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Textile Wearable Antenna for Firefighters Positioning

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Abstract

This paper presents a fully-textile wearable antenna for pinpointing the location of firefighters in emergency scenarios. The proposed antenna is an aperture coupled microstrip antenna which mimics the coat of arms of the fire brigade of Lecce (Italy). To assess the viability of the proposed solution, a fully-textile prototype has been fabricated and characterized. Numerical and experimental results are reported and discussed.

1. Introduction

Nowadays, wearable antennas are gaining a growing attention among researchers having interesting potential applications in the field of health care [1], human localization [2]-[4], body sensor networks [5],[6], and so on. The basic requirement of a wearable antenna is that it has to be easy to integrate into clothes and wearable accessories. To this aim, the best choice for the fabrication materials appears to be the use of textile materials for both the conductive parts and the substrate. In this regard, the use of non-woven conductive fabrics for fabricating the conductive parts of the antenna has proven to be particularly attractive [7]-[10].

The antenna should not be visible or, at least, its shape should have a pleasant appearance. In this regard, a possible solution is to design the antenna so to be easily integrated into wearable accessories such as glasses, belts, jewels or buttons [11]-[14]. Another attractive alternative is the logo-type antenna where the radiating element reproduces a logo; however, exploiting a specific logo as the geometry of the antenna is difficult, and each logo opens up new different problems [7],[8], [15]-[18].

Additionally, the design of wearable antennas is further complicated because these devices must operate in close proximity to the human body, which represents a hostile environment for the propagation of the electromagnetic waves [19]. Accordingly, referring to wearable applications, platform tolerant designs should be preferred for the antenna. In this regard, a viable solution consists in using grounded solutions such as microstrip patch antennas.

In this paper a fully-textile Aperture Coupled MicroStrip Antenna (ACMSA) operating in the GPS L1 band is presented. A layer of pile and jeans have been used as substrates, while a non-woven conductive fabric has been employed for the conductive parts. The intended application is the localization of firefighters in emergency scenarios. Accordingly, the patch has been designed so as to reproduce the coat of arms of the fire brigade of Lecce (Italy). Numerical and experimental results are reported and discussed.

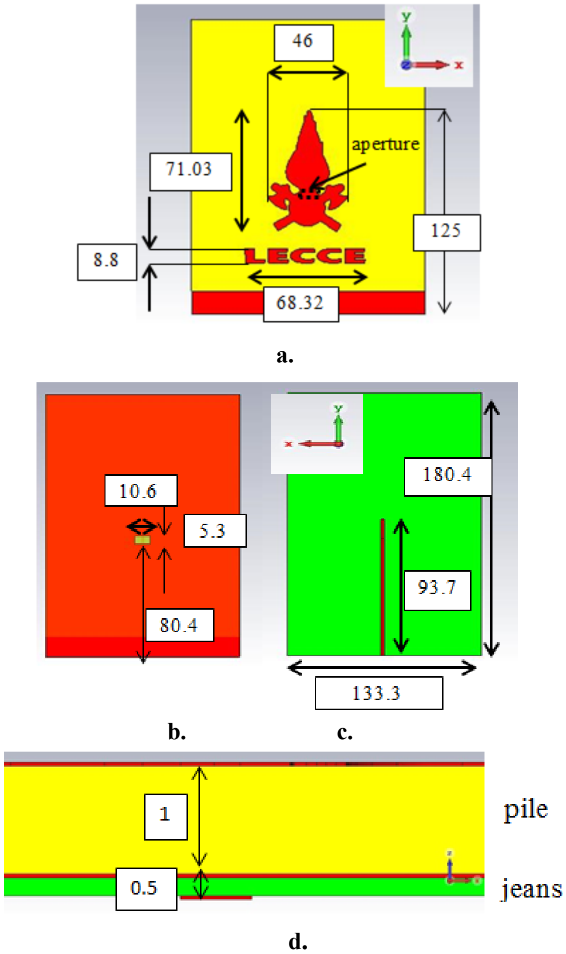


Figure 1. Geometry and dimensions (in millimeters) of the proposed antenna: a) front-view; b) aperture on the ground, c) microstrip feed-line; d) side-view. The red colour is used for the conductive parts.

