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# Dual-band Textile AMC Antenna for WLAN/WBAN Applications on the Human Arm

Wahida Bouamra, Imen Sfar, Ameni Mersani, Lotfi Osman, and Jean-Marc Ribero

*Abstract*—**This article presents a low-profile and flexible dual-band AMC Antenna operating at 2.45/ 5.8 GHz for wireless local area network (WLAN) on-body antenna applications using textile materials. A dual-band artificial magnetic conductor (AMC) structure with a dual hexagonal shape was used to reduce back radiation, therefore specific absorption rate (SAR), and improve the antenna performance parameters. To study the antenna/body interaction, a suitable comprehension and detailed studies of the wave propagation in the vicinity of the human arm in different meteorological conditions were carried out to demonstrate the effects of the skin condition on the antenna performance parameters. The simulation and measurement results indicate that electromagnetic communication on wet skin is viable. Acceptable SAR values were obtained, revealing that the body is well immune from the antenna electromagnetic radiation in functional wearable conditions. The proposed wearable AMC antenna provided engaging simulation and measurement results. It satisfies users' comfort and safety properties, making it a good candidate for WLAN/WBAN applications.**

*Keywords*—**wearable antenna; dual-band antenna; AMC; SAR; WLAN; human body models; WBAN**

## I. Introduction

RECENTLY, wearable antennas have been intensively studied due to their wide use in WLAN applications like health monitoring, emergency rescue services, and physical training [1,2]. For several years now, the theme of communications centered on the human body has aroused strong interest from the international scientific community [3,4].

Indeed, many works have already been carried out to design double-band textile antennas for WLAN, WBAN applications [5,6]. These research works aim to analyze the propagation of electromagnetic waves caused by the antenna in a specific frequency band near the body [7].

A wearable dual-band magneto-electric dipole antenna for WBAN/WLAN Applications was proposed in [8]. Besides, a dual-Band, Dual-Sense Textile Antenna with AMC Backing for Localization using GPS and WBAN/WLAN was presented in [9], and Compact All-Textile Dual-band Antenna Loaded with Metamaterial Inspired Structure was developed for WLAN applications 2.4/5.2 GHz [10]. Furthermore, a dual-mode dual-band button antenna for body-centered communications was proposed in [11].

Several antennas have already been designed for these purposes. For instance, we can cite vertical monopolies [12], micro-strip monopolies [4], inverted F antennas [13], cavity antennas, and flat slot antennas fed by a waveguide [13]. However, these antennas presented, at least, one of the following problems: very narrow bandwidth, large dimensions, which make them bulky, significant radiation to the body (you cannot solve one problem by creating another), and stability of parameters when bending off-body antennas.

As an example of wearable antennas, we can mention the monopole antenna that was essentially designed to solve one of the main weaknesses of microstrip antennas (limited bandwidth) which prevent high-speed communications [7]. However, issues driven by miniaturization remain an obstacle for communication systems. To meet the requirements of miniaturizing the antennas, several techniques were introduced to reduce the antenna size. These techniques include meander antennas, fractal geometry for printed antennas, the addition of slots engraved on the patch or in the ground plane, the meta-materials, and antennas with a dielectric resonator [7,14].

The implantation of antennas on the human body tissues affects its performance parameters, including radiation characteristics, reflection coefficient, efficiency, gains, and directivity unfavourably. Thus, it is highly recommended to consider this matter at the design stage or at least during the antenna characterization, which requires a thorough study and a full understanding of the antenna/body interaction [7] essentially.

Several researchers have investigated the wearable antennas functioning in human body environments, applying various methods to enable and give a high degree of isolation from the human body, which also considerably minimizes the SAR [15,7].

In this work, a dual-band AMC antenna is designed for WLAN/WLBN applications. The performance of the proposed antenna in bending configuration was tested. Using textile materials shows that the antenna has high stability and flexibility and resists well under bending conditions. Besides, the performance of the antenna on the human body was checked experimentally on the natural arm and numerically using a model of the average human arm, which consists of five layers representing skin, fat, muscle, cortical bone, and bone marrow. The dielectric properties of tissues were affected by the skin states, such as moisture content. To examine the

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effect of these conditions, we investigated the antenna performance when the skin is wet and dry.

