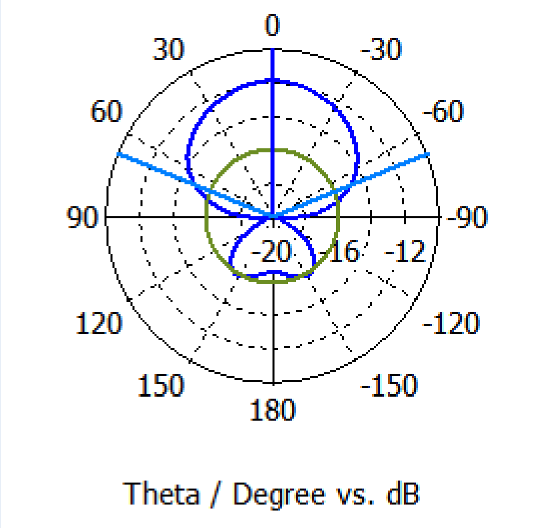
Radiation pattern

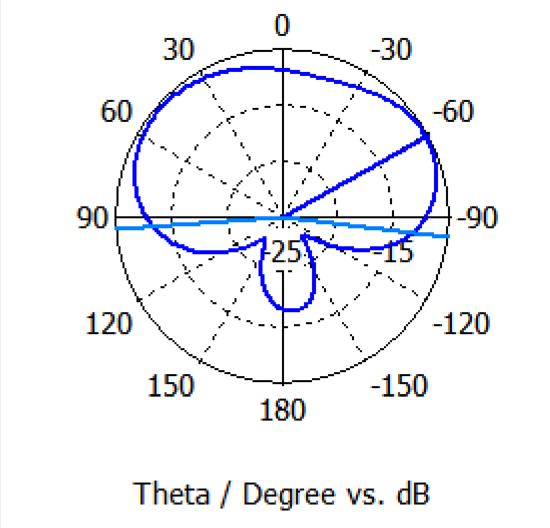
Farfield Gain Abs – 870 MHz

Φ = 0°



Main lobe magnitude = -11.9 dB
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 134.9 deg.
Side lobe level = -4.0 dB

Φ = 90°



Main lobe magnitude = -10.3 dB
Main lobe direction = -61.0 deg.
Angular width (3 dB) = 190.5 deg.