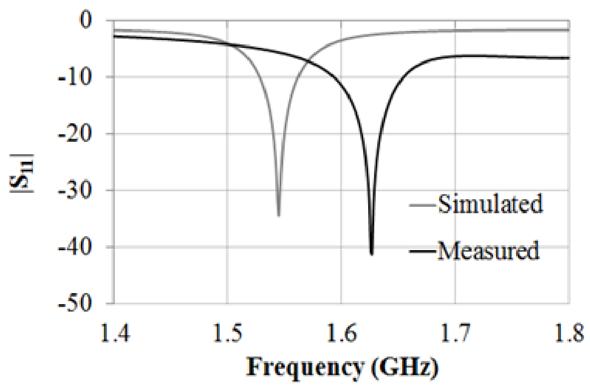


Figure 2. Comparison between the numerical data and experimental results obtained for the $|S_{11}|$ parameter.

2. Antenna Geometry

The geometry of the proposed antenna is illustrated in Fig. 1. The radiating element has been shaped so to mimic the coat of arms of the fire brigade of Lecce (Italy).

In order to obtain a platform tolerant behaviour, the design approach is an ACMSA. All the adopted materials are textiles; in particular, the microstrip line has been designed on a layer of jeans with a thickness of 0.5 mm and relative electric permittivity equal to 1.72; while, the patch has been designed on 1 mm-thick layer of pile with a relative electric permittivity of 1.18. The conductive parts were designed by using a non-woven conductive fabric having an electrical conductivity equal to 2.27e5 S/m and a thickness of 0.11 mm.

As aforementioned, the intended application is the localization of firefighters during emergency operations. Hence, the dimensions of the antenna have been optimized through full-wave simulations performed with CST Microwave Studio to operate at the GPS L1 band centered at 1.575 GHz. The final dimensions are summarized in Fig. 1; the antenna occupies a total area of about (18 x 13) cm^2. As for the aperture position, the results of the numerical optimization are illustrated in Figs. 1a and 1b.

From full-wave simulations it has been verified that the coupling between the microstrip line and the patch is almost totally magnetic. In fact, the position of the aperture corresponds to a zero of the electric field of the operating mode of the patch.

The numerical results obtained for the reflection coefficient are illustrated in Fig. 2. The antenna operates at 1.56 GHz. In particular, the minimum of the $|S_{11}|$ is approximately equal to -34.5 dB and the -10 dB bandwidth is about 33 MHz.

As for the radiation properties, the numerical results illustrated in Fig. 3 demonstrate that at the frequency of interest the antenna exhibits the desired patch-like radiation pattern and a maximum directivity of about 8 dBi.

3. Experimental Results

To assess the feasibility of the proposed solution, a prototype of the ACMSA was fabricated and characterized by means of a VNA (R&S ZVA50). The pictures of the realized prototype are given in Figs. 4a and 4b.

For implementing all the conductive parts, a self-adhesive non-woven conductive fabric was exploited. This material has no fraying problems; therefore, a cutting plotter commonly used in the graphic industry was exploited for shaping the conductive parts of the antenna [20]. As it is evident from Figs. 4a and 4b, a good accuracy was obtained in reproducing the antenna geometry.

The antenna assembly was a crucial step of the fabrication process. Particular attention was paid to the alignment between the aperture and the radiating element. In fact, as demonstrated by full-wave simulations, it strongly influences the frequency behaviour of the antenna.

First, the microstrip feed-line and the ground plane containing the aperture were attached on the layer of jeans. Successively, the radiating element was attached on the pile layer. Finally, the two layers were sewn by hand taking care to achieve a uniform thickness and to avoid the presence of air. The measured reflection coefficient is reported and compared with numerical data in Fig. 2. As it can be seen, the antenna operates with a good matching at 1.62 GHz. By comparing numerical data with experimental results, a frequency shift of about 60 MHz of the minimum of the $|S_{11}|$ parameter can be observed. This shift is probably due to a slight mismatch between the electromagnetic parameters of the textile layers adopted for the fabrication and the ones adopted in full-wave simulations.

In order to verify the robustness of the performance of the fabricated antenna, measurements were performed by placing the antenna on different parts of the body. Figure 4c shows the case of placement on the chest and on the arm. The corresponding measured reflection coefficients are illustrated in Fig. 6a; as expected, due to the presence of the ground plane, the reflection coefficient of the antenna is nearly insensitive to the surface where it is applied.

Finally, the sensitivity of the antenna performance on moisture was investigated. Experimental tests were performed by exposing the antenna to different levels of relative humidity. Each measurement was performed after a 6-minutes exposure time, the achieved results are given in Fig. 6b. As expected, in view of the porosity of the textile materials, the operating frequency and the bandwidth of the antenna depends on humidity. In particular, the electric permittivity and the conductivity of the textile materials increase as the environmental humidity increases, causing the decrease of the operating frequency and the bandwidth enhancement.