## II. AMC Antenna Topology and Materials

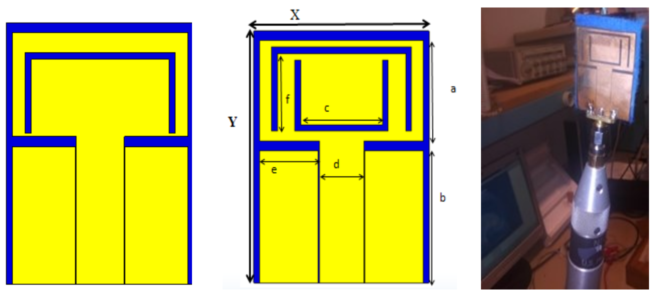
The proposed topology comprises a coplanar waveguide (CPW) fed monopole textile antenna whose dimensions are 30 × 39 mm$^2$. This antenna was put on an AMC network of three rows by two columns with total dimensions of 66 x 40 mm$^2$ and a final substrate thickness of 4 mm. The AMC unit cell geometry relies on the developed designs, as presented in [15]. The antenna and the AMC were printed on a non-conductive two mm-thick felt textile, with a relative permittivity ($\varepsilon_r$) and loss tangent (tan $\delta$) equal to 1.22 and 0.016, respectively. The conductive layers were constructed using a 0.08 mm-thick pure copper taffeta from less EMF [16]. Its conductivity is equal to $2.5\times10^5$ S/m. The electro-textile was made using pure copper. It is smooth, soft, light, and easy to cut and sew. However, it requires the use of glue to be fixed on the tissue. It is similarly flexible for bending.

### *A. Antenna Performance in Free Space Planar Conditions*

The geometry of the suggested initial design of a dual-band textile antenna with a U-shaped slot is illustrated in Fig.1a. This antenna's impedance bandwidth (S11<-10dB) covers 2.3 GHz to 2.52 GHz in the lower band and 3.5 GHz to 6.86 GHz in the upper band. Thus, this device can operate in both Wi-Fi bands. However, this prototype does not cover the entire Wi-Fi and LTE bands [2.4 -2.7] GHz and [5.1-5.875] GHz.

A solution is proposed in this sub-section using the slot technique engraved on the patch because the addition of slots in the patch allows lengthening the current path, extending its electrical length, and then reaching the characteristics of the requested patch antenna and widens the first bandwidth [14,17,18].

Figure 1b shows the ultimately produced structure of the textile antenna. To verify the simulated results, the antenna was fabricated and measured. Measurements confirmed the results of S11 with a vector network analyzer. Figure 2 compares the measurement and simulation reflection coefficient of the wearable antenna.



(a) (b) (c)

Fig. 1. Textile antenna desing, (a) initial design antenna (b) Final antenna structure. The optimized dimensions in mm are: X=30, Y=39, a=15.5, b =20.5, c = 14, d=7.65, e = 10 and f = 12 (d) measured S11 of the fabricated monopole prototype

The new proposed configuration has 1.3 GHz and 1.8 GHz bandwidth within the 2.45 GHz and the 5.8 GHz WLAN bands. Thus, it shows a significant improvement compared to the initial design of the monopole antenna.

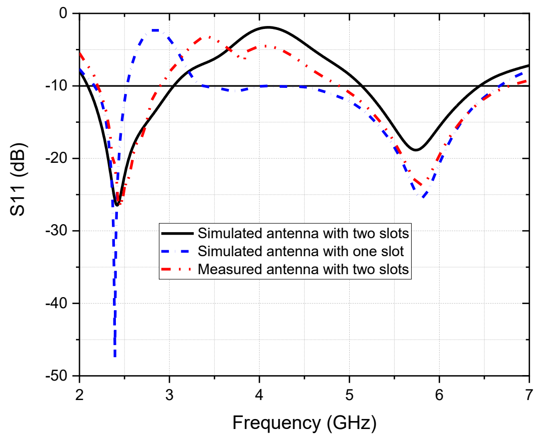



Fig. 2. Reflection coefficient of the textile antenna

The new proposed configuration has 1.3 GHz and 1.8 GHz bandwidth within the 2.45 GHz and the 5.8 GHz WLAN bands. Thus, it shows a significant improvement compared to the initial design of the monopole antenna.