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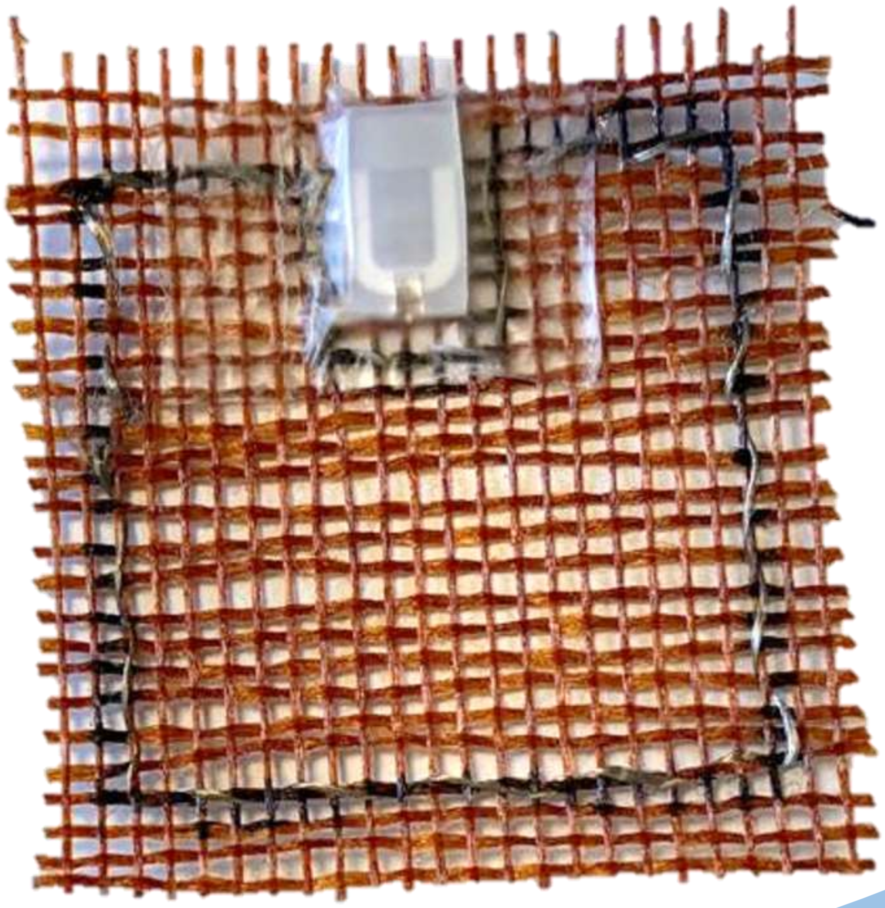
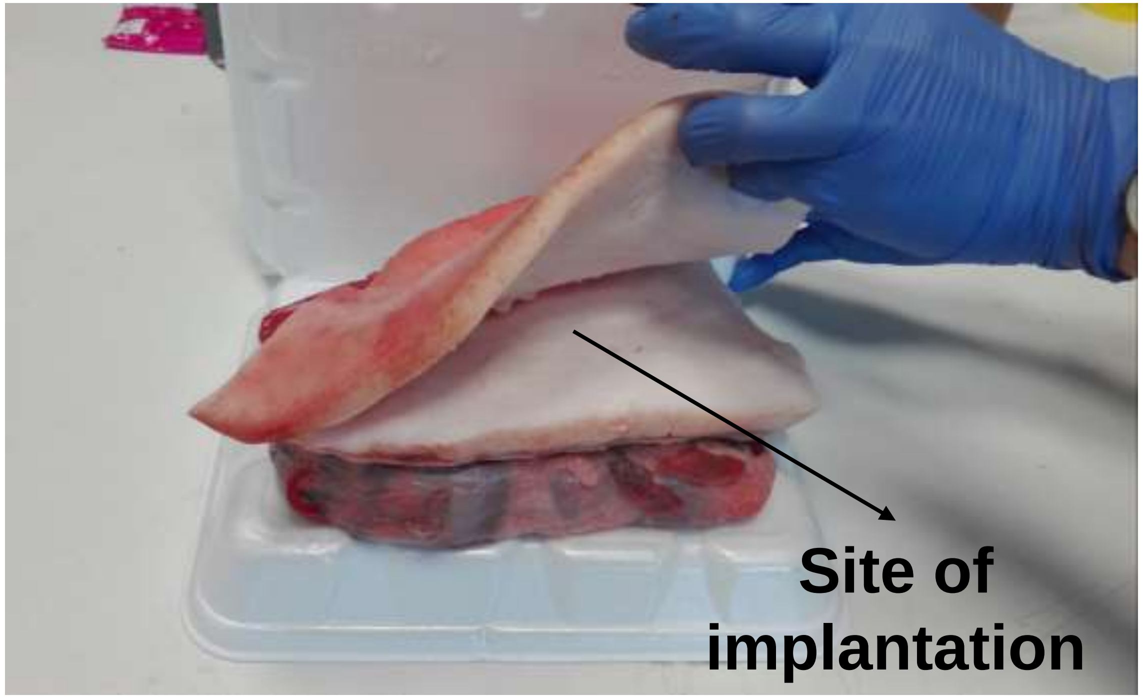
Prototype realization

