A Wideband Circularly Polarized Wearable Antenna Based on Metasurface for WBAN Applications

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***Abstract*—This conference paper presents a circularly polarized wearable antenna array based on metasurface with wideband for wireless body area network (WBAN). The antenna array consists of four metasurface antennas, and each antenna has a sub array including 2 x 2 metasurface elements. A ring-shaped feeding structure with four arms is employed in this array. Using this structure, a quasi-90° phase delay is generated between each adjacent arm, and thus the antenna array can radiate a circularly polarized pattern. For the wearable antenna array, the simulation -10 dB impedance bandwidth is from 3 GHz to 5.92 GHz with 65.5% relative bandwidth. And the 3 dB axial ratio bandwidth is from 3 GHz to 5.45 GHz with 58% relative bandwidth. The whole size of the antenna array is 1.59λ×1.59λ×0.09λ (106×106×6 mm^3) at 4.5 GHz, and the maximum gain is 8.3 dBi. Eventually, the Specific absorption rate (SAR) at different frequency of proposed antenna is assessed on the body phantom, and the values are satisfied the FCC standards. This flexible antenna array is an excellent candidate for WBAN and 5G applications.**

Keywords—wearable antenna, antenna array, circularly polarized, wideband

I. Introduction

5G wireless communications technology has developed rapidly in recent years, and internet of things (IoT) technology emerged at the historic moment, showing the trend of prosperity. Wearable antenna play a significant role gotten an broadly use due to their characteristic of lightweight, low profile, and flexibility in various life applications. Thus, many researches have focused on wearable antenna study presently [1]-[6]. Though linearly polarized antennas have been widely studied, it is still hard to keep a stable polarization performance in the moving body with different postures. Thus, circularly polarized wearable antennas are necessary for communications in complex environments. Meanwhile, it is an effective method to reduce the multipath effect, polarization mismatch, and absorption loss. Most flexible substrates such as felt, jeans, and linen, have higher losses than ordinary rigid substrates, so the gain is another problem in wearable antennas. Apart from employing background, an antenna array is an effective approach to improve the radiation gain.

Electric-Magnetic (E-M)metamaterials have become a research hotspot recently. In the design of wearable antennas, The use of this kind of E-M artificial E-M structure with new characteristics is very popular[6],[7], and one of the most important application is artificial magnetic conductor (AMC). Some researchers use AMC plane to reflector the wave with low profile, and it also has the function to expand bandwidth. so circularly polarized antennas are put on the AMC plane to improve the antenna's performances [9],[10]. To reduce the size of metamaterial based wearable antennas, some researchers proposed a new design approach, i.e., using the metasurface generate the radiation directly. The metasurface can be excited by a special feeding structure and resonates at a specific frequency [11]-[13]

Characteristic mode significance (CMA)is a very important and useful approach for antenna analysis and design. The mode significance is an index for the potential ability of a pattern to be evoked. The closer the mode significance is to 1, the easier it is to be excited. Thus, many works apply this method to study novelty antennas. In literature [14], CAM is adopted for wearable antenna analysis. By changing the shape of the radiation patch and calculating its mode significance value, a good performance PIFA is designed. In [15], a circular ring is analyzed based on CMA, a pair of degenerated modes with orthogonal polarization are excited by two microstrip lines and exciting a certain characteristic angle difference. A broadband circularly polarized antenna is designed. CMA is used to analyze the mode of the antenna, and the generation of the circular polarization is from the phase difference between the two modes [16]. Some researchers use the L shape feeding structure to excite the metasurface plane through a crossed slot and generate a circular polarization [17]. In this work, CMA is a good tool for metasurface mode analysis.

This paper presents a design of a wideband circularly polarized wearable antenna array, working from 3 GHz to5.92 GHz. A ring-shaped feeding structure with four arms is used to generate a quarter wavelength phase delay. Metasurface plane is employed using CMA in this design for improving its performance. The antenna array and the background not only increase the gain but also reduce the SAR value. All the simulation model and results in this article are based on the CST MWT, a commercial electromagnetic solver.