The antenna's simulated and measured S11 results are in good agreement but with a slight offset due to imperfections reproduced during the manufacturing process (dimensional uncertainty). On the other hand, compared to the simulation results, there is a shift in the width of the highest measured operating bandwidth from 500 MHz to higher frequencies.

To verify the radiation performance, we measured the antenna's efficiency and gain in the adaptation band utilizing the measurement station at Orange Labs. Figure 3 shows the simulated and measured efficiency of the antenna. The maximum total measured efficiencies of the antenna are 70% and 87% at 2.45 and 5.8 GHz, respectively. However, simulated efficiency at 2.45 GHz is almost equal to 86.96%, while the efficiency at 5.8 GHz is around 72.93%. We notice from these values results that the textile antenna is very efficient.

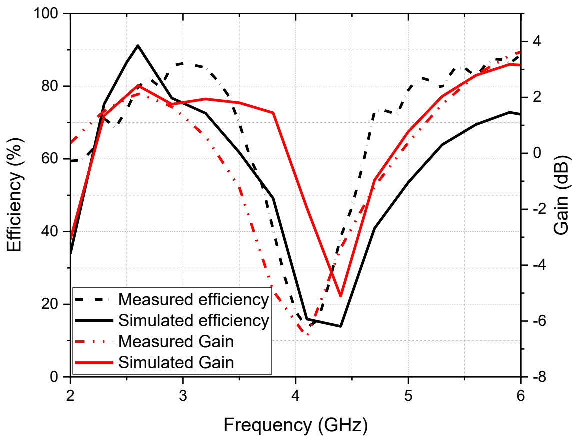



Fig. 3. Simulations and measurements performance of the dual-band antenna

The gains comparisons between the simulated and measured results of the textile antenna are shown in Fig. 3. Both results were in good agreement but with a slight lag due to manual manufacturing and measurement flexibilities and errors in measuring the dielectric properties of the substrates made up of tissue. The measured gain is 2.5 dB, in the 2.45 GHz band, and

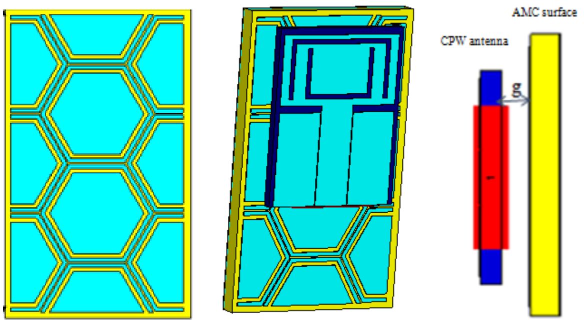
3.45 dB in the second band. As this value does not satisfy our needs, it could be improved by adding an artificial magnetic conductor AMC.

*B. Performance of Dual-band Textile Antenna and AMC*

In wearable antenna applications, the AMC structure is a favorable candidate for the radiant wave's reflective plane. It reduces the radiation absorbed by the human body and designs compact antennas [17-19].

Since the coplanar antenna has no reflecting plane and has back radiation, this device must be isolated from the human body to protect individuals and isolate this harmful radiation, hence its association with an AMC type structure.

By adjusting the geometrical dimensions of the monopole antenna and the AMC unit cell, the anticipated impedance matching and the radiation characteristics of the AMC antenna were attained at 2.45/5.8 GHz for wireless local area network (WLAN) application. Figure 5 represents the AMC unit enhanced dimensions. When designing the AMC structure and during the simulation phase, the AMC network rose by one row and one column at a time till reaching the optimum performance in terms of gain, forward to the backward ratio (FBR) [20]. Indeed, good impedance matching was attained within 2.45/5.8 GHz. In this context, the relationship between antenna size and performance was evaluated.

