# S-band Testbed for 5G Epidermal RFIDs

**F. Amato**\*,

A. Di Carlofelice+, C. Occhiuzzi\*, P. Tognolatti+, G. Marrocco\*
**\*University of Rome Tor Vergata**
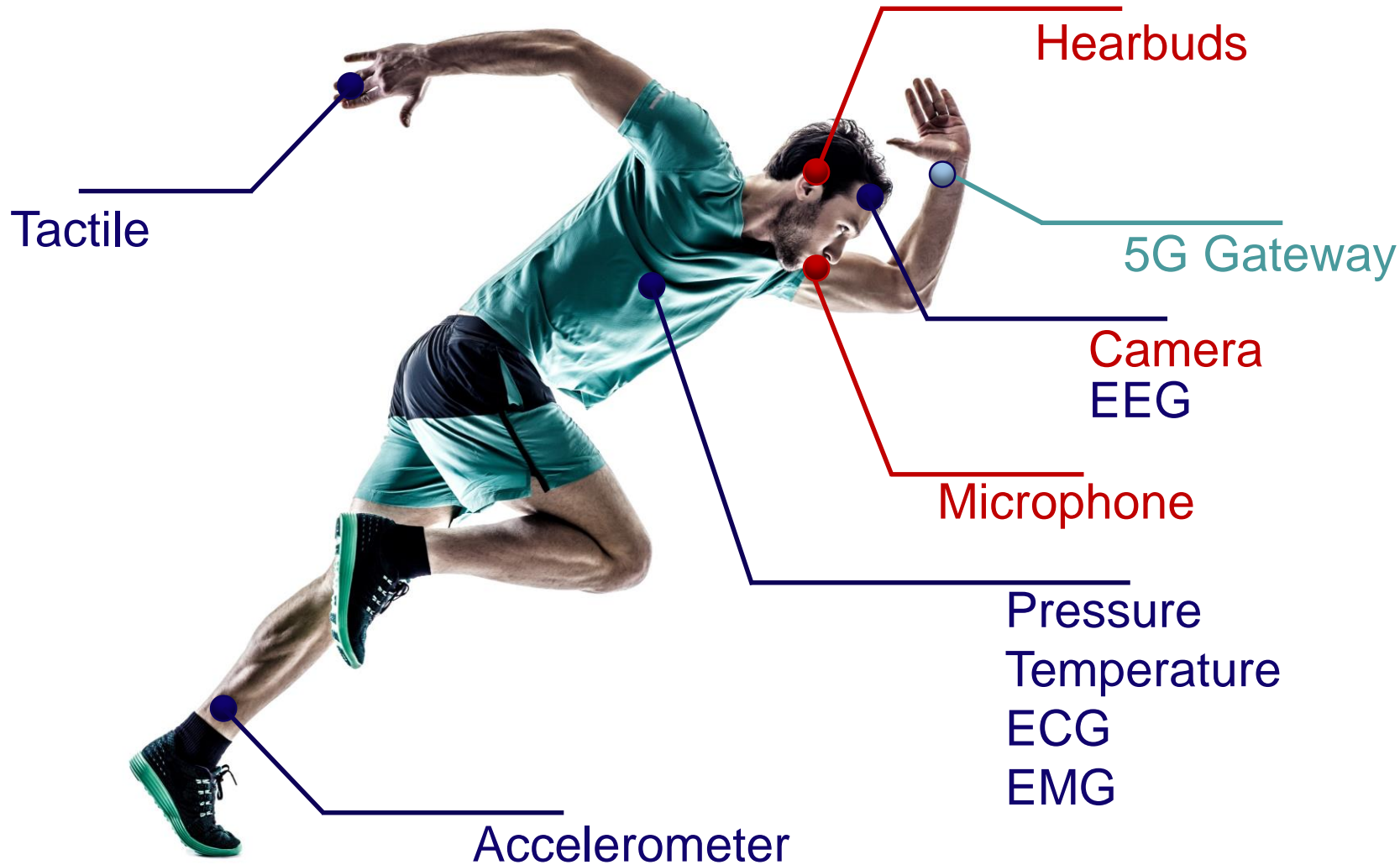**+University of L'Aquila**
www.pervasive.ing.uniroma2.it

# Wireless Health Monitoring

TOR VERGATA
UNIVERSITÀ
DEGLI STUDI
DI ROMA

Hearbuds

Tactile

5G Gateway

Camera
EEG

Microphone

Pressure
Temperature
ECG
EMG

Accelerometer

Biomedical digital and hardware sensors are essential for supporting prevention of health risks, self-empowerment of patients, diagnostics, treatments, and independent living in a world of ever-expanding and aging population

