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Miniaturized Grid Array Antenna for Body-centric RFID Communications in 5G S-band

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***Abstract* — Battery-less wearable and epidermal antennas look to converge with the emerging 5G framework, allowing ultrafast and delay-free monitoring of biophysical parameters. These antennas have been demonstrated to perform in the S-band the same as conventional UHF RFID links but with much larger bandwidths. Wearable grid-arrays show increased performance can be achieved resulting in read distances up to 6m in battery-less mode, while keeping the feeding and fabrication complexity low. Here, the optimal performance of miniaturized on-skin grid-array is investigated with a prototype manufactured and tested on a body phantom. Miniaturization results show a 35% reduction in size is possible with negligible loss of radiation performance.**

***Keywords* — 5G, wearable arrays, flexible antenna**

I. Introduction

Epidermal Electronics [1] is an emerging technological research trend aimed at developing medical devices in a soft, flexible and sometimes stretchable format for direct on-skin applications. These devices are often passive, referring to a system without a battery, functioning on harvested power alone, hence reducing impact on energy, waste, and pollution whilst requiring minimal maintenance. Coupling this with developing fifth generation (5G) systems, an envisioned future of widescale interoperability, gigabit-per-second (Gbps) data rates, low latencies, and larger bandwidths makes body-centric communication a possibility for both leisure and industry applications.

Preliminary studies have demonstrated that the new 5G allocation within the S-band has advantages over UHF Radiofrequency Identification Technology (RFID), the previously preferred band for these applications, which indicated the possibility of reaching read distances of up to 5-7 m. It was demonstrated that even though there is higher free space attenuation, 3.6 GHz antennas are suitable to provide the same read distance as UHF [4] whilst boasting higher data rates, lower latency and larger bandwidths.

Passive backscattering communication systems are limited in transmission range, especially wearable devices operating in high frequency bands in which path loss imposes attenuations up to 70 dB/m. By using multiple antennas in an array, the gain can be increased, and this loss can be mitigated. Considering the state of the art, patch and slot arrays fulfil the current on-body communication requirements however their structures lack flexibility and require large conducting ground planes making it difficult for the skin to breathe.

This paper proposes a soft, wearable/epidermal, miniaturised grid array antenna (GAA) for 3.6 GHz. Originally proposed by Kraus [6], this structure has since found application at mm-wave frequency for antenna-in-package technology due to good qualities in terms of high gain, bandwidth, simple feed, low profile, lightness and relatively straightforward construction.

Miniaturisation of the GAA is performed after the fundamental design is set, where non-radiating tracks are meandered to reduce the total area whilst leaving the resultant radiation performance unchanged.

II. Layout and Parametric Analysis

Before miniaturisation, the initial structure of the wearable grid array needs to be defined. Fig.1 describes the layout of standard GAA ‘cells’ with spacing, $s=\lambda/2$ and $l=2s$. By setting these lengths, the currents on vertical elements are in phase and act as radiators, while couplets of horizontal currents are in phase reversal acting only as transmission lines having no contribution to radiation.

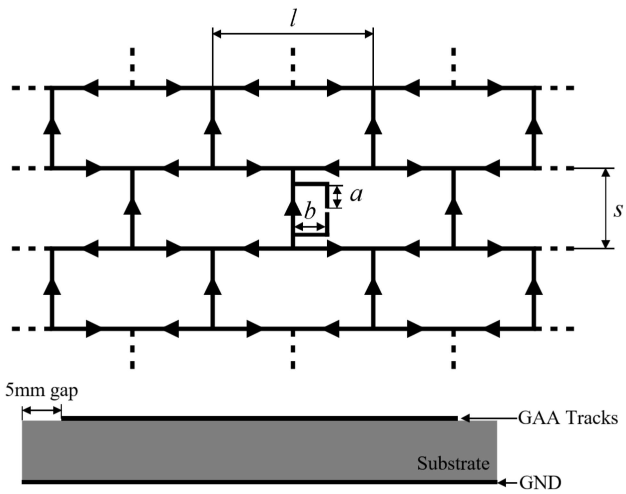


Fig. 1. Multi-cell GAA structure featuring T-match feeding network with indication of the typical current pattern and cross-sectional view.

Unlike the conventional grid-array, the proposed layout is fed at its central element to establish an integrated circuit transponder (IC), through a T-match network [7] to finely tune the input impedance. A 2 mm-thick (~λ/20) silicone rubber slab

($\varepsilon_r = 3$, tand=$1.4 \cdot 10^{-3}$) has been adopted to separate the underlying ground plane as to obtain a soft and comformable device. The substrate and ground plane extend 5mm beyond the grid on each side.