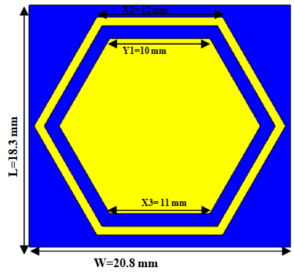



(a) (b) (c)

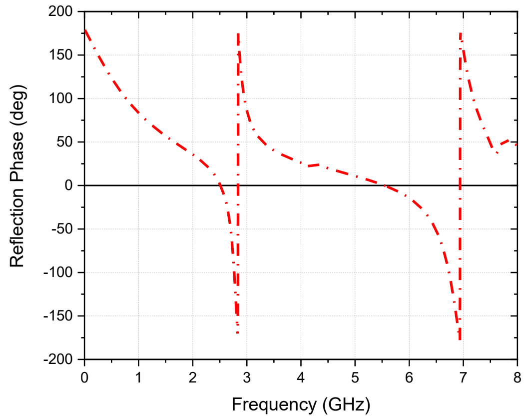
Fig. 4. AMC antenna. (a) Top view of the AMC plan (b) The antenna on the AMC plan (c) Bottom view of AMC antenna

In the literature, numerous publications are using–various classical elementary geometrical shapes (square, triangle, circle, and cross) composing a double band AMC type surface [17,15] [21-23]. We focus, in this study, on dual hexagon structures on textile because the AMC has several advantages in terms of size and bandwidth [15]. The dimensions of the different designs were optimized to obtain a 0° phase around 2.45 and 5.8 GHz. The frequency bands were marked by variations of ± 90° around the 0° phase values, as shown in Fig. 5b.

Simulation results reveal that this AMC surface covers the two desired frequency bands with bandwidths of 1.6 GHz and 3.6 GHz at 2.45 GHz and 5.8 GHz, respectively. The method of characterizing an infinite AMC using CST Microwave Studio® was detailed in [15]. To optimize the AMC antenna operation, a certain distance has to be kept between the two elements. Therefore, a Rohacell foam-type substrate was placed between the antenna and the AMC surface to separate the antenna and the AMC structure without changing the properties of the AMC antenna structure. To determine the minimum space between the antenna and the AMC structure, while operating in both Wi-Fi and LTE bands, foam layers of different thicknesses were compared.

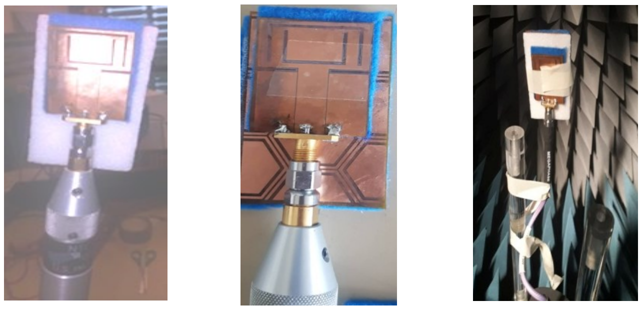



(a)




(b)

Fig. 5. AMC unit cell. (a) Design of the AMC unit cell, (b) Results of the Simulated Reflection Phase of the AMC surface

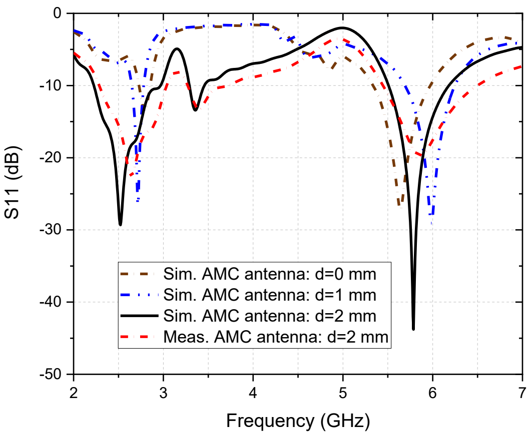


(a) (b) (c)