Nonetheless, the **hardware complexity** and the **high-power consumption** often hamper their widespread use.
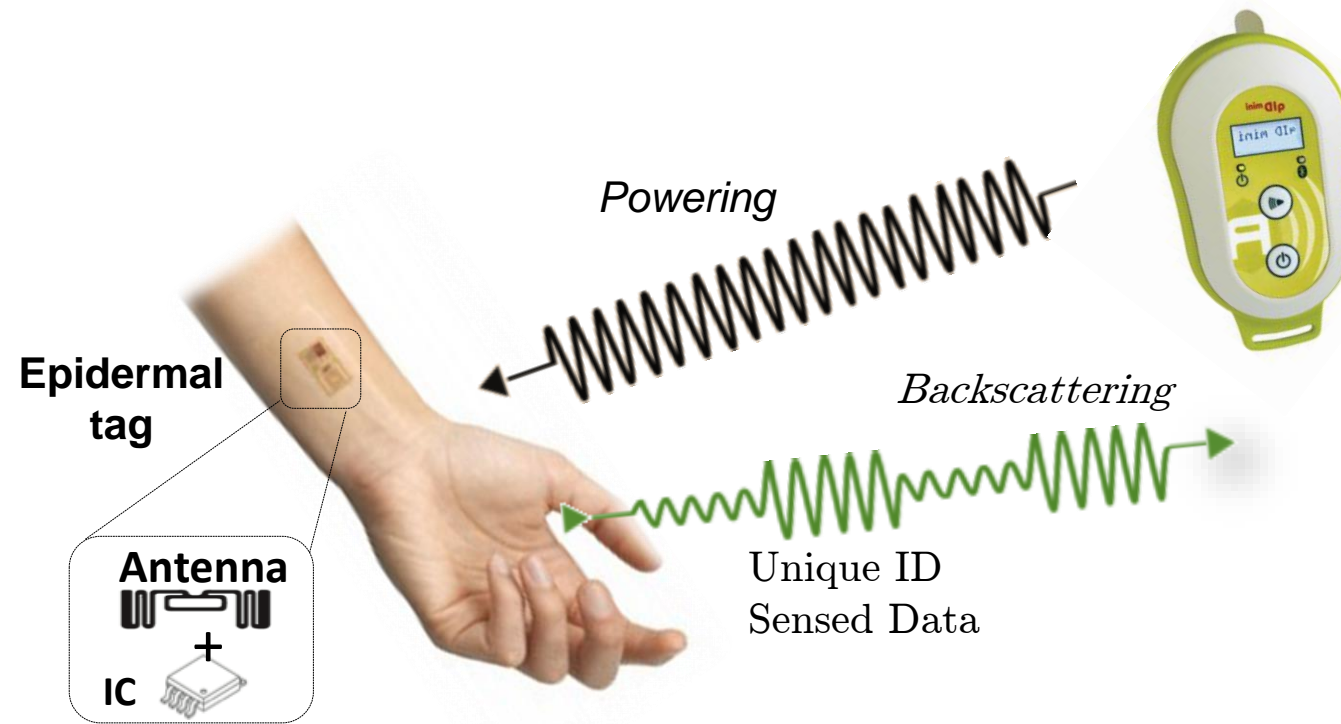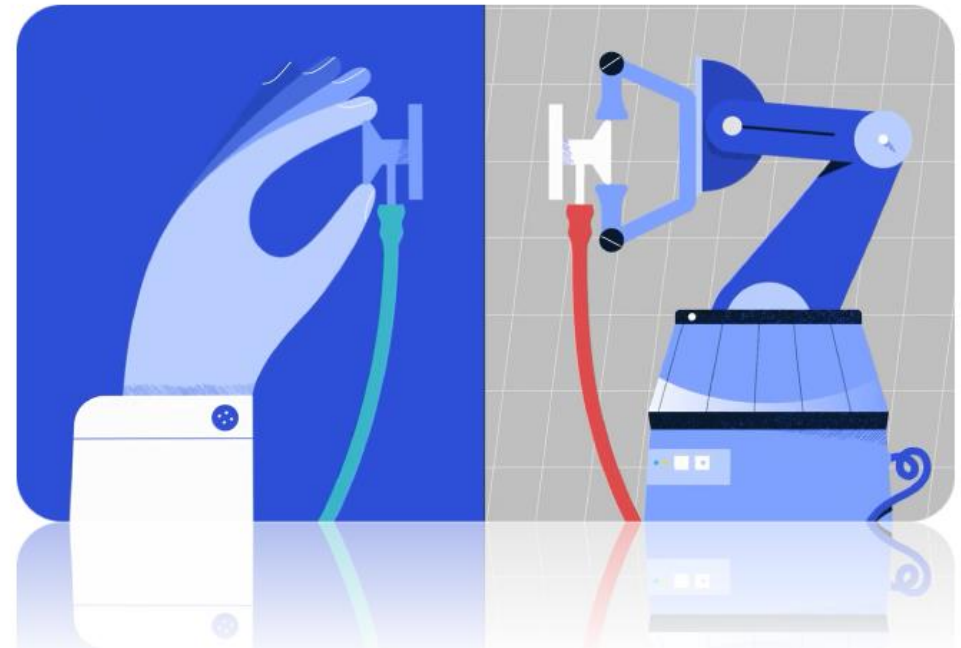
*Wearable Sensors*

