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A Novel Circular Wideband Wearable Antenna Based on DGS

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Abstract

In the design of wearable antennas, reduction of antenna size is particularly important, which can not only improve comfort of wearers, but also minimize the performance changes caused by deformation. A compact broadband circular wearable antenna using denim fabric as substrate is designed in this paper by the Theory of Characteristic Modes (TCM). By etching defective structures on the ground plane of the circular wearable antenna, the characteristic impedance can be reduced and the effective dielectric permittivity of substrate can be increased significantly. At the same time, the defect structure changes the distribution parameters of the ground plane, and the changes of different position parameters are inconsistent, which change the current flow direction on the patches. This has the same effect as the meandering technology, which uses slots to change the current distribution on the patches to increase the electric length, and realizes the miniaturization of the antenna. The experimental results show that area of the circular antenna radiating element is reduced by 32% and the bandwidth covers 5.65GHz-5.98GHz by using the DGS. Finally, the Specific Absorption Rate (SAR) value proves that the circular antenna base on DGS meets the radiation safety standard of human body.

Keywords

Wearable Antenna, DGS, TCM, Wideband, SAR.

1. Introduction

At present, intelligent wearable devices are gradually coming to public life and become a hot research topic. Wearable antenna is a kind of antenna which can be loaded on human body or clothing [1]. It is the key part of signal transmission of intelligent wearable equipment. Because of the particularity of the working area, wearable antenna must be miniaturized to meet the comfort requirement of wearer and reduce the performance changes caused by antenna deformation.

Antenna miniaturization refers to the reduction of antenna size on the premise that the antenna can reach the specified performance index in a specific operating frequency [2-5]. At present, the main methods of miniaturization of microstrip antenna include special substrate [6], antenna loading branch [7], special form patch [8] and meander technique [9]. DGS structure change the distribution parameters of microstrip patch, so as to change the direction of current on the patch and realize the miniaturization of antenna. Pandhare proposed a two-element rectangular microstrip antenna based on DGS structure [10], by etching the dumbbell groove on the connecting floor, the antenna size is reduced to 24% of the traditional rectangular microstrip antenna, the frequency range of the antenna is 2.4-2.52GHz, and the maximum gain is 2.35dB, which meets the application requirements of the ISM band and realizes the miniaturization design. In 2017, Chakraborty proposed a compact multiband circular antenna [11]. The dielectric substrate adopts FR4, and the circular patch radius is

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reduced to 7.1mm by introducing two zigzag DGS structures on both sides of the coaxial feed, and the antenna performance is improved.

In this paper, based on the classical DGS structure, the aperiodic defect structure is introduced into the curved slot circular antenna, and the antenna size is reduced by opening eight circular holes of different sizes on the ground. Through the analysis of its intrinsic mode, the feed position is used to select the excitation mode. TCM with radiation boundary conditions solved the input impedance of the antenna, and TCM based on differential equations is applied to the analysis of the circular wide-band wearable antenna with polygonal slot. The antenna dielectric substrate is made of the common cowboy cloth with 1mm thickness, and the processing test of the antenna is carried out. The measured results agree well with the simulation results.

2. Antenna Design Method

In the finite element method, the computational region is divided into many meshes, and the electromagnetic field is represented by simple functions in each mesh, these simple functions are usually referred to as basic functions. The electromagnetic field in the whole region is expanded by the local basis functions of these grids. Maxwell's equation is transformed into a finite dimensional linear algebraic equation. The electromagnetic field distribution in the studied region can be obtained by calculating the expansion coefficients.

Using the characteristic mode, the z-direction electric field E_z of microstrip antenna can be expressed as,

$$E_z(x,y,z) = j\omega\mu\sum_p \frac{1}{k^2-k_p^2}\frac{<J,\psi_p>}{<\psi_p,\psi_p>}\psi_p(x,y,z)\,. \tag{1}$$

Among them, J is the excitation current, k is the amplitude coefficient of the excitation condition, and ψ_p is the intrinsic function.

$$<J,\psi_p>=\int J\psi_p^*\,dv \tag{2}$$

In the integral of the inner product calculated above, the integral region is composed of the free space part of the radiation boundary. According to the electric field expression of the characteristic mode, it can be seen that which mode of the antenna can be excited depends on the location of the excitation source.