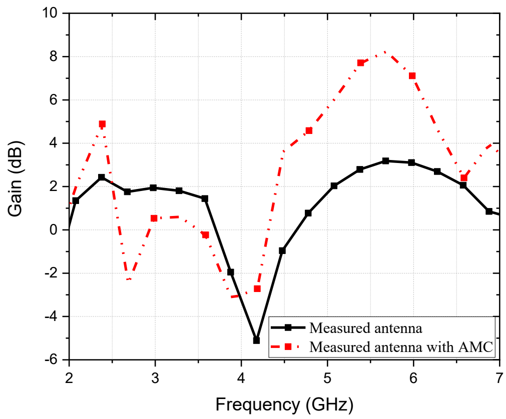
Fig. 6. Textile antenna above the AMC. (a) Rohacell foam-type substrate was added between the antenna and the AMC surface (b) Top view (c) AMC antenna in the anechoic chamber

In Fig. 7a, the reflection coefficient results of the antenna with the AMC structure are presented for spacings of 0mm, 1mm, and 2mm, respectively. When the antenna was placed directly on the AMC structure, the assembly did not allow the coverage of both frequency bands due to the strong coupling between the AMC structure and the antenna. As a result, both frequency bands are covered for 1mm and 2mm spacing, but a larger frequency band is observed for 2mm. This experimental study positioned the 2mm Rohacell foam layer between the antenna and the reflecting structure.

Figure 7b shows the measured gains of the antenna with and without AMC. There is a significant increase in measured gain of the antenna when AMC added about 2.55 dB at 2.45 GHz and 5 dB at 5.8 GHz compared to the antenna without AMC.




(a)




(b)

Fig. 7. Measurement and simulation results of the Textile antenna with and without AMC. (a) Reflection coefficient, (b) Realised gain

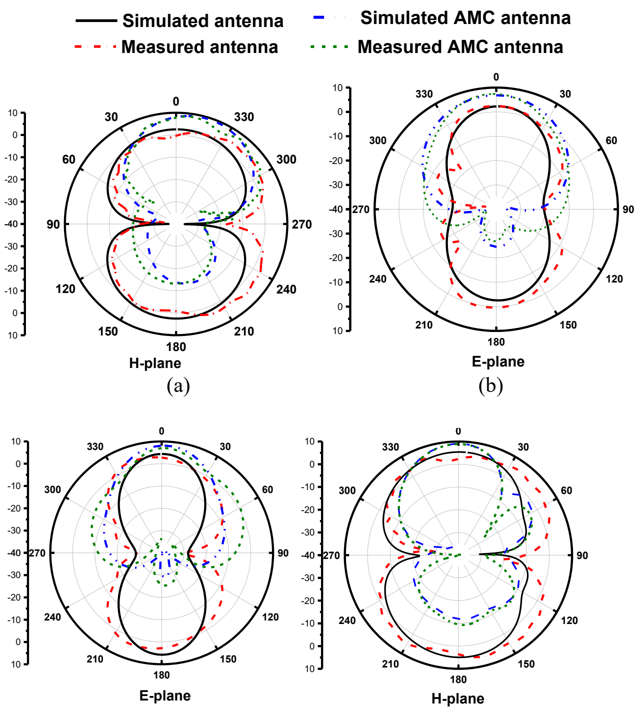



Fig. 8. Measured radiation pattern of the textile antenna with and without AMC. (a- b) @ 2.45 GHz (c- d) @ 5.8 GHz

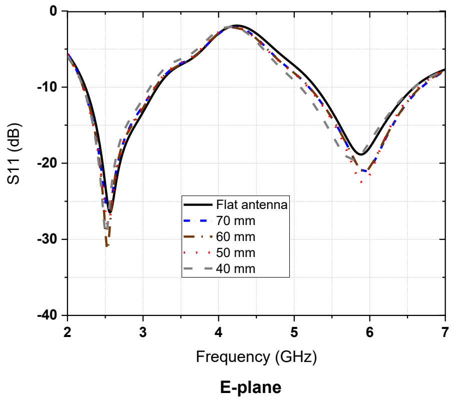
To verify that the use of a dual hexagonal reflecting surface reduces the rear radiation emitted by the antenna, measurements of the radiation patterns plots of both textile antennas in the E plane and the H plane were carried out in an anechoic chamber at Orange Labs, the results are shown in Fig. 8.

The measurement results show that the addition of AMC structure reduced the rear radiation into the human body and improved the antenna directivity in a direction opposite to the body. For example, at 2.45 GHz in the H- plane, the back radiation was reduced by 12.5 dB, while in the E-plane, the attenuation was 20 dB.