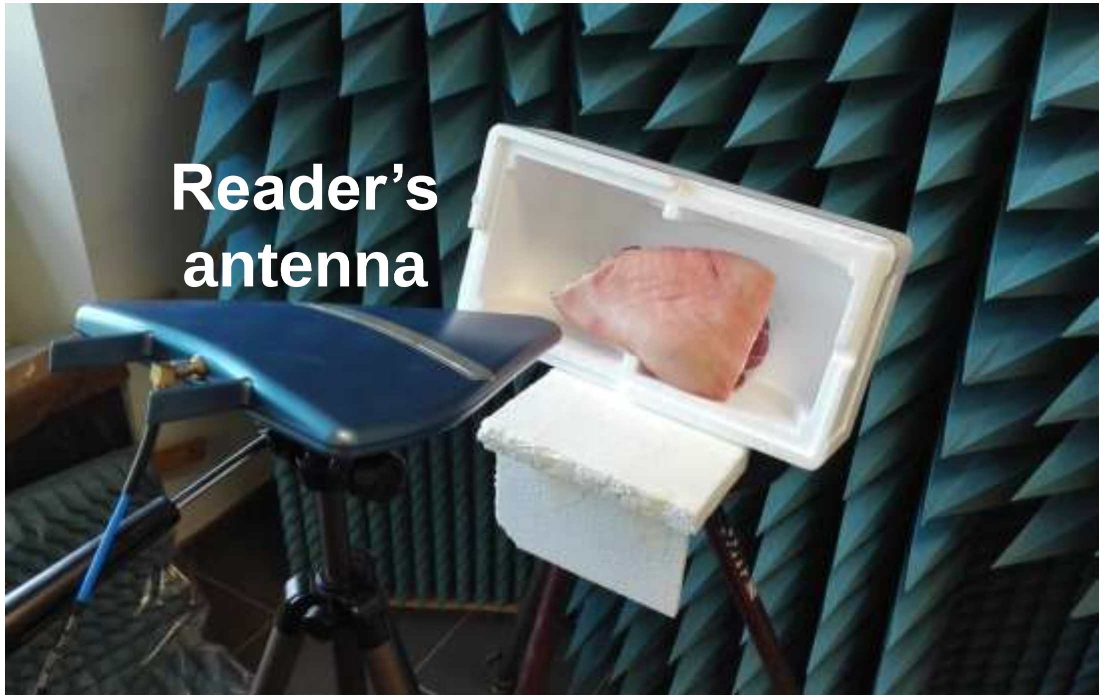
- Radiating loop antenna realized with **conductive yarn**
- Radiating antenna sewn on a **meshed support**
- Ultra-thin film for **coating** and providing biocompatibility
- **Silicone substrate** under loop exciter