As shown in Fig.1, the antenna substrate is a dielectric substrate with a relative dielectric constant of 1.511, and the specific parameters are shown in Table 1. The antenna is placed parallel on the xoy-plane, and the center coordinate is (0, 0). And the size of the substrate is *W*L*h*, the radius of the circular patch is 28 mm, the position of the feed point is (x_0, y_0), and the polygonal slot is opened on the patch. The bottom of the dielectric substrate is the metal ground plate of DGS, which is different from the traditional dumbbell-like DGS structure. The metal ground is independently etched with 8 circular holes, and the position of the distance center d_1 is separated by a circular hole with four radius r_1, and the circular hole with the four radius r_2 is separated at the position of the distance center d_2. There is no strip groove in the ‘dumbbell’ structure in the middle of the circular hole, which aims to reduce the size of the antenna while minimizing the increase in backward radiation.

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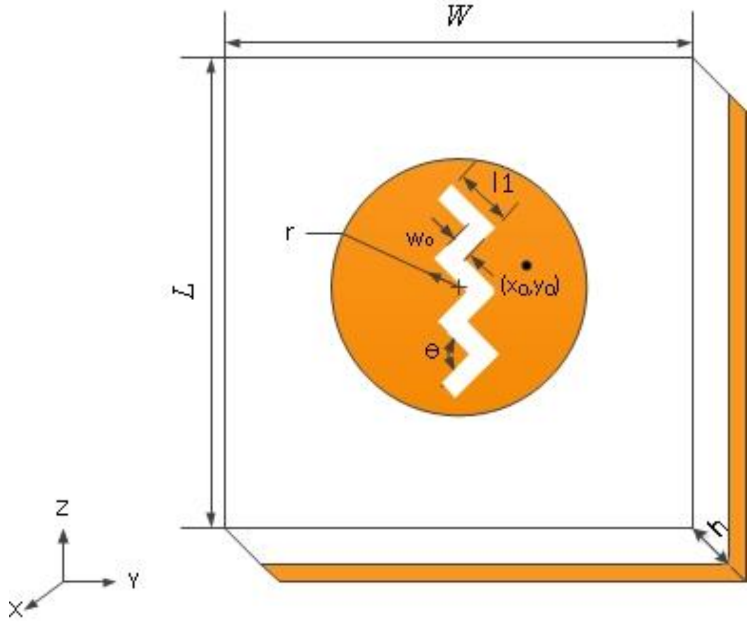

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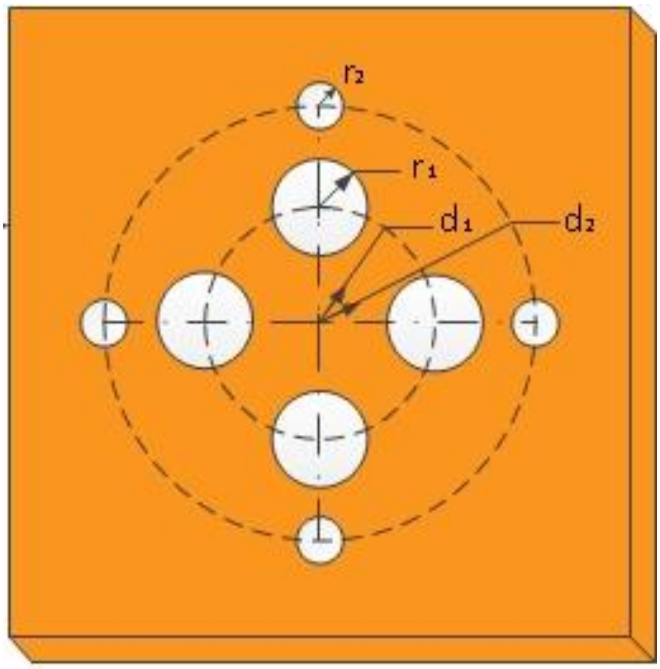