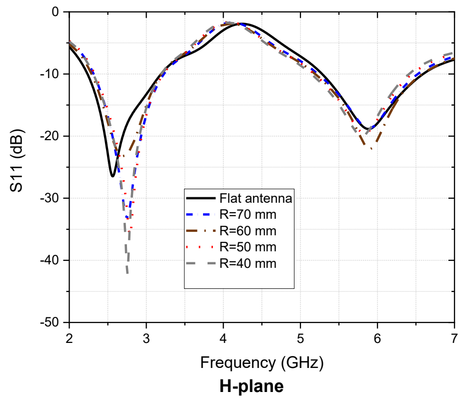
## III. Antenna On The Human Arm

### A. *Antenna Performance in Bending Configuration*

In mobile systems, the antenna is shaped since it is made of flexible textile. Besides, the wearable antenna is often bent due to the movements of the human body. To study the antenna performance in the dynamical body environment, the textile antenna was bent over a cylinder of 30 cm long with different radii in two planes (E plane and H plane), modeling the arm of a human body. This step allowed studying the performance of this latter under deformation. The simulated $S11$, when bent in both planes in the x and y-axis, is plotted in Fig. 9 and compared when the antenna was flat. Four models of the human arm were designed: an arm with a radius equal to 40 mm worst condition, a middle arm with a radius of 50 mm, a healthy arm with a radius of 60 mm, and an arm with a radius of 70 mm.




(a)




(b)

Fig. 9. Simulated return loss of the proposed antenna when bent : (a) bent along X-axis, (b) bent along the y-axis.

It is worth noting that the antenna's bandwidth when bent was stable and covered both frequency bands, regardless of the selected bending plane. Besides, an enhancement of the return loss by nearly 10 dB for the two bands plane bending around the 40 mm arm was observed in the E plane.

As a result, this compact dual-band textile antenna may be successfully utilized in wearable applications. Compliance is the most critical requirement as bending does not considerably affect the antenna performance.

*B. Study of* the *Effect of Skin Conditions on the antenna's performance*

To study the antenna performance on the human body, the proposed antenna with and without AMC was implanted and tested on the average human arm model. The latter contains five heterogeneous cylindrical layers: skin, fat, muscle, cortical bone, and bone marrow [24], on Gustav voxel model, and an arm of an authentic volunteer, as shown in Figure 10a. Each layer of the proposed human arm has its dielectric properties, which are highly dependent on the functioning frequency and skin condition, rely on the work of the Italian National Research Council [25], which is accessible online [26] and can be obtained at [24,15,21,22,27]. The relative permittivity and conductivity at 2.45 GHz and 5.8 GHz of different tissue layers of the human arm are given in Table I.

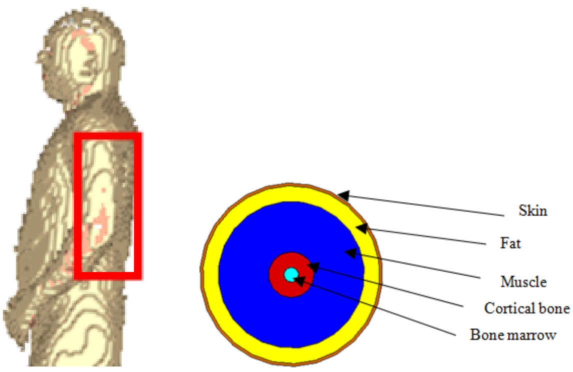



Fig. 10. The arm model: (a) Gustav voxel model [28], (b) 5 -tissue-layer model of human body [24,29].

TABLE I

PROPERTIES OF HUMAN ARM MODEL AT 2.45 GHZ AND 5.8 GHZ [26]

| Frequency (GHz) | 2.45/5.8 | 2.45/5.8 |
|---|---|---|
| ***Tissue layer*** | ***Conductivity [S/m]*** | ***Relative permittivity*** |
| Fat | 0.102/ 0.293 | 5.285/ 4.954 |
| Skin Dry | 1.441/ 3.717 | 38.063/ 35.114 |
| Skin Wet | 1.562/ 4.342 | 42.923/38.624 |
| Muscle | 1.705/ 4.962 | 52.791/ 48.485 |
| Bone Cortical | 0.385/ 1.154 | 11.41/ 9.674 |
| Bone Marrow | 0.093/ 0.285 | 5.302/ 4.963 |

In this configuration, the transmission distance was kept identical, and the skin condition in the transmission range was the only variable. In the measurement of wet skin, the arm was wetted by a wipe, and the measure of path loss was carried out to ensure that the arm remained soaked in the measurement process.