The performance of the grid-array when placed onto the skin is numerically investigated by FDTD in CST, with simulations including a 150x150 mm^2 3-layers body phantom [4] (Skin 1mm, $\varepsilon_r = 36.92$, $\sigma = 2.08$ - Fat 3mm, $\varepsilon_r = 5.16$, $\sigma = 0.16$ - Muscle 31mm, $\varepsilon_r = 51.32$, $\sigma = 2.65$). Fixing the cell size to 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, thereafter the gain remains nearly stable.

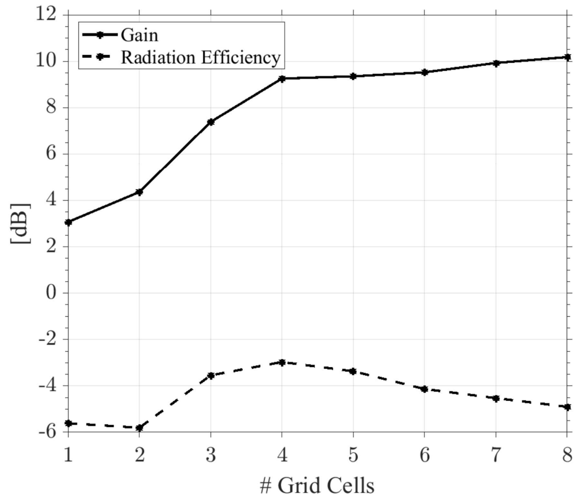


Fig. 2. Simulated upper-bound gains and efficiency of wearable grids vs. number of grid array cells. Maximum efficiency is achieved by a 4-cell grid with 7 radiating elements.

The input impedance of the GAA can be controlled by the use of a T-match, as shown in 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 Ω to simplify the measurement. After a few 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.

III. Miniaturisation

One of the main limitations of Grid-Array for wearable applications is related to the size. Being the vertical λ/2 elements spaced by λ-length horizontal traces, the layout is inherently large compared to other radiating elements, e.g. the 4-cell grid is approximately 2λx3/2λ.

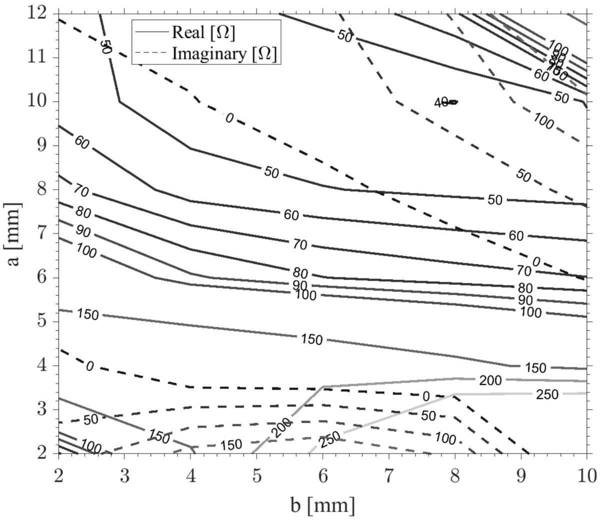


Fig. 3. GAA matching chart by varying T-match shape factor a, b.

Reducing the area of the GAA has been performed by the technique outlined by Nakano in [8]. The non-radiating sides of the grid (l) were divided into 10 equal lengths and meandered in the fashion shown in Fig. 4, resulting in a layout 3/5th of the original width. Meandering each line twice mirrored from the centre allows the radiating elements to remain unaffected, as the electrical distance between the parallel vertices and vertices on adjacent rows is maintained. The 4-cell GAA structure was reproduced with the meandered cells, slight adjustments to the dimensions being required: s = 30.9 mm, l = 61.8 mm, track width w = 1 mm, a = 9.7 mm and b = 6.4 mm.