(*b*)

Fig.1 The geometrical structure of polygonal slot circular antenna base on DGS
(a) front view (b) back view

The characteristic mode of circular antenna with polygonal slot based on the defect ground structure is analyzed by TCM. After a circular slot is opened on the ground, the characteristic mode changes. The three dominant modes in the frequency band 5GHz-6GHz correspond to the resonant frequency shifted to the low frequency(5.51GHz,5.68GHz,5.84GHz), because the DGS structure which increases the effective dielectric constant. The high dielectric constant is favorable for reducing the size of the antenna. When the radius is reduced to 22mm, the center frequency is returned to 5.8GHz, the frequency is in the range of 5GHz-6GHz, and the normalized distribution of the electric field of the three dominant modes are shown in Fig.2.

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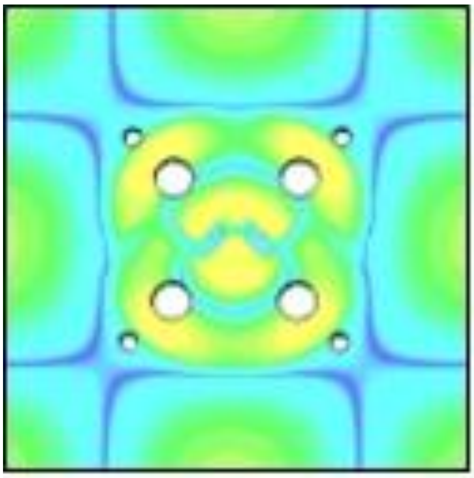
Table 1 Parameters of the circular antenna with polygonal slot base on DGS [mm]

W	L	h	r	l_1	w_0	x_0	y_0	r_1	r_2	d_1	d_2
100	100	1	22	4	2.6	9	6	4	2	13	31



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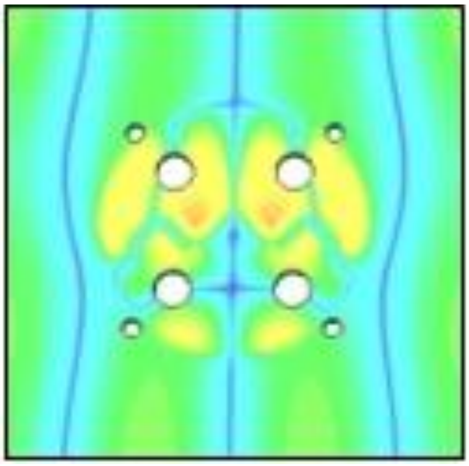

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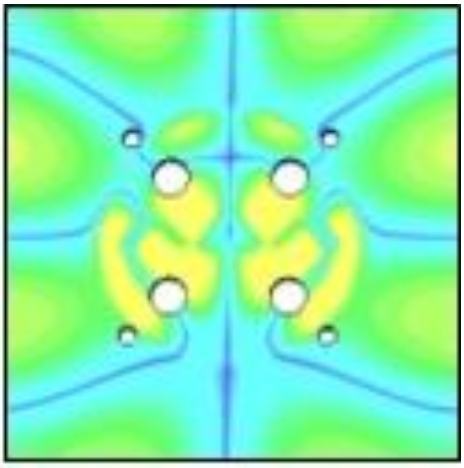

(*c*)

Fig. 2 The normalized electric field distribution of the DGS
(a)5.51GHz (b)5.68GHz (c)5.84GHz

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3. Results and Discussion

According to the parametric dimension in Table 1, the antenna is processed as shown in Fig.3. The antenna patch and ground plane are made of stackable copper foil and are pasted on the denim with dielectric constant of 1.511 and thickness of 1mm. In microwave anechoic chamber of Communication University of China, the performance of circular antenna with polygonal slot base on DGS is tested, and the vector network analyzer is Agilent E5071C.