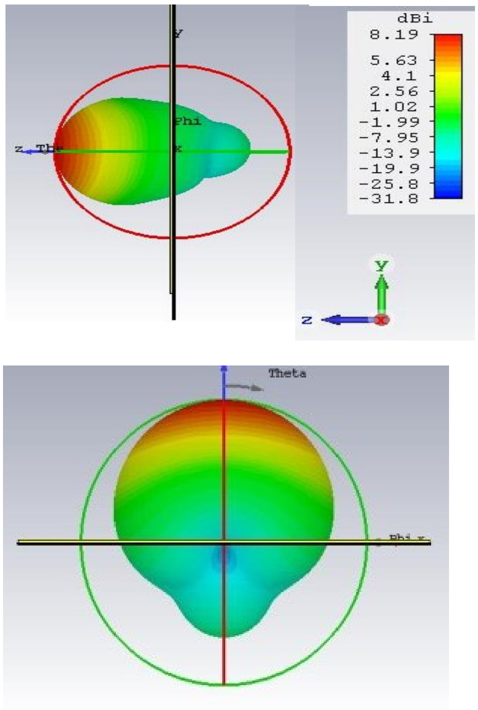


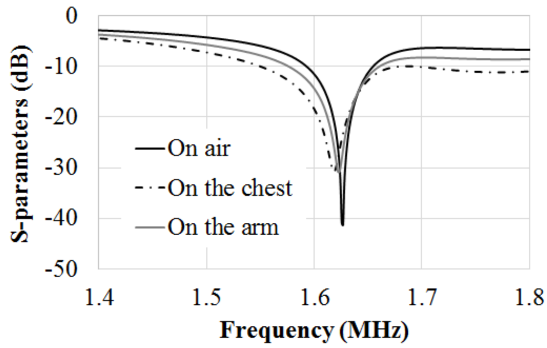
Figure 3. Radiation pattern calculated from full-wave simulations.

a. b.

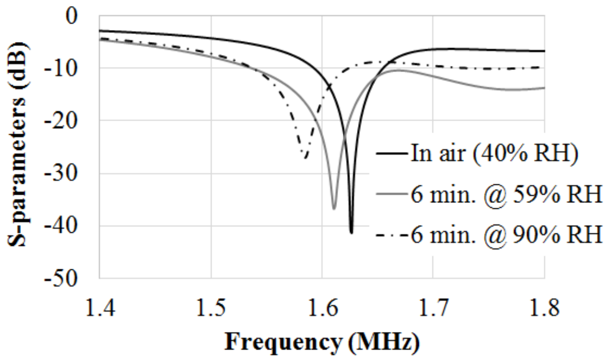
c.

Figure 4. Pictures of the fabricated prototype: a) front view; b) back view; c) experimental setup adopted for evaluating the robustness of the performance when the prototype is placed on different parts of the human body.

Figure 5. Experimental setup adopted for evaluating the sensitivity of the antenna performance to humidity.



a.



b.

Figure 6. Measurements performed: a) by placing the antenna on different parts of the body; (b) by exposing the antenna to different levels of relative humidity (RH).

4. Conclusion

A fully-textile wearable antenna for firefighters localization has been presented. The proposed antenna operates in the GPS L1 band centered at 1.575 GHz.

In order to guarantee a robust performance with respect to the surface of application, a grounded design has been adopted. More in detail, the presented antenna is an aperture coupled microstrip patch whose radiating element has been shaped so as to mimic the coat of arms of the fire brigade of Lecce (Italy). A careful reproduction of the desired geometry has been achieved exploiting a time-saving and inexpensive fabrication process based on the combined use of a cutting plotter and a self-adhesive non-woven conductive fabric.

Experimental tests performed on the fabricated prototype showed that the antenna is well matched to 50 Ω, even if a slight frequency shift of the operating frequency has been observed. Experimental tests were performed on the antenna prototype in order to evaluate the robustness of its performance with respect to the operation on different parts of the human body and to various levels of environmental relative humidity. The reported results demonstrate that the operating frequency depends on the humidity. In particular, it shifts from 1.62 GHz to 1.58 GHz for a relative humidity increasing from 40% to 90%. Overall, the achieved results demonstrate the suitability of the proposed antenna for the intended application (i.e. firefighters localization in emergency scenarios).