Measurement set up

Realistic pork phantom

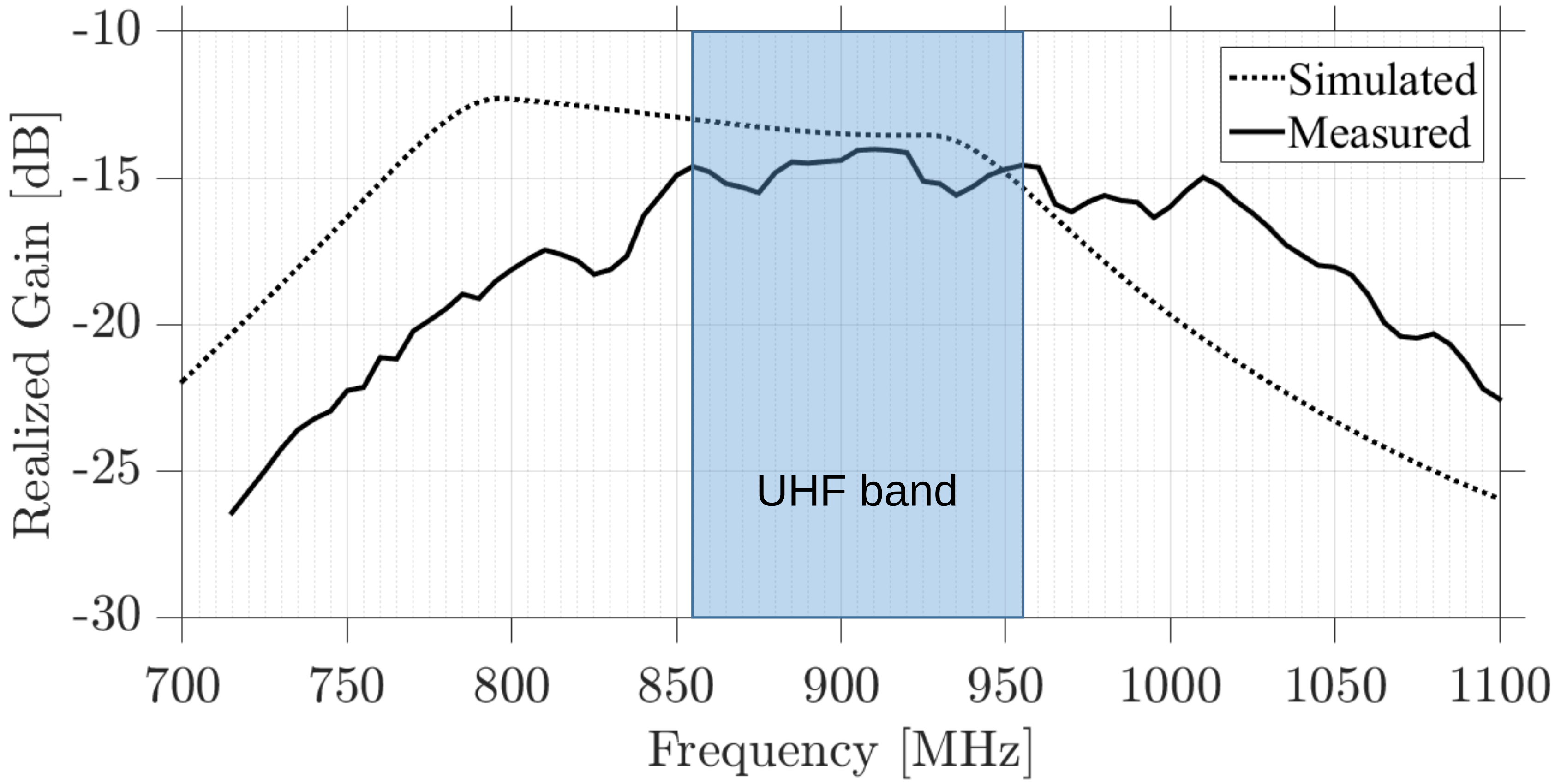




Measurement station: ***TAGFORMANCE -Voyantic***

Electromagnetic measurements

Realized broadside gain



Well accordance between measured and simulated results

The theoretical **read distance** at 870 MHz is up to 1.3 m

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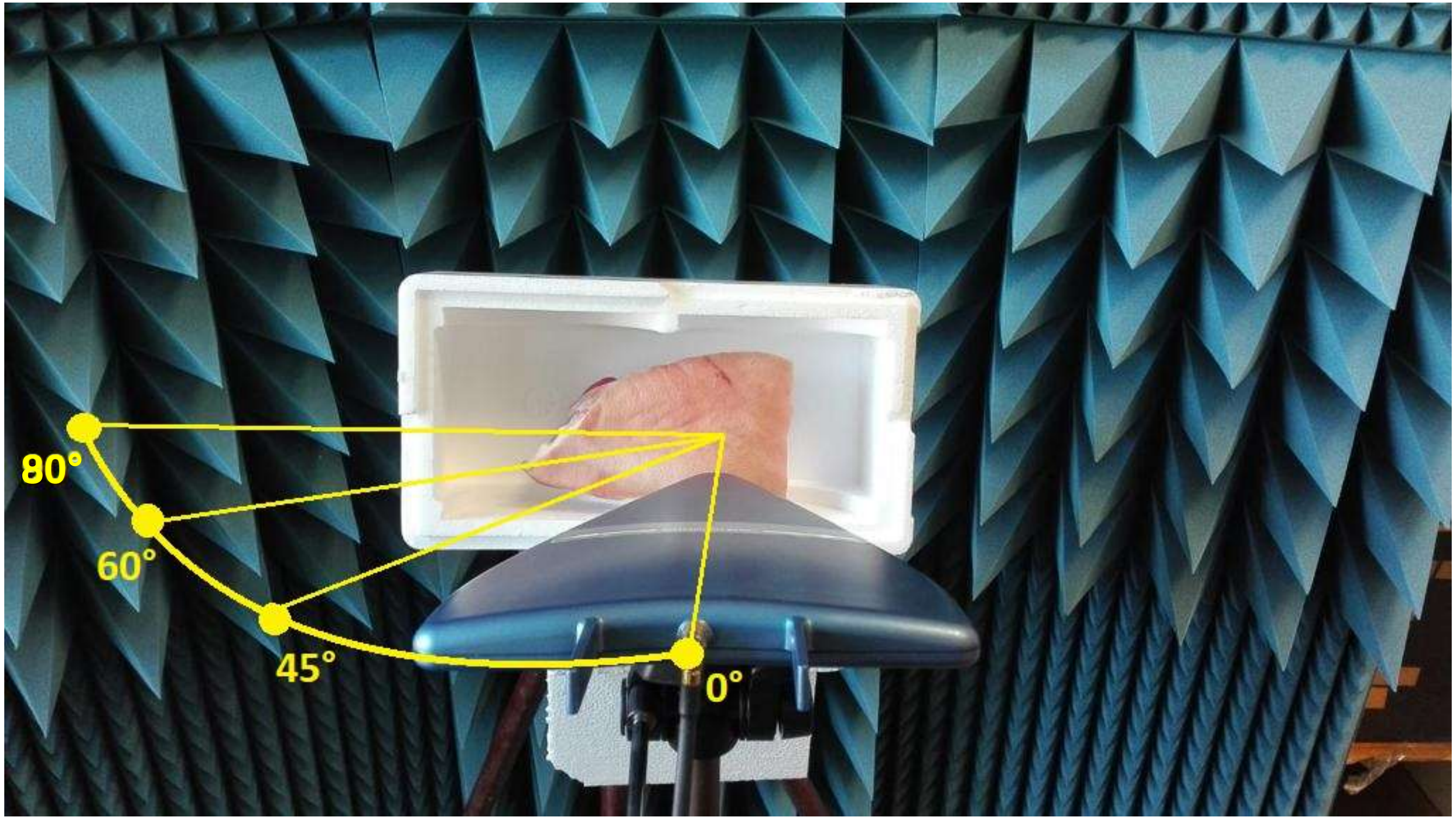
Reader-tag misalignments



