Wearable Soft Grid Array Antenna for S-band 5G Communication

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Abstract

Potential convergence of wearable and epidermal antennas for battery-less communication with the emerging 5G framework, may boost the ultrafast and delay-free monitoring of biophysical parameters. 3.6 GHz epidermal antennas have already been demonstrated to possibly provide the same performance of a conventional UHF RFID link but with much larger band. Even better performance can be achieved by using wearable grid-arrays that may increase the read distance up to 6m in battery-less mode while keeping the feeding and fabrication complexity low. Here, the optimal performance of on-skin grid-arrays are investigated and a first prototype is manufactured and tested onto a body phantom.

1 Introduction

Forthcoming fifth generation (5G) systems promise to offer the next big step forward in data communication with higher data rate, lower latencies and wider bandwidths than previously available. Many local area networks, from leisure to industry, could take advantage of 5G capabilities, thanks also to the envisaged interoperability of platforms and technologies. Among them, wearable devices and body-centric communication will sensibly boost their adoption, especially backscattering-based passive radios which require neither batteries nor local power supply, and hence they will not impact on energy, waste and pollution [1].

UHF Radiofrequency Identification Technology (RFID) has been identified as well suited to these applications for some time, thanks to the absence of batteries, the minimal required electronics, the sensing capabilities and the possibility to reach read distance up to 5-7 m [2]. A particular class of RFID devices are those for Epidermal Electronics, another emerging technology aimed at turning bulk medical devices into soft, flexible and sometimes even stretchable membranes, for direct on-skin applications [3]. Preliminary studies demonstrated the potential advantage of on-skin antennas at 3.6 GHz for future 5G RFID systems. Even accounting for the higher free space attenuation, 3.6 GHz antennas are suitable to provide the same read distance of the corresponding UHF [4] whilst boasting aforementioned advantages.

However, the major limitation of on-skin passive backscattering communication remains the short transmission range, especially for wearable devices operating in high frequency bands in which the path loss imposes attenuations up to 70 dB/m.

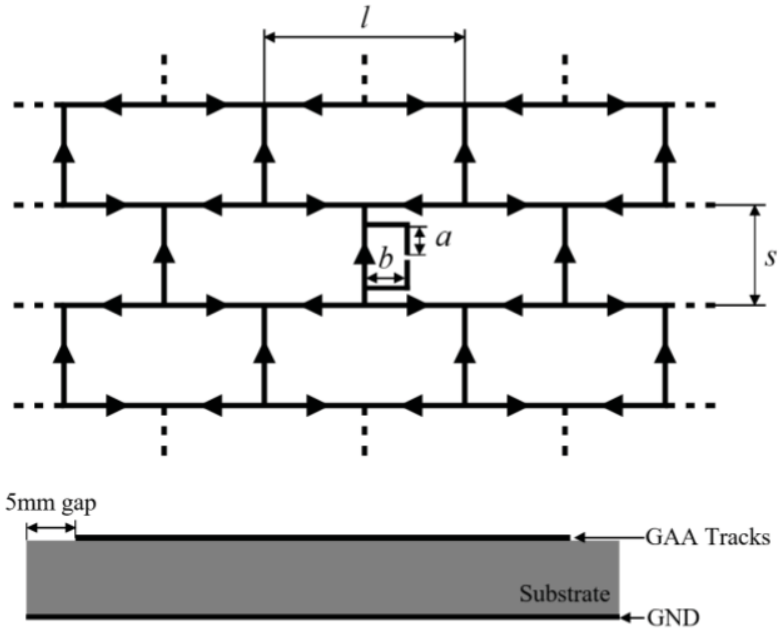


Figure 1 Multi-cell GAA structure featuring T-match feeding network with indication of the typical current pattern and cross-sectional view.