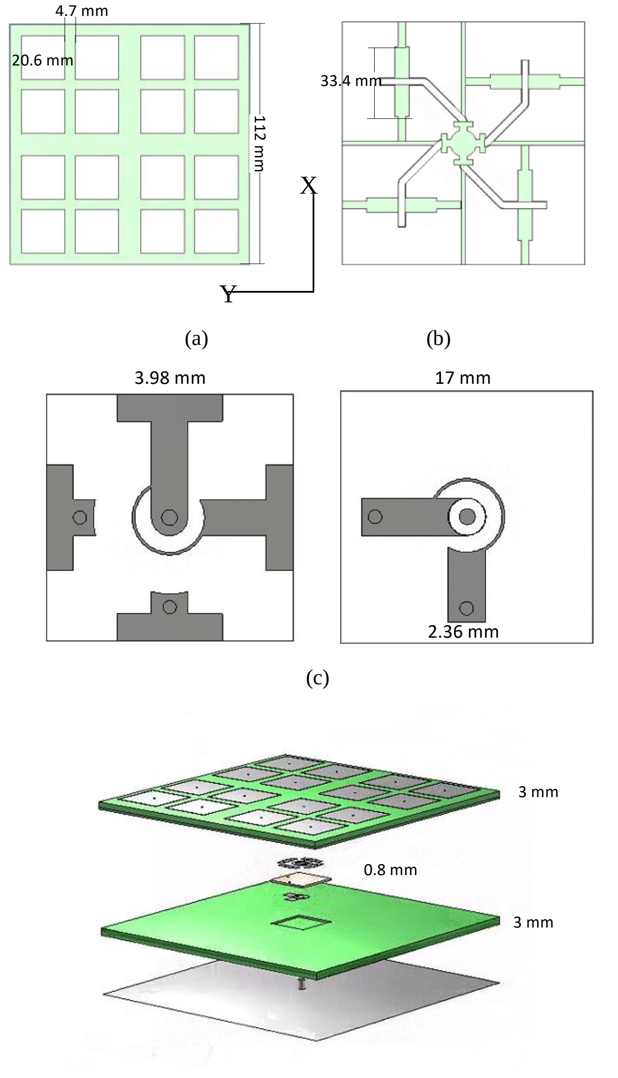


Fig. 1. Wearable antenna model. (a) top side of first layer, (b) bottom side of first layer, (c) two sides of the feeding structure, (d) assembly drawing.

II. CIRCULAR POLARIZION ANTENNA DESIGN

The proposed flexible antenna array in this article is presented in Fig. 1 (a). The antenna array consists of three parts, i.e., the top layer including four metasurface antennas, the AMC plane with the mushroom structures fabricated by the felt and flexible conductive textile, the feeding ring etched on a 0.8 mm-thick FR4 broad, and a reflector covered a conductive textile. The felt has a thickness of 3 mm-thick for the flexible substrate and its electric characters are εr = 1.3 and loss tand = 0.044. the conductive textile has a conductivity of 1.18 × 10^5 S/m. its thickness is 0.017 mm and stick on the substrate felt. The small size of the FR4 has little effect on the flexibility of the antenna. For the low profile, the feeding structure is embedded in the bottom layer as shown in Fig. 1(d).

A. Feeding structure Design

To better understand the wearable antenna array's operating principle of the circular polarization, a simple diagram is present