(*a*)

(*b*)

Fig.3. Photos of prototype circular antenna with polygonal slot base on DGS
(a) front view (b) back view

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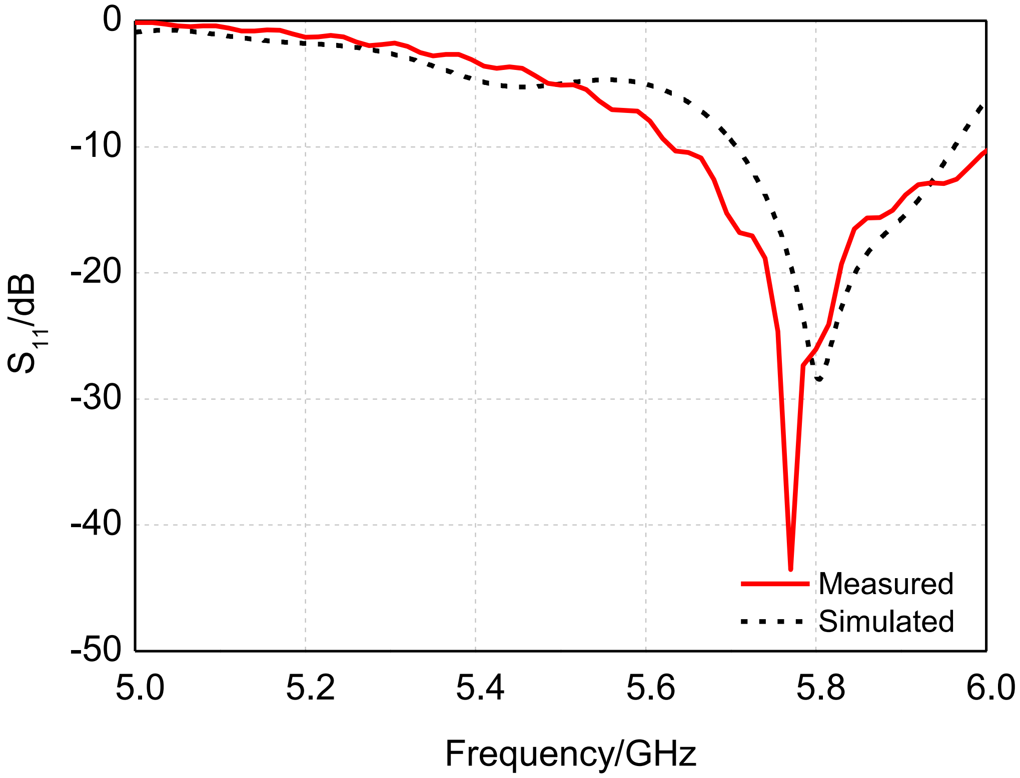
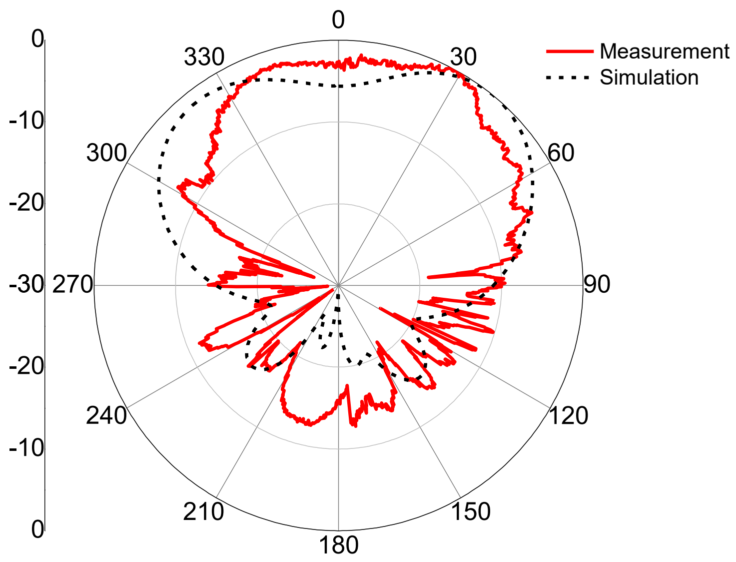