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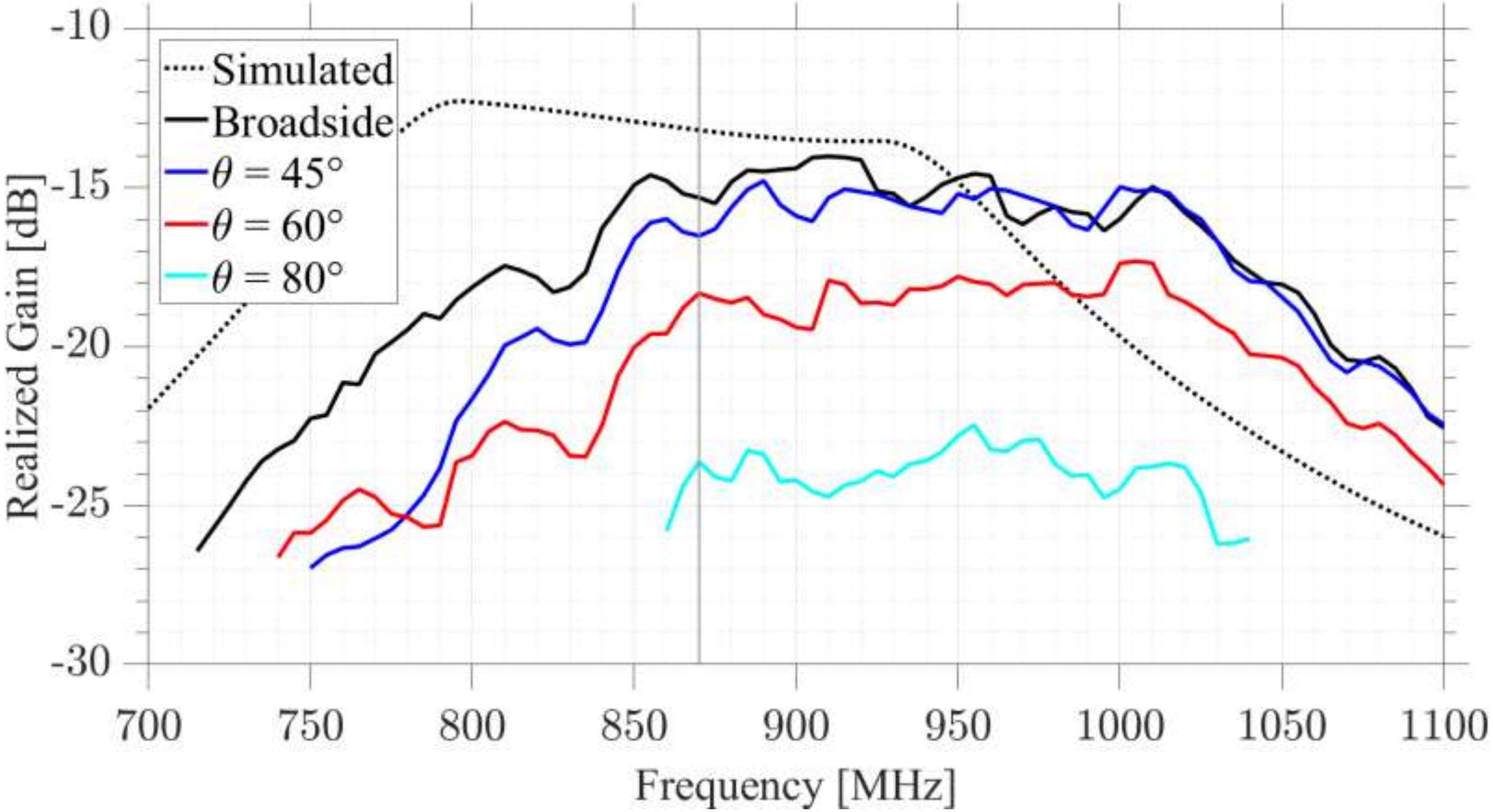