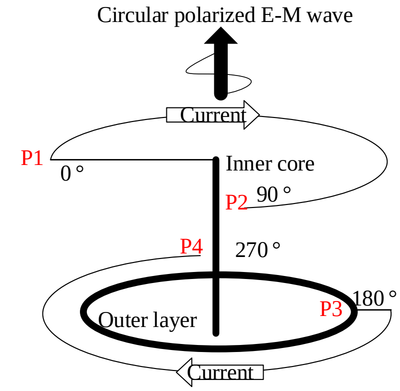


Fig. 2. The principle of the circular polarization

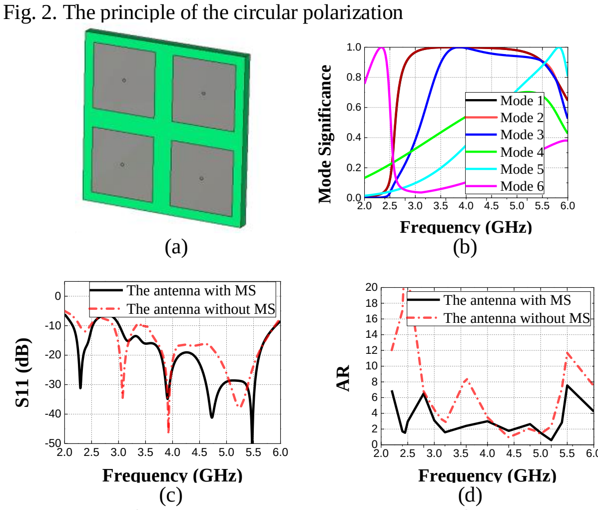


Fig. 3. Metasurface design.(a) unit cell, (b) mode significance, (c) S11 curve and (d) axial ratio.

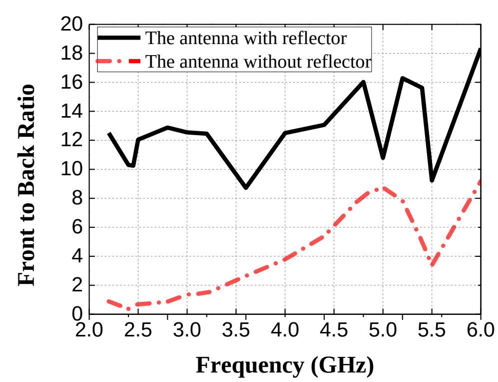


Fig. 4 Front to back ratio over frequency.

in Fig.2. Thin lines with arrows are the current paths with quarter-wavelength, and bold lines are the inner core and outer layer of a cable. When P1 is initial zero phase, the phase of P2 is 90° and P3 is 180° due to the property of the cable, which has 180° phase difference between P1 and P3, and the phase of P4 is 270° . For this reason, the excited cable can generate a circularly polarization among these four points.

B. Metasurface Design

Fig. 3(a) shows one of the 4×4 metasurface unit's physical layouts. CMA is used for model significance in CST software.