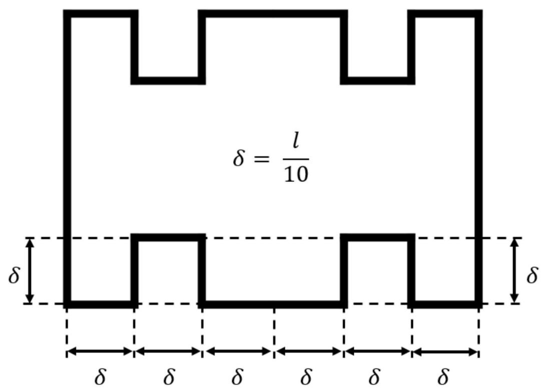


Fig. 4. Meandered GAA Cell

The currents pattern appears as expected corresponding to that of 7 vertical dipoles radiating in phase, whilst the meandered horizontal lines support phase revered current segments (Fig. 5 a). Radiation performance of this structure is described and compared to the GAA without meander and a patch array of a similar size under perfect conditions (lossless feed network assumed) in Table 1. The maximum broadside gain of the meandered GAA is 9.6dB ($BW_{H,V}$ = 48°, 48°, Fig. 5 b), almost equal to the non-meandered GAA and less than the ideal patch system by only 1dB. Efficiency is also comparable,

Table 1. GAA, meandered GAA and equivalent size patch array comparison

confirming that the meandering of the horizontal traces does not affect the radiation performances. A gain of 9.6 dB corresponds to a maximum read distance of approximately 6.5 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 regulations in terms of power density, could be hence established [8].

IV. Prototype

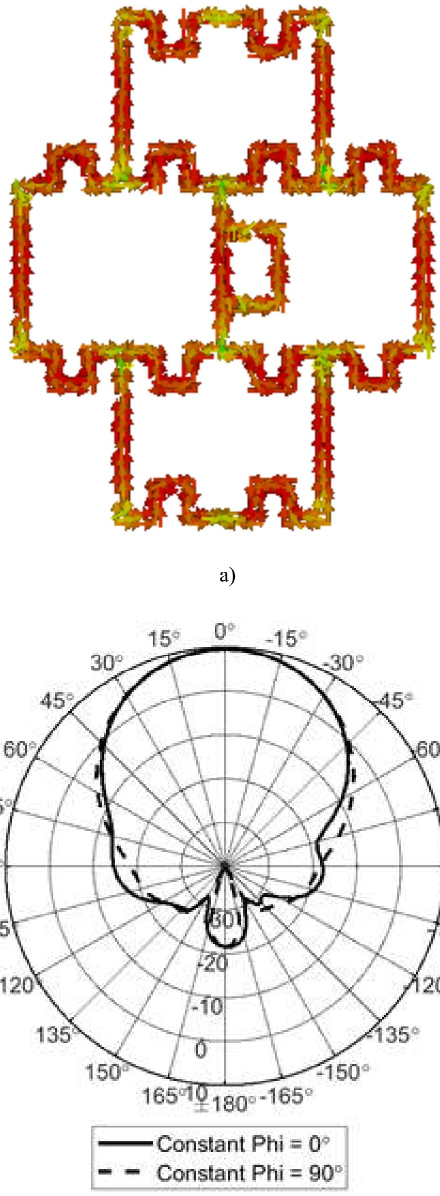
A prototype of the meandered GAA has been fabricated by carving out adhesive copper with a two-axis cutter. A planar half-structure was mounted on a ground plane and vertically attached onto a cubic phantom (roasted pork with estimated parameters εr = 40, σ = 2 S/m). Gain was indirectly measured through a test monopole (Fig. 6). The scattering parameters S were measured by a VNA (HP 8517A), so that S_{11} gives indication of the tag matching and S_{12} is related to the radiation gain.

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

V. Conclusion

A soft miniaturised grid array antenna has been simulated and fabricated for on-body applications at the 5G sub 6-GHz band. Promising measurement results have been obtained with negligible performance differences after miniaturisation. However, this miniaturisation could be further extended by meandering the radiating elements, with preliminary investigations showing a 50% reduction in area from the original to have comparative performance to a patch array of the same area. Also, the substantial ground plane covering the rear of the antenna blocks access to the skin which is problematic for sensing, preliminary research has been made into replacing this with a thread-like gridded ground plane, 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.



a)

b)

Fig. 5. Simulated pattern of current (a). Simulated radiation gain for the meandered 4-cell wearable GAA (b).

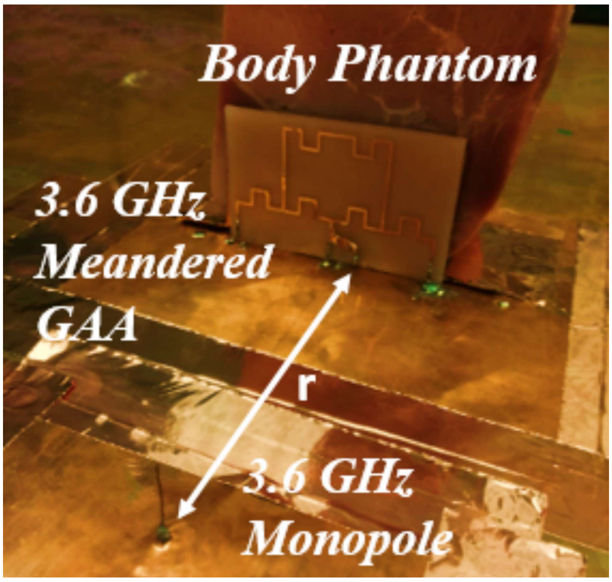


Fig. 6. Experimental setup for measuring the input impedance and gain of half-grid when attached onto a roasted pork phantom; probe monopole length l= 20 mm and r = 13 cm.