*I/O Devices*

*Smartwatch*

L E₂P

# Wireless Health Monitoring with RFIDs

UHF RFIDs allow to use **low-cost**, **comfortable** and **battery-less** epidermal configurations by exploiting **backscattering modulation.**
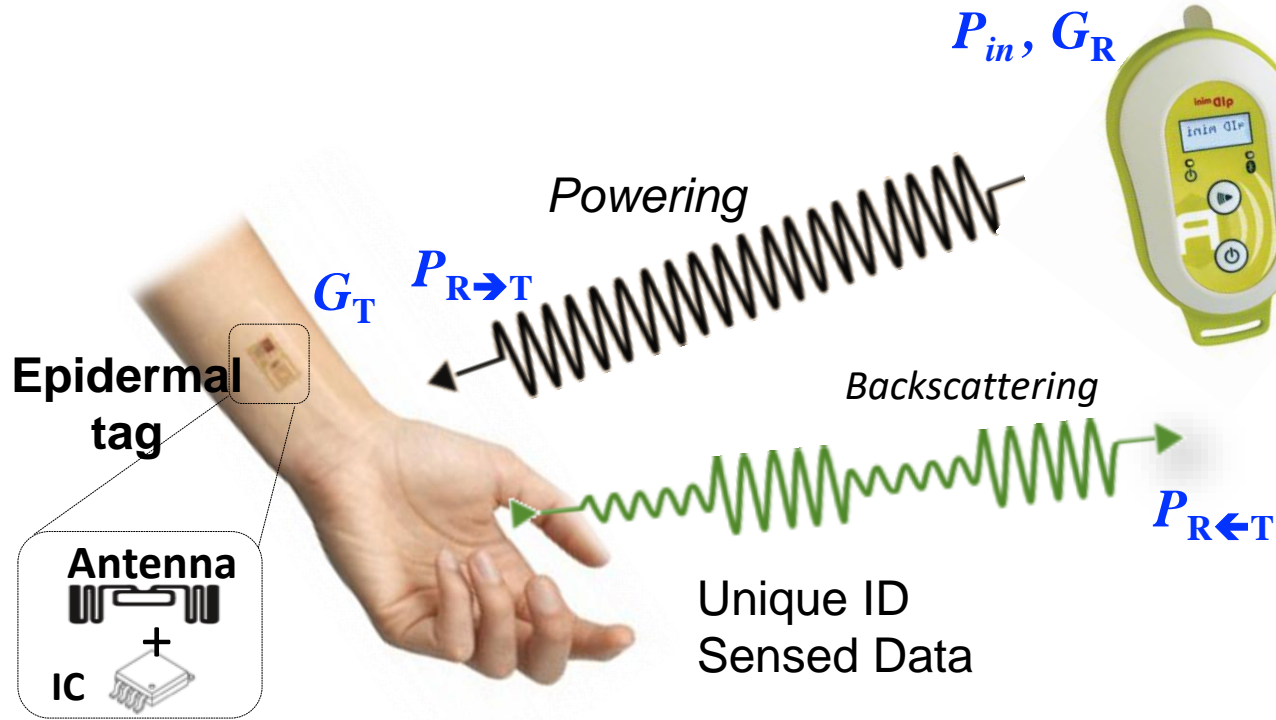
# 5G Communications & Healthcare



Since UHF-RFIDs have **short ranges**, **a narrow bandwidth**, and a limited use due to **the need of an RFID reader,** a convergence **RFIDs** within the forthcoming wide-band, high-speed Fifth Generation (5G) wireless communication systems operating at **microwave** and **mmWave** frequencies should be encouraged to develop a **5G-RFID network embedded within the 5G infrastructure**.

This presentation introduces an **experimental setup** for testing **5G-RFID epidermal tags** operating in **S-band** (3.6 GHz)

The benefits of backscattering communications at **microwave frequencies**, outlined for the first time in 2008 [1], triggered the development of new RFID applications [2] and devices [3]. Recently, these advantages have been highlighted for **epidermal and wearable RFID** [4] as well.

# RFID Links

Although counter intuitive at first, similar UHF communication ranges can be achieved at both microwaves and mmWaves if the **effective aperture of a 5G-RFID tag remains constant** with respect to frequency *f*.
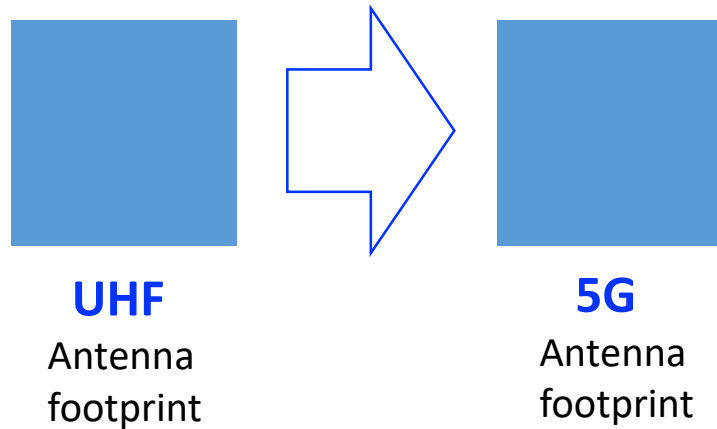
$P_{in}, G_R$

*Powering*

$G_T$    $P_{R \to T}$

**Epidermal tag**

*Backscattering*

$P_{R \leftarrow T}$

Unique ID
Sensed Data

**Antenna**

**+**

**IC**

$$r_{max} = \sqrt{\frac{P_{in} G_R G_T}{p_{chip}} \frac{c}{4\pi f}}$$

Max read distance

○ Path-loss increases with frequency

○ **Designing an RFID system at mW and mmW might sound counter-intuitive because of a reduction of read distance is expected…**