To mitigate the problem and establish a robust link, an increase of the gain is required, and hence the use of multiple antennas to form high efficiency arrays would be suitable. Currently, only arrays of patch or slot antennas, including dedicated beam forming network (BFN) have been proposed for wearable applications. However, since they are multi-layered and bulky structures, concerns related to their effective usability cannot be neglected [5]. Hence, alternative layouts must be introduced.

The paper investigates a soft wearable/epidermal grid array for 3.6 GHz communications. The grid-array antenna (GAA) was originally proposed by Kraus in 1964 [6]. It is nowadays a well-known structure, largely exploited at mm-wave frequency for antenna-in-package technology and with great advantages in terms of high gain, bandwidth, simple feed, low profile, lightness and easy construction. Such features are also suitable for wearable antennas, since they guarantee lightweight, thin, and even highly breathable layouts.

2 Layout and Parametric Analysis

The elementary structure of the wearable grid array is shown in Fig.1. Four cells are spaced, with $s = \lambda / 2$ and $l = 2 s$. The form factor of the cells is such that currents on vertical elements are in phase and act as radiators, while couplets of horizontal currents are in phase reversal, and they hence act as transmission lines without contributing to radiation.

Unlike the conventional grid-array, the proposed layout is fed at its central element to allocate an integrated circuit transponder (IC), through a T-match network [7] to finely tune the input impedance. The layout is particularly thin, since a 2 mm-thick ($\sim\lambda /20$) silicone rubber slab ($\varepsilon_r= 3$, $\text{tg}\delta=1.4\cdot10^{-3}$) has been adopted to separate the underlying ground plane, protruding 5mm over the grid for each side, as well as to obtain a soft and conformable device.

The performance of the grid-array when placed onto the skin is here numerically investigated by FDTD simulations including a 150x150 mm^2 3-layers body phantom [4] (Skin 1mm, ε_r = 36.92, σ = 2.08 - Fat 3mm, ε_r = 5.16, σ = 0.16 - Muscle 31mm, ε_r = 51.32, σ = 2.65).

Having fixed the cell size s=28.25 mm and l=56.5 mm, the optimum number of elements has been identified as a trade-off between radiation performances and size.

Fig. 2 shows the maximum radiation gain and the efficiency when moving from 1 cell (a single loop – two vertical radiators) to eight cells (15 radiators). As expected, the profile of gain and efficiency is not linear with the overall size of the antenna due to the combination of the increasing directivity and power dissipation into the human body. The optimal efficiency arises for a grid-array of four cells, after that the gain remains nearly stable.