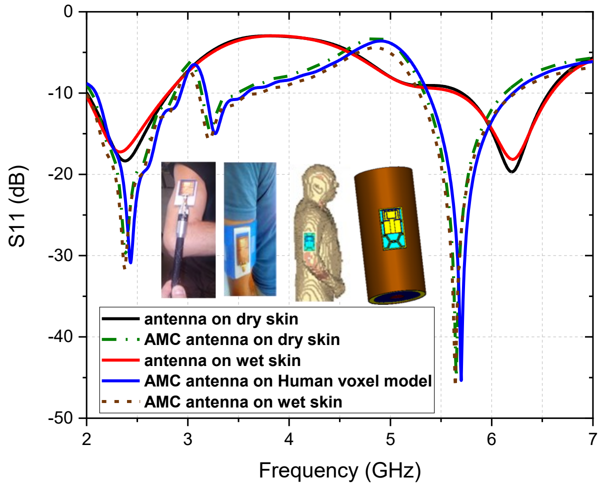
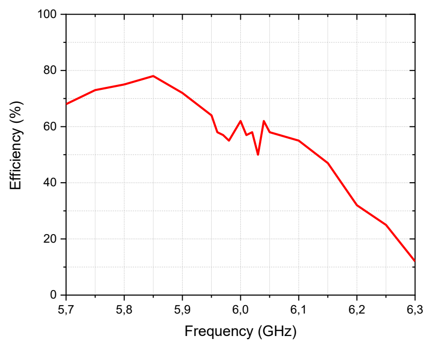


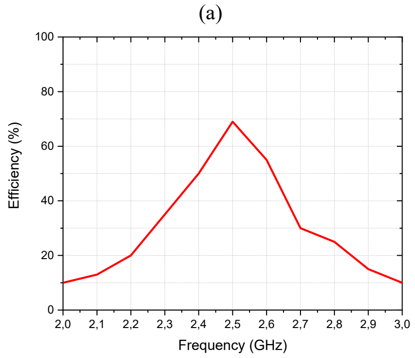

Fig. 11. measured reflection coefficient of the wearable on the upper arm in a different state of the skin

Figure 11 shows the measured reflection coefficient of the AMC antenna on the human body with wet skin and dry skin. A good agreement between the measurement and simulation results is obtained in both the 2.45 and 5.8 GHz bands. The resonant frequency of the AMC antenna, when placed on the human arm in different skin conditions (Wet skin/ Dry skin), varied slightly, and the bandwidth covered the desired bands in all states. This can prove that the proposed AMC antenna presents good immunity to Wetness. But when the antenna is placed on the human body, a frequency detuning is observed.

The measured efficiencies of the AMC antenna above a human arm are 65% and 75% at 2.45 GHz and 5.8 GHz, respectively, are plotted in Fig.12.




(a)




(b)

Fig. 12. Measured efficiency of the AMC wearable antenna on the human arm (a) 2.45 GHz, (b) 5.8 GHz.

### C. *Specific Absorption Rate*

However, the major problem in designing an antenna for body-centered communication systems is the back radiation absorbed by the human body. The latter's exposure to electromagnetic radiation is generally stated in terms of specific absorption rate (SAR), which is the power absorbed in the tissues [W/kg]. The SAR is expressed as Equation (1):

$$SAR\ (W/Kg) = \frac{\sigma E^2}{\rho} \quad (1)$$

Where σ represents the conductivity in (S/m), ρ corresponds to the Mass density in (Kg/m$^3$) and E denotes the electric field in (V/m).