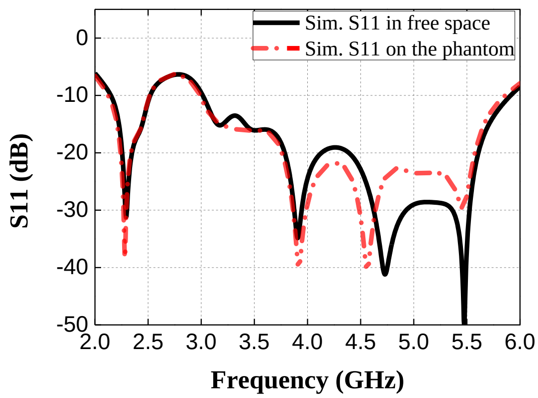


Fig. 5. S11 curves in different cases

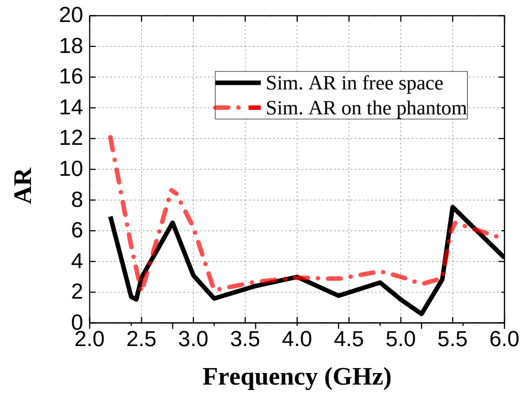


Fig. 6. AR performance in different cases

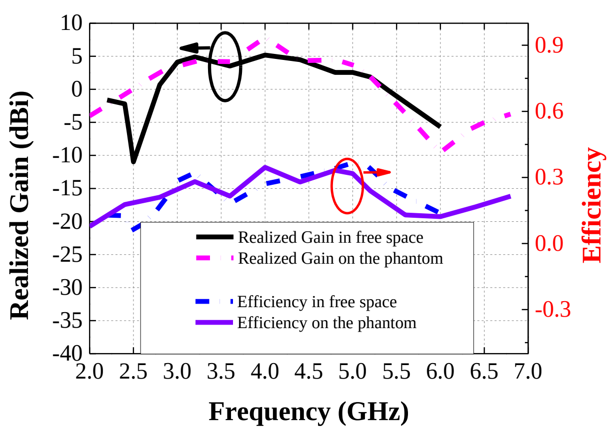


Fig. 7. Gain and efficiency results of the antenna in different situations.

The mode sorting of frequency in softer ware is 4 GHz, and the results are shown in Fig. 3(b). From these curves, mode 1 and 2 are coincident because of the rectangular antenna unit, which cover from 3 GHz to 5.5 GHz. At the same time, mode significance of model 6 is also strong at 2.45 GHz. They have high potential to be excited to improve the antenna's performance. The comparisons between the antenna with and without metasurface plane are shown in Fig. 3(c) and (d). they indicate that the MS plane have improvement both in S11 and axial ratio.

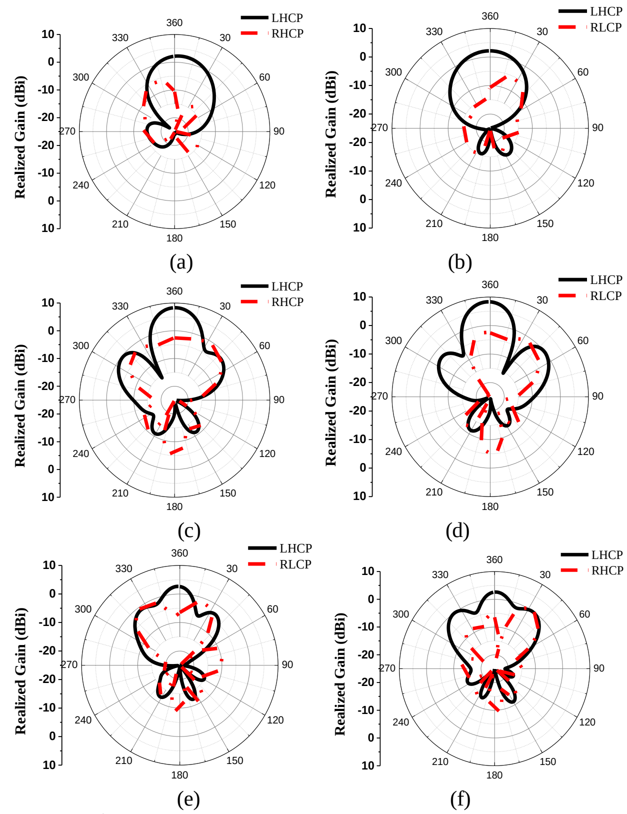


Fig. 8. Far-field pattern in simulation and measurement. (a) 3 GHz in xoz plane. (b) 3 GHz in yoz plane. (c) 4 GHz in xoz plane. (d) 4 GHz in yoz plane. (d) 5 GHz in xoz plane. (e) 5 GHz in yoz plane.