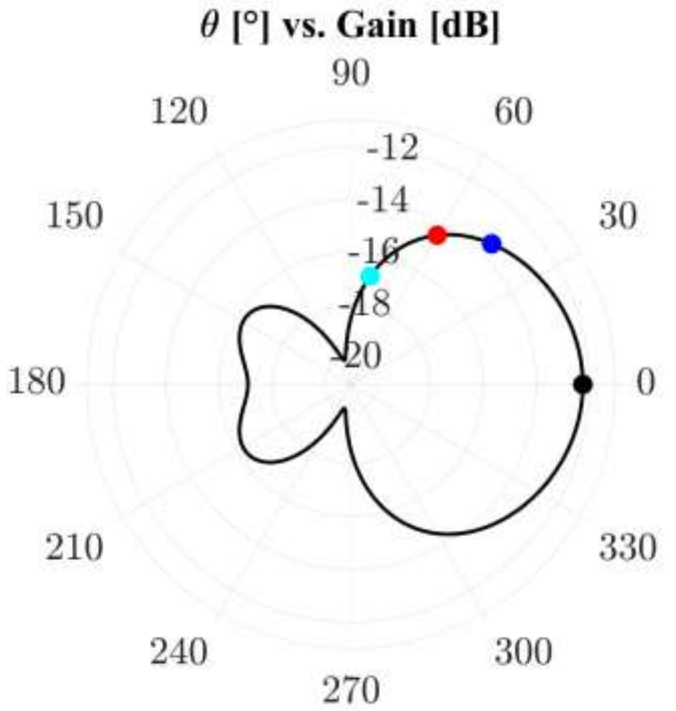

3 dB of gain degradation with a misalignment of 60°, representing the possible **cattle movements** during temperature detection

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Biocompatible meshed scaffold and metallic wire