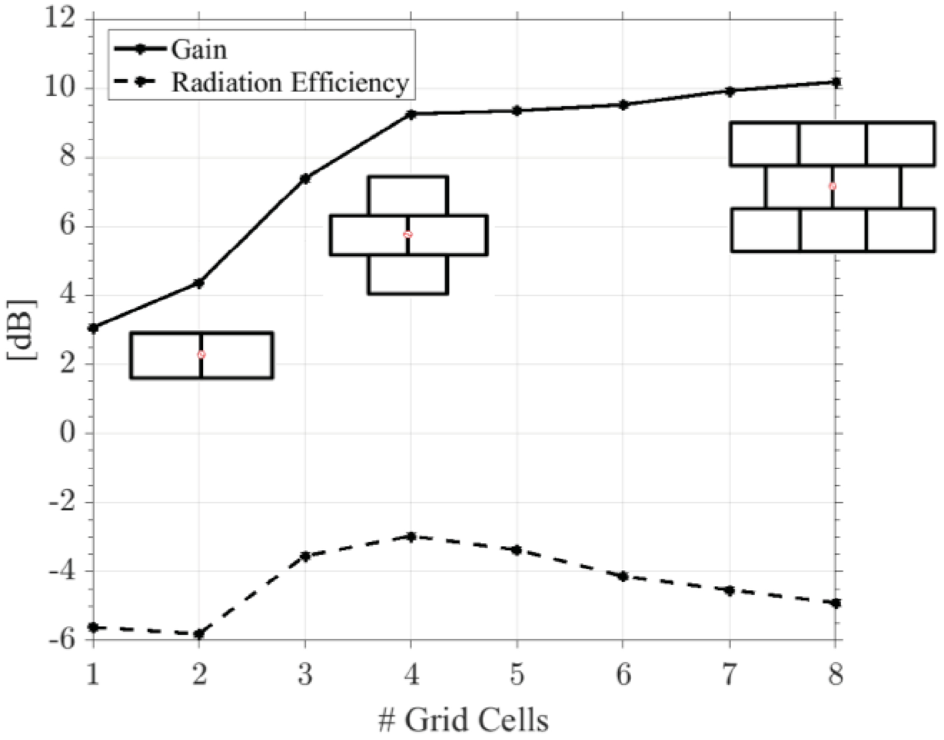


Figure 2 Simulated upper-bound gains and efficiency of wearable grids vs. number of grid array cells. Maximum efficiency is achieved by a 4-cell grid with 7 radiating elements.

The input impedance of the GAA can be freely controlled by the use of a T-match, as visible from the matching chart in Fig.3, in which length *a* and width *b* have been progressively changed to get a wide span of values of both resistance and positive reactance as required to match an RFID IC.

However, as RFID ICs are not yet available in the S-band, the antenna was tuned at 50: to simplify the measurement. After a few geometrical refinements, the optimum layout was hence achieved for s = 28.45 mm, l = 56.9 mm, track width w = 1 mm, a = 8 mm, and b = 6.8 mm.

As expected, the pattern of currents (Fig. 4 a) corresponds to that of 7 vertical dipoles radiating in phase. The radiator is capable to provide a maximum broadside gain of 9.3dB

($BW_{H,V}$ = 32°, 51°, Fig. 4 b), corresponding to a maximum read distance of approximately 6.4 m with a reader emitting EIRP = 3.2W and a chip sensitivity p_{chip} = 15dBm (typical value for the standard UHF RFID sensing systems). A safe backscattering communication link, that is compliant with the actual regulations in terms of power density, could be hence established [8].

