S-band Testbed for 5G Epidermal RFIDs

Francesco Amato*(1), Alessandro Di Carlofelice(2), Cecilia Occhiuzzi(1), Piero Tognolatti(2), and Gaetano Marrocco(1)
(1) Pervasive Electromagnetic Lab, Department of Civil and Computer Science Engineering, University of Roma Tor Vergata, Italy (e-mail: francesco.amato@uniroma2.it).
(2) Department of Industrial and Information Engineering, and Economics, University of L'Aquila, Italy.

Abstract

RFID-based epidermal electronics for healthcare applications, if integrated within the next-generation (5G) wireless network, could enable new sensing abilities characterized by high-speed transfer of data, small sizes, and reduced complexity. Within the 5G spectrum, the S-band allows to design antennas with small footprint and higher gains than UHF-RFIDs. This paper introduces, therefore, a 5G-RFID experimental setup to investigate the performance of epidermal RFID tags operating at S-band.

1 Introduction

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 antennas [4] as well. Both High Frequencies (HF) and Ultra High Frequencies (UHF) do not allow to either simultaneously read multiple epidermal sensors collecting biophysical signals (ECG, EEG, EMG) or to read data when an user is walking or running across a reading gate. The forthcoming Fifth Generation (5G) of wireless communication systems, instead, provides larger bandwidths, lower latency (down to 1 ms), and high data rates at both microwaves and mmWave frequencies [5]. In particular, the 5G S-band (2 - 4 GHz) is a good compromise for obtaining both high gains and small antenna footprint. The high-speed communication links (above 0.5 Gbps) up to 1 meter would encourage the deployment of massive epidermal sensors to collect detailed maps of biophysical parameters of both single and multiple users. Following preliminary results, this paper introduces an experimental setup for testing 5G-RFID epidermal tags operating in S-band (3.6 GHz).

2 S-band RFIDs

Although counter intuitive at first, similar UHF communication ranges can be achieved at both microwave and mmWave frequencies as long as the effective aperture of a 5G-RFID tag remains constant with respect to frequency f. Therefore, the gain of an RFID tag G_t has to increase as: $G_t(f) = \frac{G_t(f_{UHF})}{f_{UHF}^2} f^2$, where $G_t(f_{UHF})$ = -14 dBi for typical epidermal loops at $f_{UHF} = 870$ MHz. 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. In particular, the degradation due to path loss in the S-band can be almost entirely compensated by the gain improvements of a single loop antenna whose optimal size L_{opt} is below 2 cm. At higher frequencies (28 GHz and 60 GHz), instead, a loop array will be required, but the size of each element will be less than 2 mm. Finally, the frequencies within the 7 - 20 GHz region should be avoided because the relaxation of human body tissues degrades performances. The results shown in Fig. 1 highlight that, at S-band, there is a good trade-off between optimal communication performances and reduced size and complexity for an epidermal RFID link.

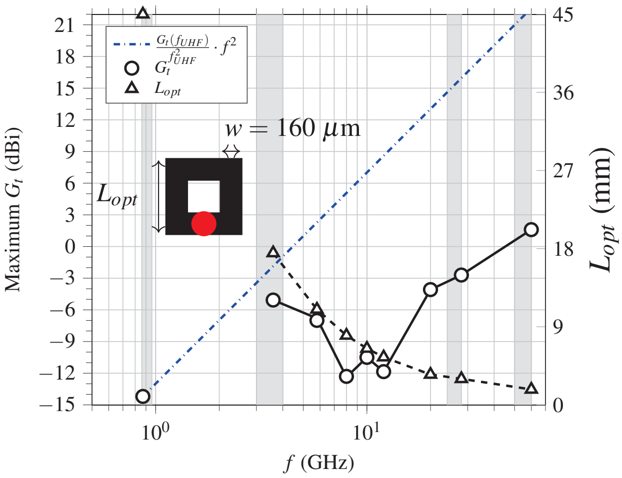
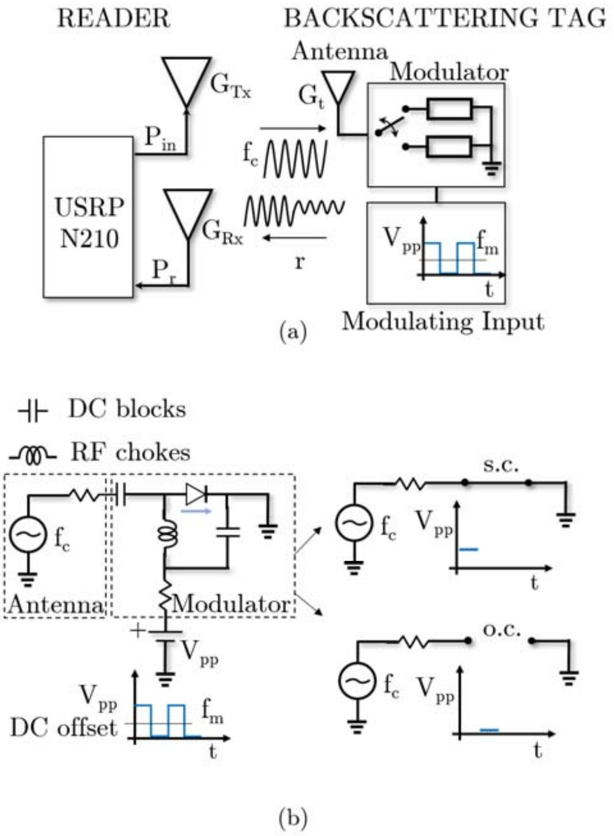


Figure 1. Simulated optimal gains of epidermal loops on skin. The 5G frequency bands are shaded in gray. The dashdotted line displays the theoretical $G_t(f)$ required to keep unchanged, at every frequency f, the tag read distance.