Premilene mesh® by B.Braun

Non-absorbable threads used in surgical sutures

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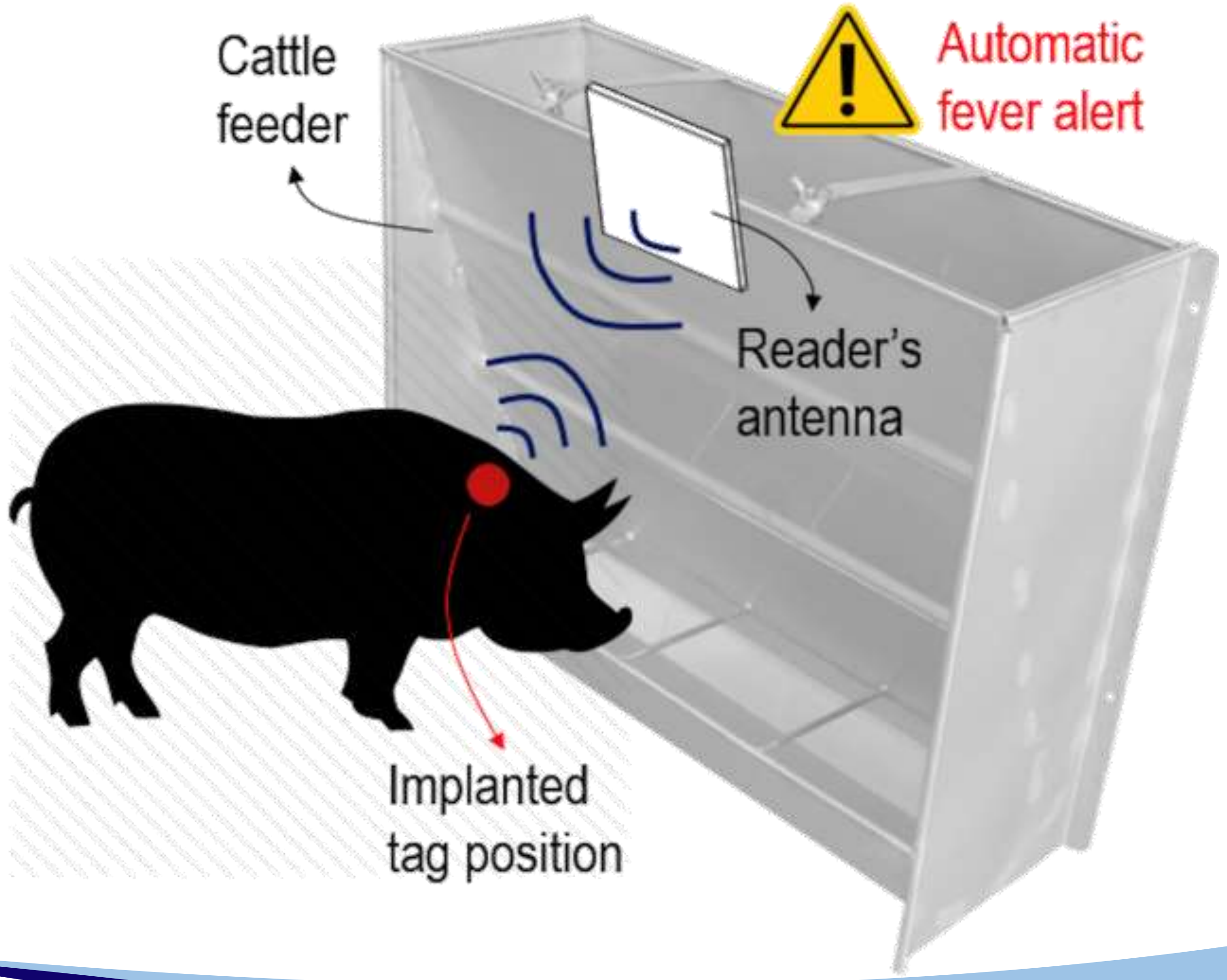
Biocompatible RFID temprature sensor

- Biocompatible
- **Battery-less**
- **Anti-migration** system thanks to meshed scaffold
- **Size** compatible with implantation
- Communication performance compatible with **automatic temperature detection**

Automatic fever measurement setup inside the cattle feeder



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Conclusions

- Feasibility of a **UHF-RFID telemetry** system for the detection of core **temperature in cattle**
- Design and **optimization** of an implantable antenna
- Prototyping of an **ultra-thin** square loop, deployed onto a scaffold-like textile substrate, working as **anti-migration support**.
- **Read distance** up to 1.3 m, compatible with automatic fever monitoring
- Indentification of **bio-compatible materials** for device manufacturing

Next step…

- **Realistic temperature measurements** inside cattle and validation of the whole system