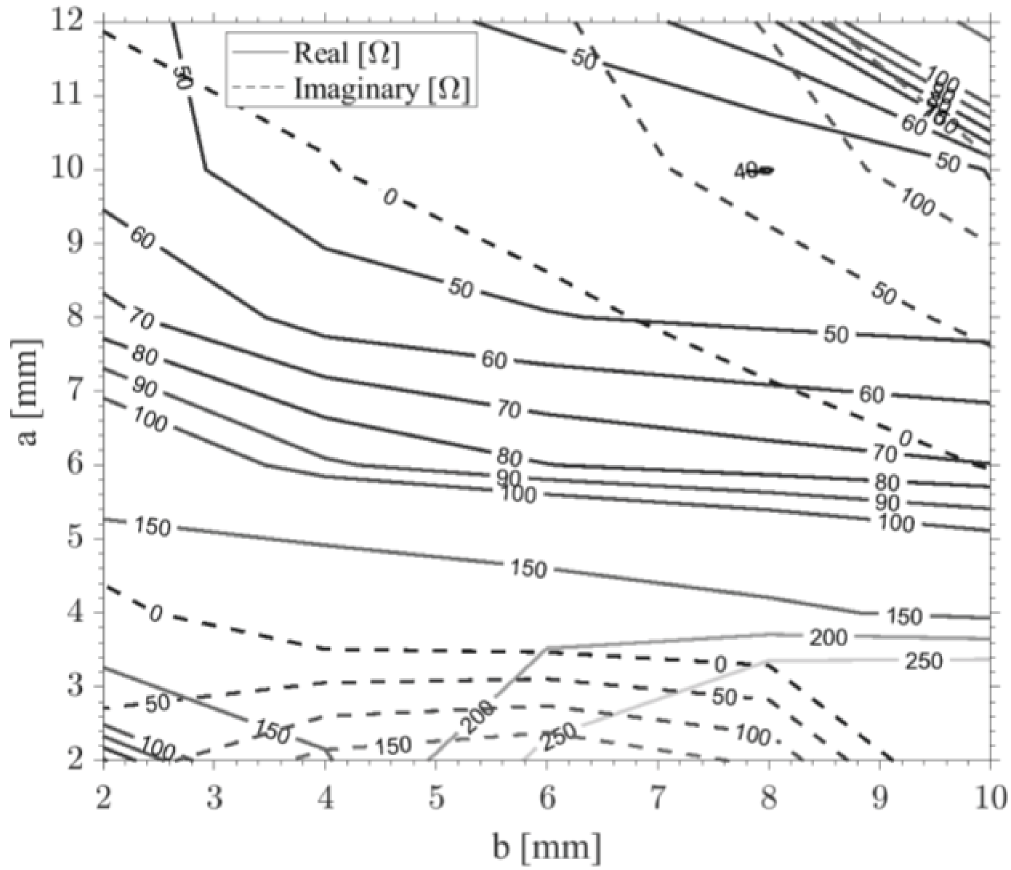
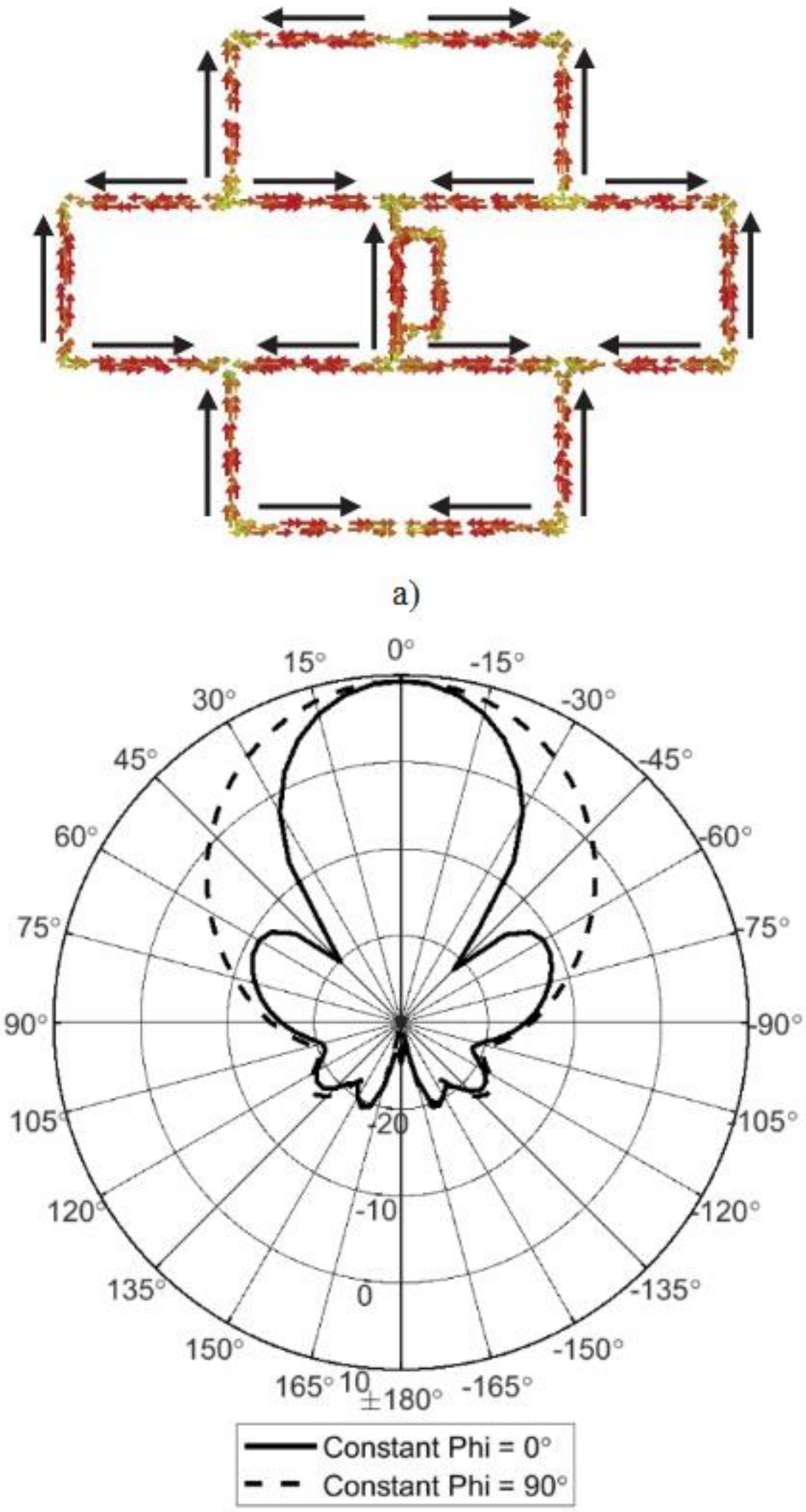