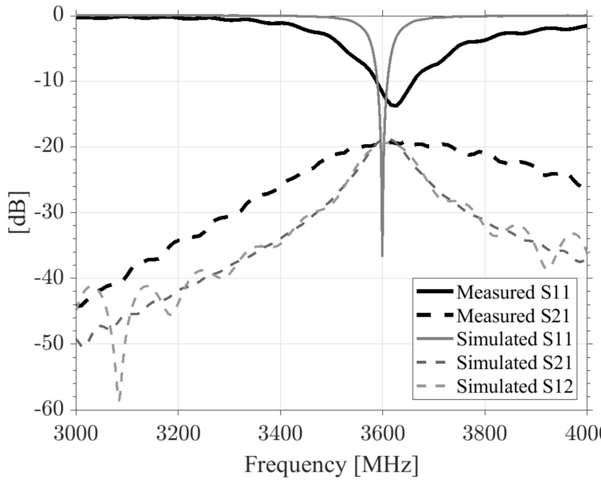


Fig. 7. Simulated and Measured S-parameters of the meandered half-grid sourced by a test monopole.

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REFERENCES

[1] N. F. M. Aun, P. J. Soh, A. A. Al-Hadi, M. F. Jamlos, G. A. E. Vandenbosch, and D. Schreurs, "Revolutionizing wearables for 5G: 5G technologies: Recent developments and future perspectives for wearable devices and antennas," *IEEE Microwave Magazine*, vol. 18, no. 3, pp. 108–124, May 2017.

[2] S. Manzari, C. Occhiuzzi and G. Marrocco, "Feasibility of Body-Centric Systems Using Passive Textile RFID Tags," in *IEEE Antennas and Propagation Magazine*, vol. 54, no. 4, pp. 49-62, Aug. 2012.

[3] D. H. Kim, N. Lu, R. Ma, Y. S. Kim, R. H. Kim, S. Wang, J. Wu, S. M. Won, H. Tao, A. Islam, K. J. Yu, T. Kim, R. Chowdhury, M. Ying, L. Xu, M. Li, H. J. Chung, H. Keum, M. McCormick, P. Liu, Y. W. Zhang, F. G. Omenetto, Y. Huang, T. Coleman, and J. A. Rogers, "Epidermal Electronics," Science, vol. 333, no. 6044, pp. 838–843, Aug 2011.

[4] F. Amato, S. Amendola, and G. Marrocco, "Upper-bound performances of RFID epidermal sensor networks at 5G frequencies," in *2019 IEEE 16th International Conference on Wearable*

[5] A. Pellegrini, A. Brizzi, L. Zhang, K. Ali, Y. Hao, X. Wu, C. C. Constantinou, Y. Nechayev, P. S. Hall, N. Chahat, M. Zhadobov, and R. Sauleau, "Antennas and propagation for body-centric wireless communications at millimeter-wave frequencies: A review [wireless corner]," *IEEE Antennas and Propagation Magazine*, vol. 55, no. 4, pp. 262–287, Aug 2013.

[6] J. Kraus, "A backward angle-fire array antenna," in *IEEE Transactions on Antennas and Propagation*, vol. 12, no. 1, pp. 48-50, January 1964.

[7] G. Marrocco, "The art of UHF RFID antenna design: impedance-matching and size-reduction techniques," *IEEE Antennas and Propagation Magazine*, vol. 50, no. 1, pp. 66–79, Feb 2008.

[8] H. Nakano, T. Kawano and J. Yamauchi, "Meander-line grid-array antenna," in *IEE Proceedings - Microwaves, Antennas and Propagation*, vol. 145, no. 4, pp. 309-312, Aug. 1998.

[9] T. Wu, T. S. Rappaport, and C. M. Collins, "Safe for generations to come: Considerations of safety for millimeter waves in wireless communications," *IEEE Microwave Magazine*, vol. 16, no. 2, pp. 65–84, March 2015.