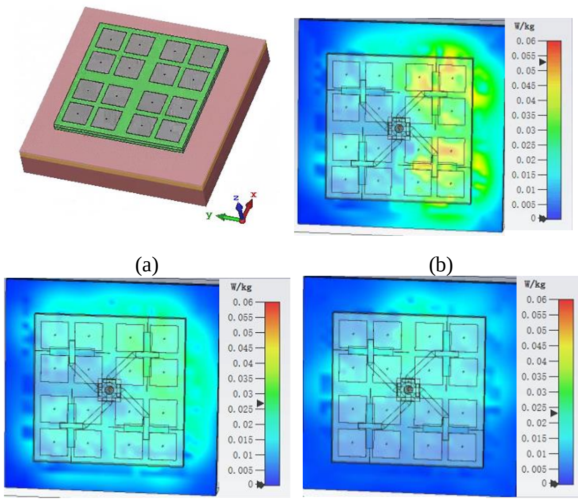
C. Front to Back Ratio

As a wearable device, the Front-back ratio is a very important index for the high direction of the antenna and low SAR. In this work, a coplanar waveguide is adopted in the feeding structure for low profile, leading to a worse front-to-back ratio. A reflector plane is attached to the back of the antenna to improve the front-to-back ratio and keep the other antenna's performance. Fig. 4 is the performance between these two cases, And it shows that a reflector is an effective way to reduce back radiation.

III. Simulation Rresults and Analysis

The textile antenna array is simulated and the performance results in free space and on the human phantom are implemented. A size of 160×160 mm^2 human body model with three-layered tissues is constructed, and the thickness of the tissues are 2 mm, 5 mmm and 20 mm with skin, fat, and muscle respectively. The tissue parameters are exported from the CST materials library. When the antenna simulated on the human phantom, a10 mm gap is set between the device and the phantom to imitate the real situation. the model is present in Fig. 9(a).

The solid black line in Fig. 5 represents the simulated result of the antenna in free space, and spans the range of 3 GHz to5.92 GHz with bandwidth of 2920 MHz. The frequency range when the antenna is on the human phantom is between 2.98 GHz and 5.86 GHz. The 3 axial ratio in free space is between 3 GHz and 5.45 GHz, and on the phantom is from 3.1 GHz to 5.45 GHz. Because of the back plane that reflect most radiation energy



(a) (b)

(c) (b)

Fig. 9. SAR simulation result (a) simulation model, (b) SAR distribution at 3 GHz, (c) 4 GHz, and (d) 5GHz

from the antenna to the phantom, the performances of proposed antenna are stable when it is simulated with the human body. The slight difference between the antenna in free space and on the human body is due to the electromagnetic wave's diffraction.

Meanwhile, far-field performances and radiation patterns are simulated in the CST software. The simulated gain and the efficiency are presented in Fig. 7. From this diagram, the efficiency on the body is agree with the curve in free space. The maximum realized gain is 8.3 dBi at 4 GHz in simulation. The radiation pattern are also presented in Fig. 8. The simulation patterns have a same reference frame with the model in Section I. It can be seen that the proposed antenna in this article has a steady broadside pattern in the operating frequency band, which is suitable for the off-body communication.

In Fig. 9, the SAR distribution is simulated at 3, 4, and 5 GHz. SAR is used for assess the radiation power loss of an antenna to the human body, which is a crucial values for wearable devices. The FCC recommends that SAR should be less than 1.6 W/kg averaged over 10 g of actual tissue standard. 0.2 W input power is loaded to the proposed antenna in this article, and the peak SAR values are 0.0537 W/kg, 0.0272 W/kg and 0.0241 W/kg at 3 GHz, 4 GHz and 5 GHz, respectively, which are satisfied the requirements and is acceptable working on the human body.

IV. CONCLUSION

In this paper, a wideband circularly polarized wearable antenna array based on metasurface is proposed. The array consists of four antennas and a feeding structure. A ring-shaped feeding circuit with four arms excites the antenna elements and generates circularly polarized radiation. The size of the flexible antenna array is $1.59\lambda\times1.59\lambda\times0.09\lambda$ at 4.5 GHz ($112\times112\times6$ mm^3). It has a wideband from 3 GHz to 5.92 GHz (65.5%), and 8.3 dBi maximum gain. Eventually, the performances of the wearable circularly polarized antenna array are evaluated both in air space and on the human phantom.

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