Figure 3 GAA matching chart by varying T-match shape factor *a*, *b*.

3 Prototype

A first prototype of the GAA has been fabricated by carving out adhesive copper by means of a two-axis cutter. A planar half-structure was mounted on a ground plane and vertically attached onto a cubic phantom (roasted pork with estimated parameters ε_r = 40, σ = 2 S/m). Gain was indirectly measured through a test monopole (Fig. 5). The scattering parameters S were measured by a VNA (HP 8517A), upon calibration, so that S11 gives indication of the tag matching and S12 is related to the radiation gain.

The tag was perfectly matched at 3.6 GHz (Fig.7) and the experimental data compare well with the simulations. Measured Q-factor is lower than the numerical one probably, due to additional losses in the phantom, glue and coaxial cables.



a)

b)

Figure 4 Pattern of current (a). Radiation gain for the 4-cell wearable GAA

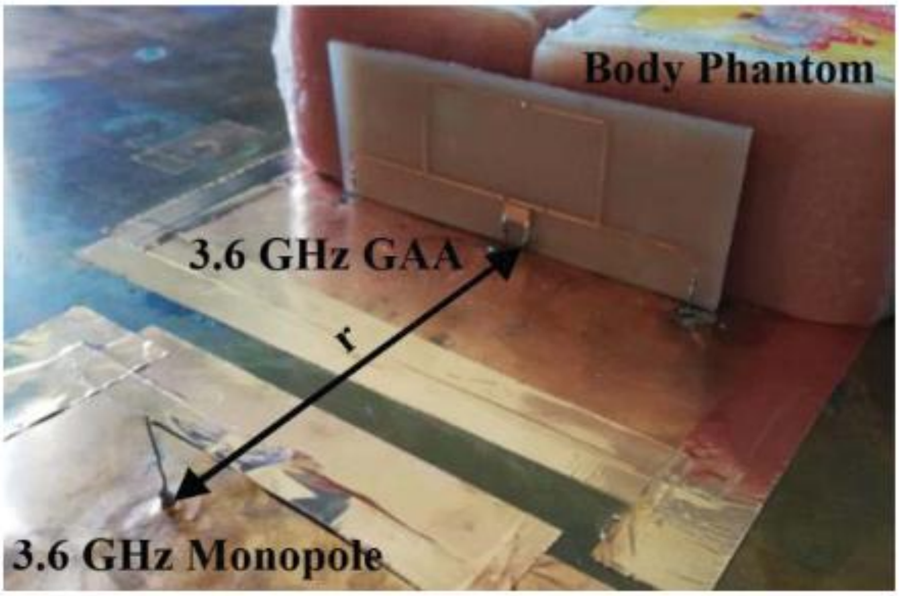


Figure 5 Experimental setup for measuring the input impedance and gain of half-grid when attached onto a roasted pork phantom; probe monopole length l = 20 mm and r = 13 cm.