Free-space attenuation

$$P_{R \to T} = P_{in} G_R G_T \tau \eta \left( \frac{c}{4\pi f r} \right)^2$$

L E P

**UHF**
Antenna footprint

**5G**
Antenna footprint

.. however, if the same effective aperture of the UHF is preserved for higher 5G antennas, **the path loss increase could be compensated,** and same performance would be obtained
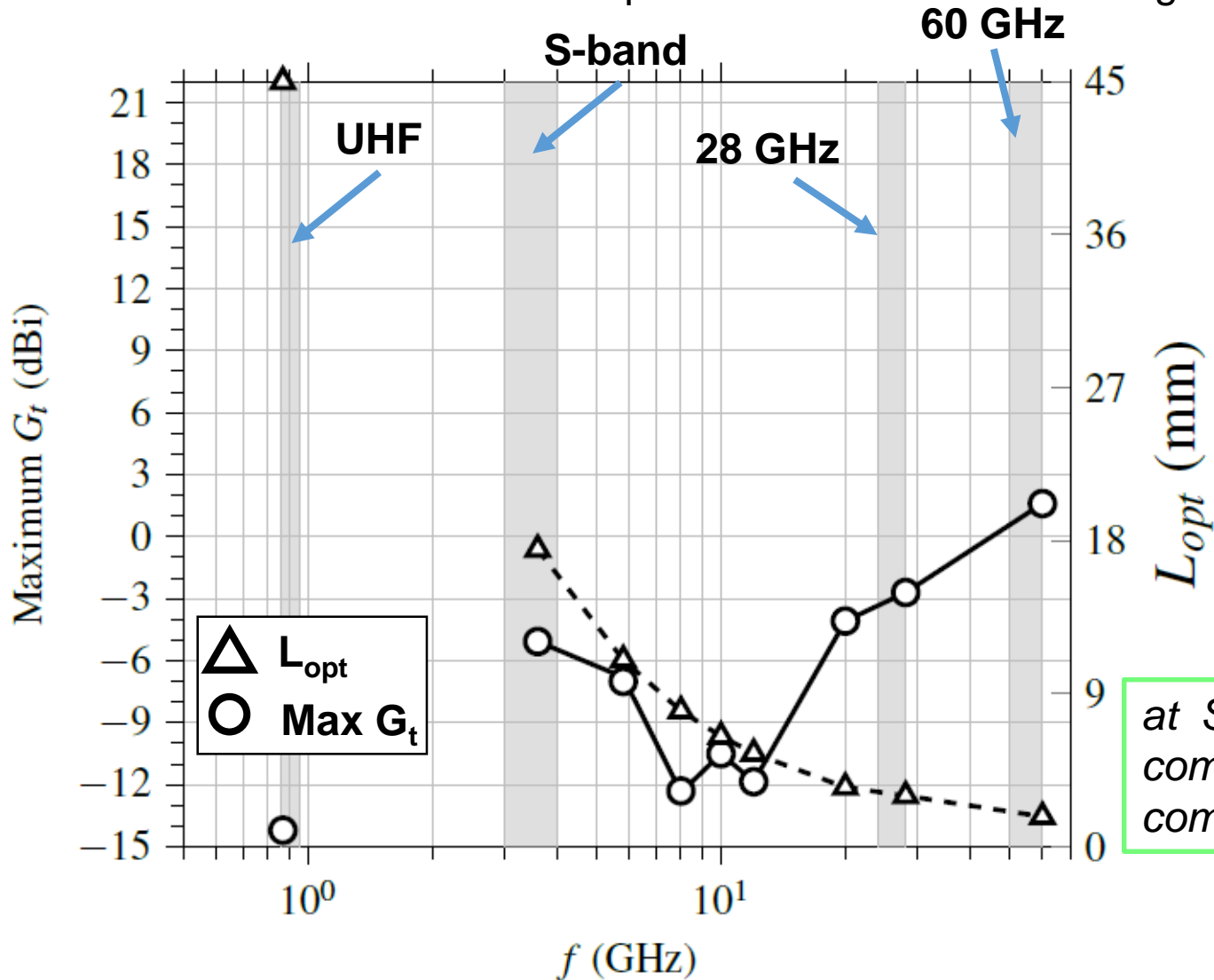
$A_{eT}$ Effective aperture of the antenna

$$A_{eT} = G_T c^2/(4\pi f^2)$$

$$P_{R \to T} = P_{in} G_R A_{eT}/r^2$$

Independent on frequency

# Frequency Bands, Gains, and Sizes

Epidermal tags at 5G frequencies can have higher gains than at UHF, despite the higher body losses, because there is a lower penetration of the electromagnetic fields into the deeper tissues of the body.



- Path loss degradations at **S-bands (2 – 4 GHz)** can be almost entirely compensated by the gain improvements of a single antenna whose size is **below 2 cm;**

- At **higher frequencies** (28 GHz and 60 GHz), an **array** will be required, but the size of each element will be **less than 2 mm;**

- Frequencies within the **7 - 20 GHz region** should be avoided because the **relaxation** of human body tissues degrades performances.

*at S-band there is a good trade-off between optimal communication performances and reduced size and complexity for an epidermal RFID link.*

Since dedicated RFID readers and microchip transponders are not available for 3.6 GHz RFIDs yet, a **custom testbed operating in the S-band** was arranged to experimentally characterize the radiation and communication performances (data rate, and backscattering) of new families of tags.

The setup consists of **two modules**:

- a bistatic **READER** system based on Universal Software Radio Peripheral (USRP) N210 by Ettus Research,
- a **BACKSCATTERING TAG** equipped with a two-state impedance modulator emulating the RFID chip to be connected to the tag antenna.
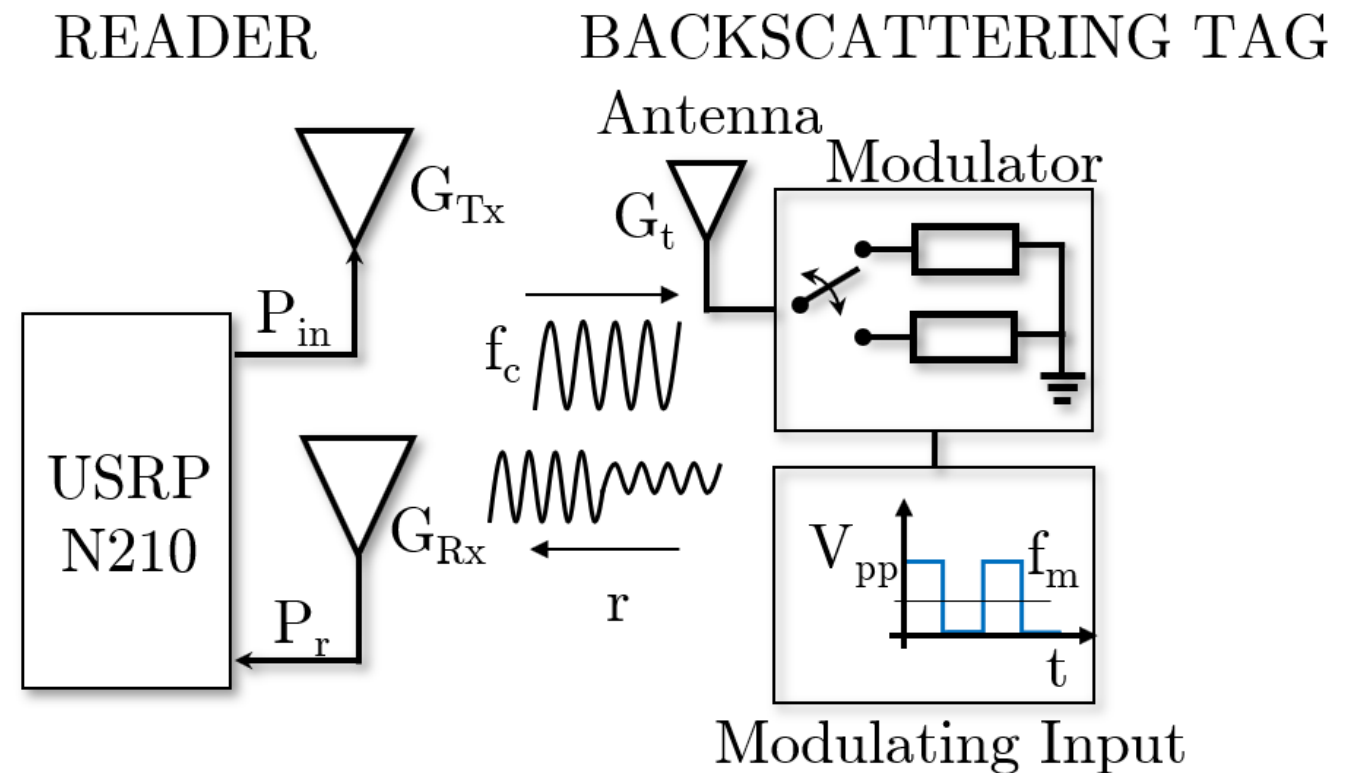


The reader generates a continuous wave (CW) at carrier frequency $f_c$ = 3.6 GHz and, through the transmitting antenna, it sends it to the tag that modulates and reflects the data back to the receiving antenna

The **modulator** includes:

- a **biasing network** that injects, through a waveform generator, a modulating square wave of frequency $f_m$, peak-to-peak voltage $V_{pp}$, and a DC offset.
- a **PIN diode** (BAP55LX) that ideally acts either as a short (s.c.) or an open circuit (o.c.) if either forward or no biasing voltages are applied, respectively.

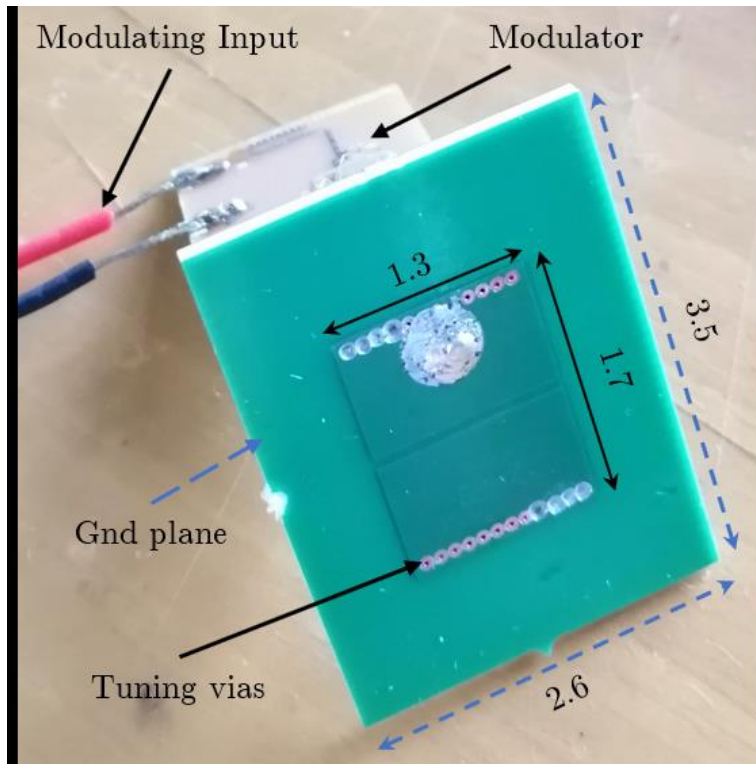The layout was fabricated onto a 0.8 mm thick FR4 PCB.