TABLE II
SIMULATED SAR VALUE OF THE ANTENNAS ON THE UPPER ARM

| | SAR | SAR, W/kg for 1 g tissue | | SAR, W/kg for 10 g tissue | |
|---|---|---|---|---|---|
| | Frequency, GHz | 2.45 | 5.8 | 2.45 | 5.8 |
| Antenna without AMC | Dry Skin | 38.9 | 37.4 | 15.6 | 8.03 |
| | Wet skin | 40.2 | 37.4 | 16.1 | 11,4 |
| Antenna with AMC | Dry Skin | 0.035 | 0.014 | 0.018 | 0.032 |
| | Wet skin | 0.068 | 0.017 | 0.048 | 0.090 |

Table II shows the SAR values of the proposed antenna with and without AMC on the human arm. The specific absorption rate (SAR) value was calculated and compared using the CST software and applying the IEEE C95.3 standard [6].
The obtained results show that the presence of AMC led to a decrease in SAR. They also reveal that the AMC antenna reduced the SAR value by 96.5% for 1 g of tissues and 97.3% for 10 g of tissues compared to the antenna without AMC.

## IV. PERFORMANCE COMPARISON

Table III presents the performance of the proposed wearable antenna compared to the previously reported dual-band wearable antennas on the body. In [30], they are only applicable to off-body communications due to the rigid substrate, which can't conform to the human body.

Hence, the proposed antenna has the advantage of conformability due to the textile substrate worn on the human body and presents satisfying performances such as good efficiency, high gain, low SAR, dual bands. Moreover, it applies to both on and off-body communications. These features make the proposed wearable antenna a strong candidate for WBAN/ WLAN applications.

TABLE III
COMPARISON OF PROPOSED ANTENNA WITH PREVIOUS DUAL-BAND ANTENNAS ON BODY

| Ref/ Year | Main Topology | Freq. (GHz) | Study of the state of skin: W.S/D.S | SAR, W/kg for 1g tissue | SAR, W/kg For 10g tissue | Efficiency % | Gain (dBi) | Flexible |
|---|---|---|---|---|---|---|---|---|
| This work | AMC-CPW antenna | 2.45/ 5.8 | Yes<br>Wet skin<br>Dry skin | 0.034/ 0.014<br>0.068/ 0.017 | 0.0182/0.0318<br>0.0486/0.09 | 65/ 75<br>65/ 75 | 8.5/9.2<br>8.5/ 9.2 | Yes |
| [31]/2020 | Microstrip Patch Antenna (MPA) | 2.38/ 3.5 | No | 0.722/ 0.533 | - - | 63.3/ 59.2 | 1.38 / 7.7 | Yes |
| [32]/2020 | Probe | 2.45/5.8 | No | 0.042/ 0.09 | - - | 53.6/ 70.1 | 5.86/ 6.94 | Yes |
| [9]/2020 | Patch antenna | 1.575/2.45 | No | - | 0.111/0.111<br>0.086/0.0877 | - | 1.98/ 1.94 | Yes |
| [30]/2019 | GCPW slot antennas | 2.4/5.8 | No | - | - | 31~48<br>40~43 | - | No |
| [25]/2018 | CPW antenna | 2.45/5.8 | No | 0.34/ 0.270 | - | 55/60 | - | Yes |
| [33]/2016 | Microstrip Patch Antenna (MPA) | 2.34/5.8 | No | 0.74/ 0.852 | - - | 26/ 52 | -4.75/ 3.8 | No |

## CONCLUSION

A compact dual-band textile AMC-antenna, covering both the Wi-Fi and LTE bands [2.3-2.7] GHz and [5.1-5.875] GHz, was presented in this paper. The problem of rear radiation from the antenna to the human body was addressed by using a meta-material of the artificial magnetic conductor type dual-band for the two Wi-Fi frequency bands, using the same flexible textile as a substrate.

To study the effects of the human body in different meteorological conditions, a multilayer tissue model representing the human upper arm and a Human voxel model was used on the antenna performance. The simulation and measurement results of the proposed AMC antenna under wet and dry skin were plotted, they satisfy the comfort and safety properties of users. Therefore, the proposed wearable AMC antenna is suitable for WBAN/ WLAN applications.

## ACKNOWLEDGMENTS

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