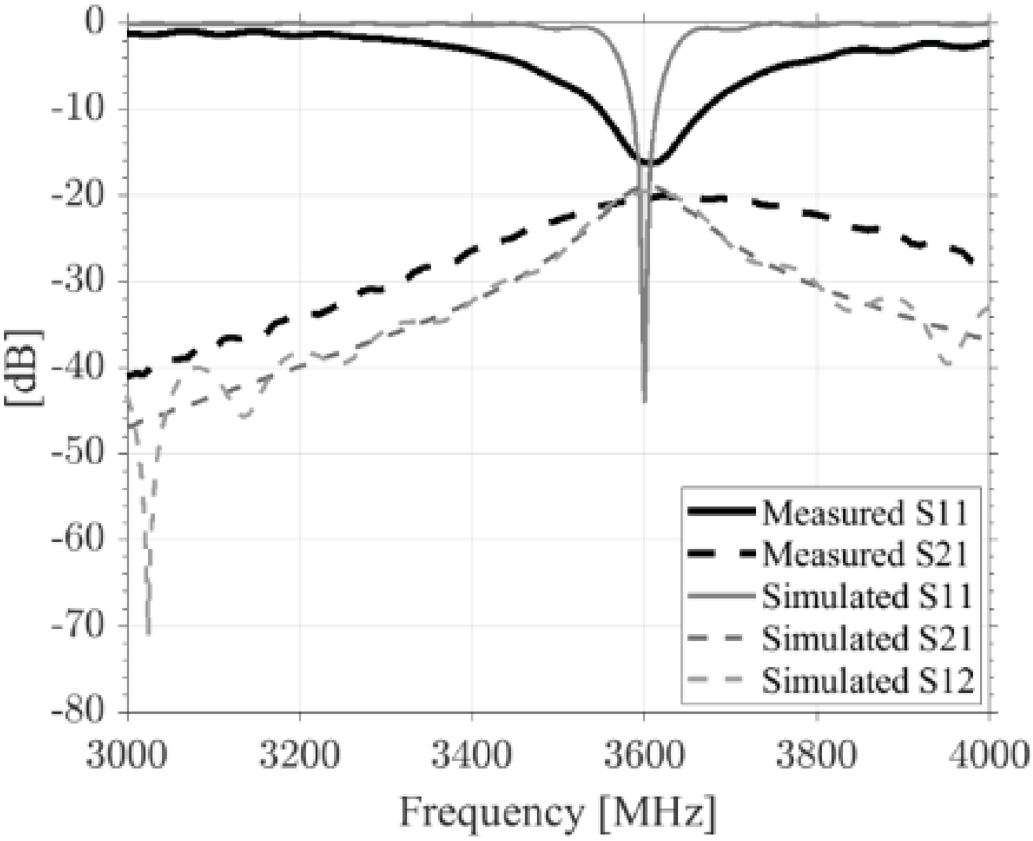


Figure 6 Simulated and Measured S-parameters of the half-grid sourced by a test monopole.

4 Conclusion

A soft Grid Array Antenna has been simulated and fabricated for on-body applications at the 5G sub 6-GHz band and promising measurement results have been obtained. However, the sizes of the design are considerably larger than desired and the substantial ground plane covering the rear of the antenna blocks access to the skin. Acknowledging this, miniaturization of the antenna has had preliminary testing, with estimated size reduction of up to 50%, maintaining radiation performance comparable to a patch antenna array of the same size. Furthermore, thread-like ground planes are under investigation, with the aim to further increase the breathability and the wearability of the structure. Results of this on-going analysis will be presented during the Symposium.

5 Acknowledgements

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6 References

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