PIN diode

Modulating wave
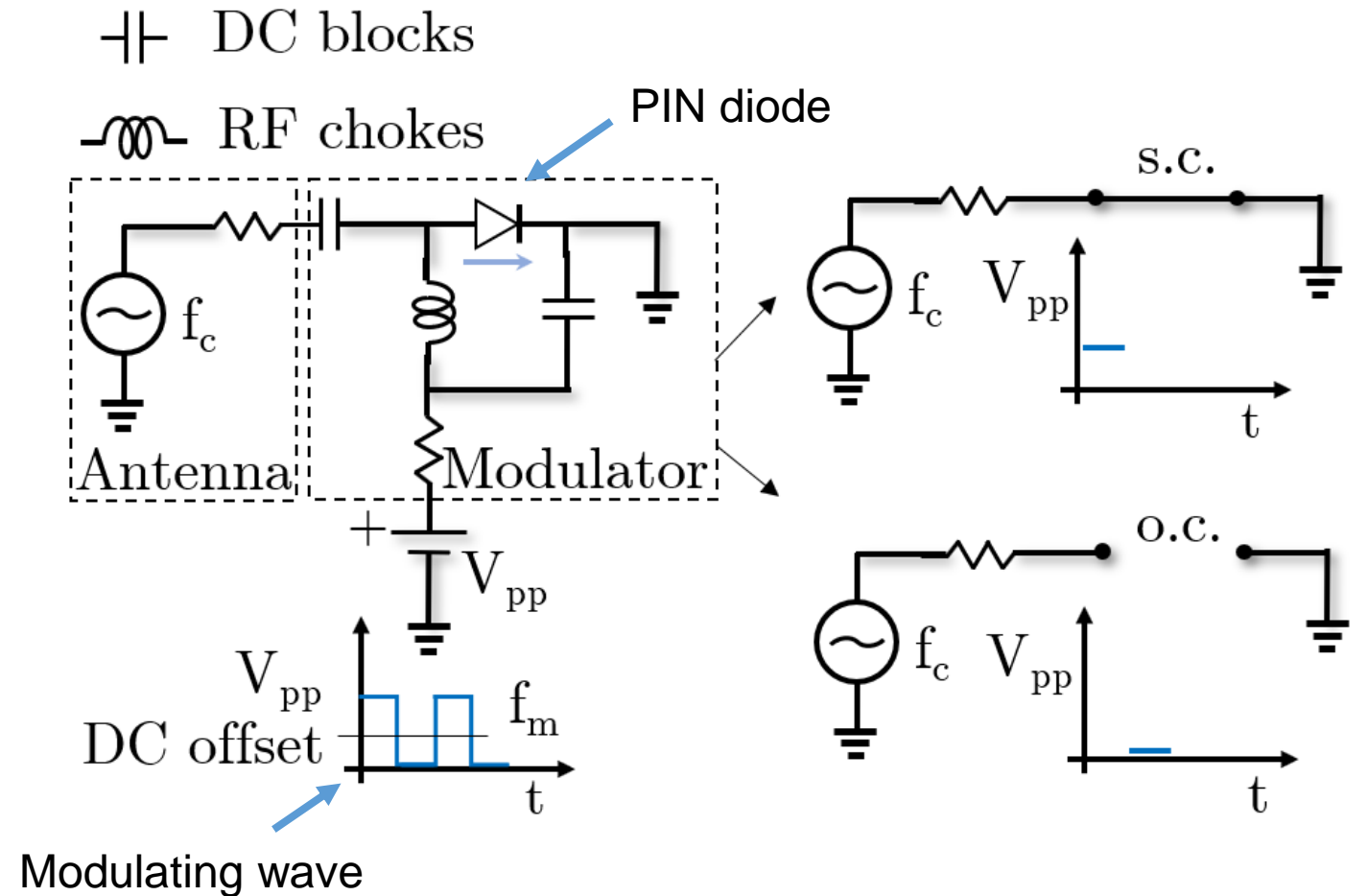
The setup was preliminary tested with a patch antenna, to be used as reference for the measurement of new designs of S-band tags.

The patch has a double-folded layout with a central radiating slot.

1.52 mm thick IS680 AG345 substrate, $\varepsilon_r$ = 3.45, tan$\delta$ = 0.0026, at 5 GHz