6. Acknowledgements

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7. References

1. L. Corchia, E. De Benedetto, G. Monti, A. Cataldo and L. Tarricone, "Wearable antennas for applications in remote assistance to elderly people," *2017 IEEE International Workshop on Measurement and Networking (M&N)*, Naples, 2017, pp. 1-6.
2. H. Lee, J. Tak and J. Choi, "Wearable Antenna Integrated into Military Berets for Indoor/Outdoor Positioning System," in *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 1919-1922, 2017.
3. Z. H. Jiang, M. D. Gregory and D. H. Werner, "Design and Experimental Investigation of a Compact Circularly Polarized Integrated Filtering Antenna for Wearable Biotelemetric Devices," in *IEEE Trans. on Biom. Circ. and Syst.*, vol. 10, no. 2, pp. 328-338, 2016.
4. H. Bahramiabarghouei, E. Porter, A. Santorelli, B. Gosselin, M. Popović and L. A. Rusch, "Flexible 16 Antenna Array for Microwave Breast Cancer Detection," in *IEEE Transactions on Biomedical Engineering*, vol. 62, no. 10, pp. 2516-2525, Oct. 2015.
5. G. Gao, B. Hu, S. Wang and C. Yang, "Wearable Circular Ring Slot Antenna with EBG Structure for Wireless Body Area Network," in *IEEE Antennas and Wireless Propagation Lett.*, vol. PP, no. 99, pp. 1-1.
6. K. Venugopal and R. W. Heath, "Millimeter Wave Networked Wearables in Dense Indoor Environments," in *IEEE Access*, vol. 4, pp. 1205-1221, 2016.
7. G. Monti, L. Corchia, E. De Benedetto, and L. Tarricone, “Wearable logo-antenna for gps-gsm-based tracking systems,” *IET Microw., Antennas and Propagation*, vol. 10, no. 12, pp. 1332–1338, 2016.
8. G. Monti, L. Corchia and L. Tarricone, "Logo antenna on textile materials," in *44th European Microw. Conf.*, Rome, 2014, pp. 516-519.
9. G. Monti, L. Corchia and L. Tarricone, "A wearable wireless energy link," *2015 European Microwave Conference (EuMC)*, Paris, 2015, pp. 143-146.
10. G. Monti, L. Corchia, E. D. Benedetto and L. Tarricone, "Compact resonator on leather for nonradiative inductive power transfer and far-field data links," *Radio Science*, vol. 51, no. 6, pp. 629-637, June 2016.
11. B. Saravanya, “A miniaturized wearable button antenna for WiGig applications,” in *Proc. 2017 4th Int. Conf. on Advanced Computing and Communication Systems (ICACCS),* 2017, pp. 1 – 4.
12. X. Y. Zhang, H. Wong, T. Mo and Y. F. Cao, "Dual-Band Dual-Mode Button Antenna for On-Body and Off-Body Communications," in *IEEE Trans. on Biom. Circ. and Syst.*, vol. 11, no. 4, pp. 933-941, Aug. 2017.
13. S. Hong, S. H. Kang, Y. Kim and C. W. Jung, "Transparent and Flexible Antenna for Wearable Glasses Applications," in *IEEE Trans. on Antennas and Propagation*, vol. 64, no. 7, pp. 2797-2804, July 2016.
14. S. H. Nguyen, N. Ellis and R. Amirtharajah, "Powering smart jewelry using an RF energy harvesting necklace," in proc. *IEEE MTT-S Int. Microwave Symp. (IMS)*, San Francisco, CA, 2016, pp. 1-4.
15. P. Saha, B. Mandal, A. Chatterjee and S. K. Parui, "Harmes Paris logo shaped wearable antenna for multiband applications," *2016 Asia-Pacific Microw. Conf. (APMC)*, New Delhi, 2016, pp. 1-3.
16. J. Tak and J. Choi, "An All-Textile Louis Vuitton Logo Antenna," in *IEEE Antenn. and Wireless Prop. Lett.*, vol. 14, pp. 1211-1214, 2015.
17. A. Kiourti, J.L. Volakis, “Colorful Textile Antennas Integrated into Embroidered Logos,” *in Journ. Sens. Actuator Netw.*, vol. 4, pp. 371-377, 2015.
18. K. V. Tumsare and P. L. Zade, "Dual band logo antenna for WLAN application," *2016 World Conf. on Futuristic Trends in Research and Innovation for Social Welfare*, Coimbatore, 2016, pp. 1-4.
19. D. Wen, Y. Hao, M. O. Munoz, H. Wang and H. Zhou, "A Compact and Low-Profile MIMO Antenna Using a Miniature Circular High-Impedance Surface for Wearable Applications," in *IEEE Trans. on Antennas and Propagation*, vol. 66, no. 1, pp. 96-104, Jan. 2018.
20. G. Monti, L. Corchia, and L. Tarricone, “UHF wearable rectenna on textile materials,” *IEEE Trans. on Antenn. and Propag.*, vol. 61, no. 7, pp. 3869–3873, 2013.