Fig.4. The $|S_{11}|$ comparison of circular antenna with polygonal slot base on DGS with measurement and simulation

As can be seen from Fig.4, the bandwidth of circular antenna with polygonal slot base on DGS with radius of 22mm is 5.65GHz-5.98GHz. In Fig.5, the front-to-back ratio is 11.5dB, the maximum direction gain is 8.1dB, and the experimental results are agreed with the simulation results. The loss of common dielectric material is larger and the radiation efficiency of the antenna is lower. Because of the high loss of denim and the low radiation efficiency of the antenna, the measurement bandwidth of the antenna is wider. While, low backward radiation is required to ensure human safety as a wearable antenna. The simulation of the SAR value of the antenna are as follows.



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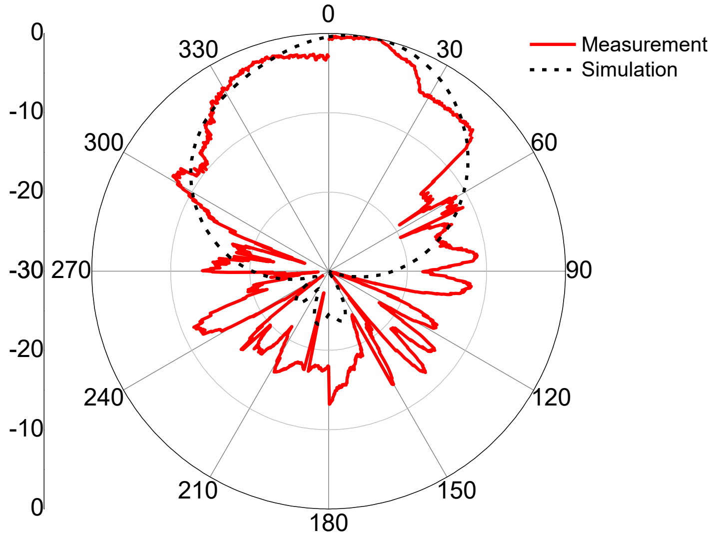

(*b*)

Fig.5. The directivity diagrams experiment comparison of circular antenna with polygonal slot base on DGS at 5.8GHz (a) E-plane (b) H-plane

As shown in Fig.6, the human body model established in this section consists of skin and muscle, with thickness of 0.05mm and 60mm respectively, and its electromagnetic parameters vary with frequency. Table2 shows the electromagnetic parameters of the human body in 2.45GHz and 5.8GHz [12].