By selectively removing vias (12 for side) at the two edges of the patch, a fine tuning can be achieved in the surroundings of 3.6 GHz to optimize the antenna response when it is placed onto different materials.
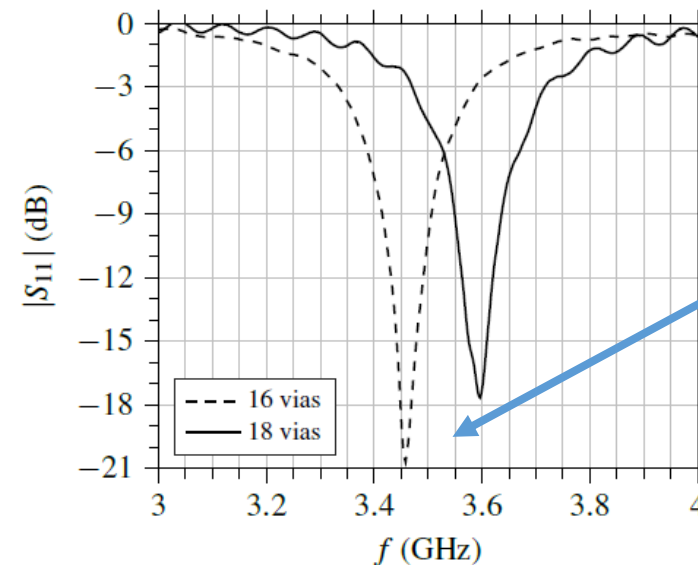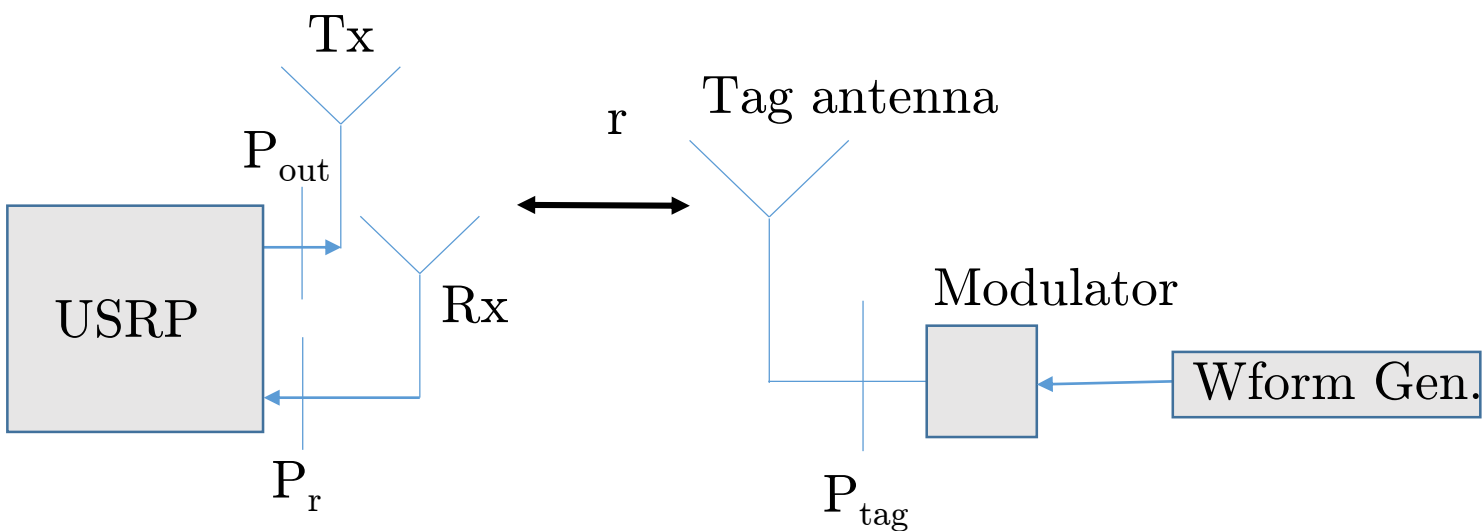
A frequency shift is observed when removing either 3 or 4 vias per side on the patch antenna placed in free-space.
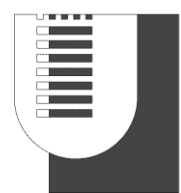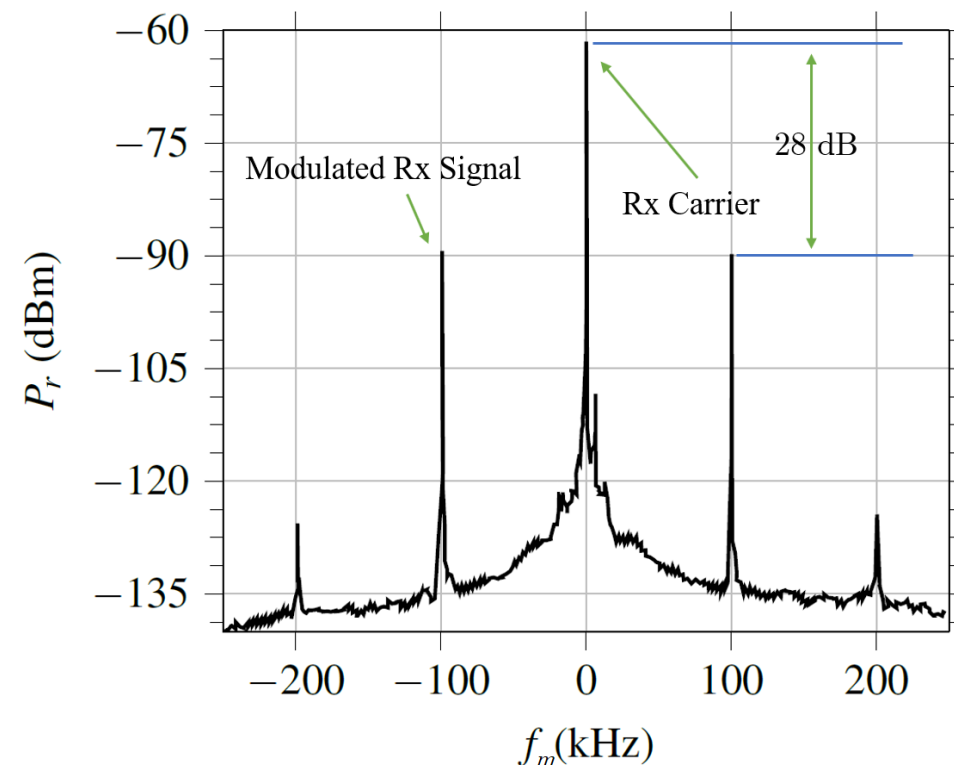
# Backscattering at 3.6 GHz

The whole 3.6 GHz epidermal RFID link was tested by placing the transmitting and receiving antennas of the reader at 15 cm from the tag.
The reader generates a CW of -30 dBm that the tag modulates with a 100 kHz square wave.