3 Experimental Characterization Setup and Results

As 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



(a)

(b)

Figure 2. (a) Block diagram of the experimental setup in bistatic configuration; and (b) simplified schematic of the impedance modulating tag.

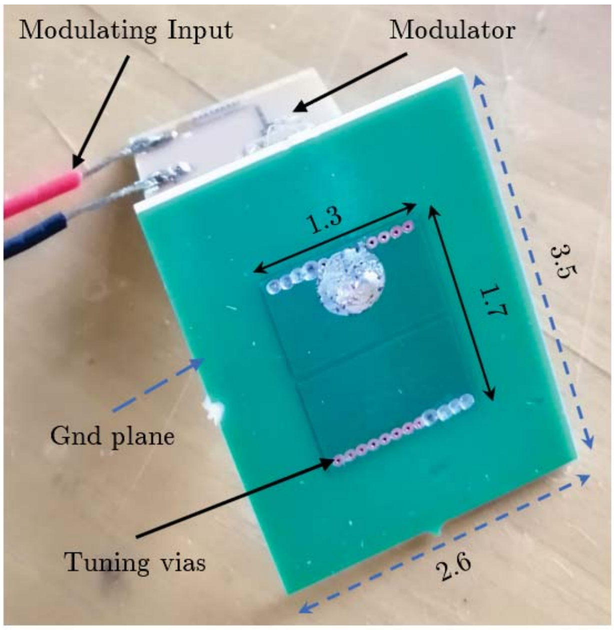


Figure 3. The 3.6 GHz RFID tag. Sizes are in cm.

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$^{\text{TM}}$, and 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 (Fig. 2a).

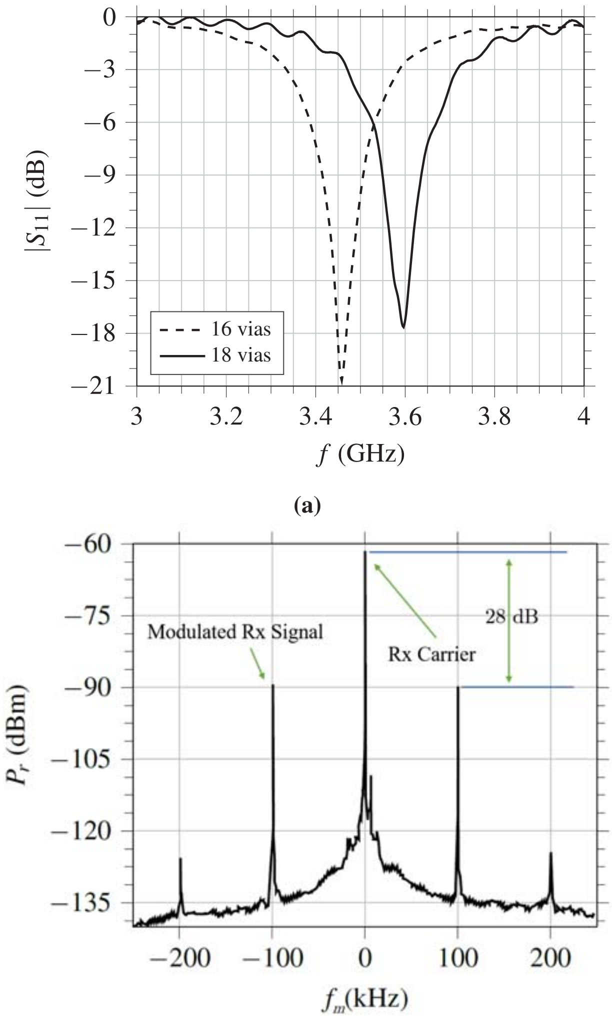
The modulator includes (Fig. 2b) a biasing network and a PIN diode (BAP55LX) that ideally acts either as a short (s.c.) or an open circuit (o.c.) if either forward or no biasing voltages are applied, respectively. The biasing network injects, through a waveform generator, a modulating square wave of frequency f_m, peak-to-peak voltage V_{pp}, and a DC offset. The layout was fabricated onto a 0.8 mm thick FR4 PCB.

The setup was preliminary experimented with a patch antenna, to be hereafter used as calibrated reference for the measurement of new designs of S-band tags. The patch has a double-folded layout with a central radiating slot (Fig. 3). It was fabricated on a 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. An example of tuning through vias is shown in Fig. 4a, where a frequency shift is observed when removing either 3 or 4 vias per side on the patch antenna placed in free-space.

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. An example of the spectrum of whole received signal, P_r, is shown in Fig. 4b.

4 Conclusion

Epidermal RFID sensors operating at microwave and mmWave frequencies could open up 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 5G-RFIDs. In a future expansion, the impedance modulator will be modified to transmit sensor data. For this purpose, some lumped components of the modulator will be made variable with some external parameters, for instance by using chemical loaded inter-digital capacitors that are sensitive to pH or skin electrolytes, so that sensor data will be



(a)

(b)

Figure 4. (a) Power reflection coefficients of the reference patch antenna. Tuning through vias is highlighted. (b) Received spectrum upon backscattering. r = 15 cm, P_{in} = -30 dBm. Modulation: f_m = 100 kHz, V_{pp} = 750 mV, DC offset = 375 mV.

transmitted through an amplitude/phase modulation.

5 Acknowledgements

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