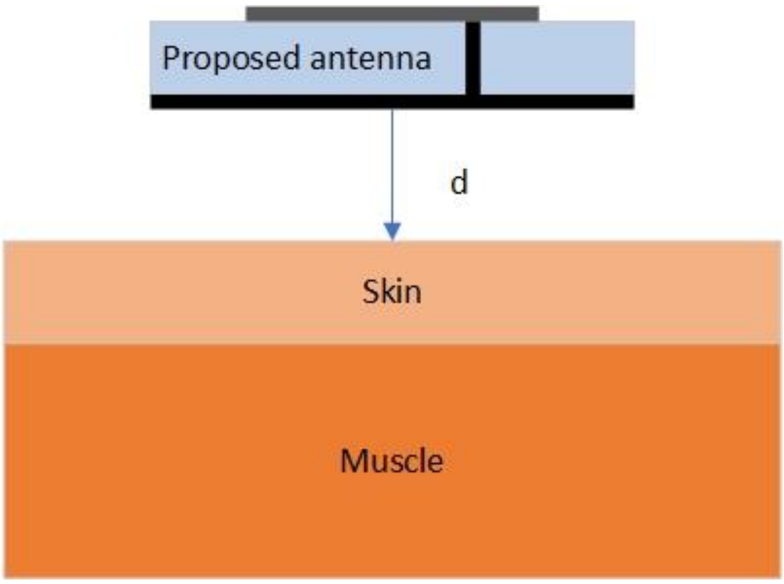

Fig.6. Circular Antenna and Human Body Model

Table 2 Electromagnetic parameter table of human model at 2.45GHz and 5.8GHz Frequency

Frequency	Skin		Muscle	
	ε_r	σ	ε_r	σ
2.45GHz	3.354	1.464	54.417	1.882
5.8GHz	3.113	3.717	49.498	5.440

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The circular antenna with polygonal slot base on DGS is placed at a distance from the 1mm of the human body. The distribution of SAR value in the muscle tissue at the center of the antenna and the center of the feed is measured as shown in Fig.7, the maximum SAR is about 1.05W/kg, lower than the IEEE standard maximum of 2W/kg, which proves the safety of the antenna as a wearable antenna.

Above all, it is known that the DGS can reduce the size of the antenna patch under the condition of ensuring the radiation safety of the human body. With the introduction of the DGS structure, the area of the radiation unit of the circular antenna with polygonal slot base on DGS is reduced by 32%, and the bandwidth is 5.65GHz-5.98GHz, which is 3.3times that of the traditional circular antenna.

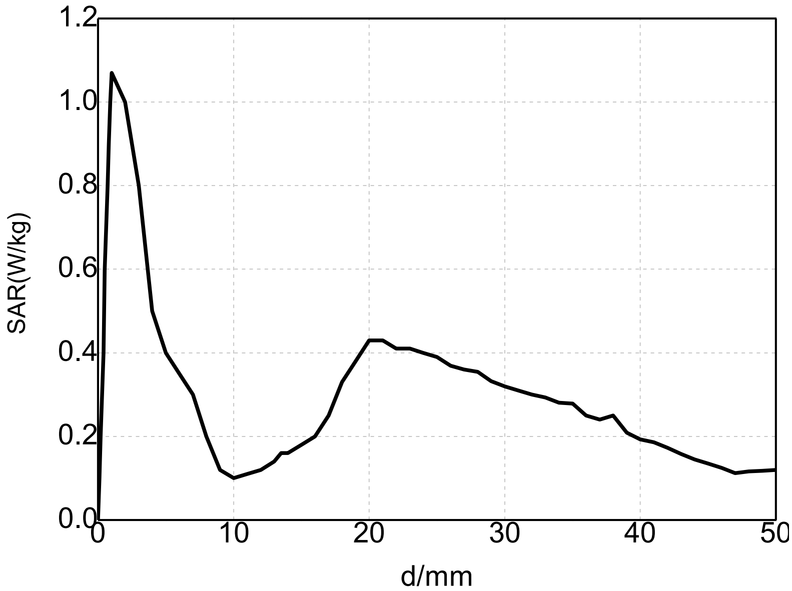

Fig.7. SAR of circular antenna with polygonal slot base on DGS

4. Summary

With the DGS, the distribution parameters of microstrip patch and direction of current on the patch can be changed and the antenna is miniaturized. In this paper, a broadband circular antenna with polygonal slot base on DGS is proposed, and the area of the antenna radiation unit is reduced by 32% by etching 8 unequal-sized circular holes on the ground. The bandwidth of the novel antenna is 5.65GHz-5.98GHz, and the front-to-back ratio is 11.5dB, the maximum directional gain is 8.1dB, with higher antenna radiation efficiency, lower backward radiation, and better performance, which is suitable for wearable system applications.

Acknowledgments

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