**r = 15 cm, Pin = -30 dBm**
Modulation: $f_m$ = 100 kHz,
$V_{pp}$ = 750 mV,
DC offset = 375 mV

Received spectrum upon backscattering

Epidermal RFID sensors operating at microwave and mmWave frequencies could open new solutions for monitoring health parameters of multiple users in real-time and without using cables.

This work has introduced a **testbed**, consisting of an **USRP-based reader** and **a reference tag**, for investigating the capabilities of 5G-RFID sensors operating at 3.6 GHz and used either in free-space, or on wearables, or on the body.

By collecting both amplitude and phase of backscattered signals in S-band, **this setup will be the starting point for investigating wearable and epidermal 5GRFIDs.**

# References
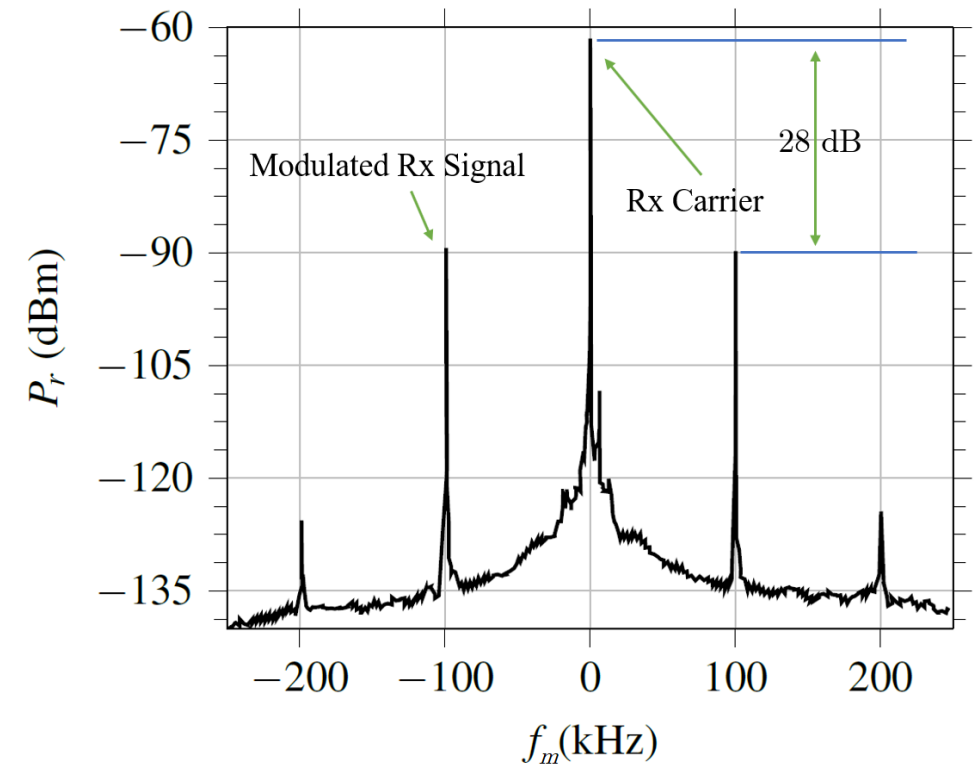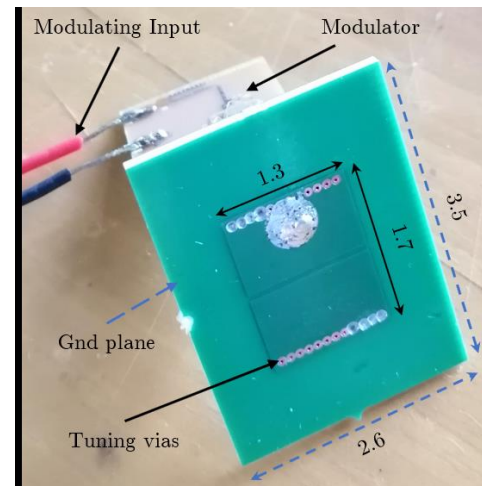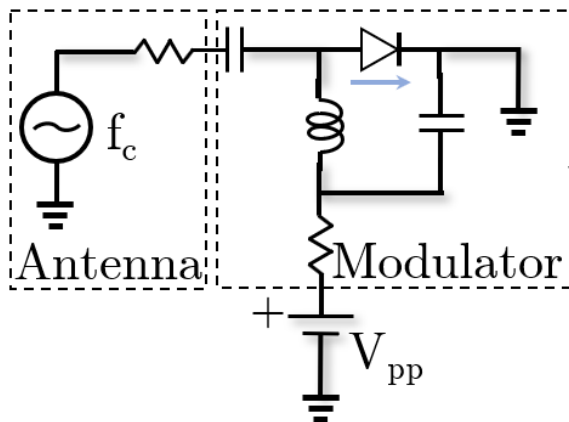
[1] G. D. Durgin, "The hidden benefits of backscatter radio at 5.8 GHz," in *2008 USNC/URSI National Radio Science Meeting*, Jan. 2008.

[2] M. B. Akbar, F. Amato, G. D. Durgin, G. Pisharody, and S. . Suh, "RFID tag load impedance measurement using backscattered signal," in *2015 USNC/URSI National Radio Science Meeting*, July 2015, pp. 1762–1763.

[3] F. Amato and G. D. Durgin, "Tunnel diodes for backscattering communications," in *2018 ATRASC/URSI Atlantic Radio Science Meeting*, May 2018, pp. 1–3.

[4] F. Amato, C. Occhiuzzi and G. Marrocco, "Epidermal Backscattering Antennas in the 5G Framework: Performance and Perspectives," in *IEEE Journal of Radio Frequency Identification.*