Polarization performance analysis of linear polarized antenna in 2.45GHz on-body communications

Lingfeng Liu, Xiaonan Wang, and Peng Zhang.

***Abstract*—In this paper, three kinds of compact linearly polarized antennas are proposed, and the effects of horizontal polarization and vertical polarization on the polarization performance of the antenna are analyzed based on the simulation. Antennas are inverted F antenna, MIFA and printed dipole. Simulated human chest model includes skin, fatmuscle three-tier structure. The results show that the change of resonant frequency is small after loading the human body, but the radiation orientation of the antenna is more obvious due to the coupling effect of the human body, and the bandwidth, center frequency and S11 are affected by the distance between the antenna and the body surface and the relative orientation. After loading the human body, the resonant frequency of the antenna changes little, the pattern is relatively stable.**

***Index Terms*—IFA, MIFA, printed dipole, horizontal polarization, vertical polarization, Body Area Network(BAN).**

I. Introduction

RECENT years, the use of cellular phones and other personal communication services has gradually widened, making the focus of research on the human body wearing antennas. In the WBAN communication system, the 2.4GHz frequency band is widely used in various areas of WBAN, such as health care in the health of the monitoring and prevention of health and the detection of attitude and motion in fitness in the entertainment due to the small size of the antenna, high transmission rate and low power consumption. Characteristics of antennas and propagation channels in on-body communications have been ascertained [1]- [4]. At present, some textile patch antennas had been proposed for wearable applications [5], most of the research is placed the antenna in the shape of the phone on the head of the assumptions for simulation and testing [6], [7], but the wearing antenna is usually placed in the human body torso or limbs, the recent studies have shown that these are optimal locations for wearable antennas [8].

Studies as [9], [10] also reveal the possibility to explore the polarization spatial diversity in on-body channels to improve the performance of e.g. realying and Multi-Input Multi-Output (MIMO) in WBANs. In the study of the antenna on body surface, the following problems usually arise: the antenna is integrated in the clothing or placed on the human body surface [11], [12]. The human body can be seen as a media of complex characteristics and must have an impact on antenna performance parameters [13], [14]. At the same time the distance between antenna and human body is also one of the important factors. In order to study the impacts of these factors on antenna performance, three kinds of linear polarized antennas were selected and placed on the surface of the human body. The antenna performance was observed by changing the distance between antenna and the human body. This paper consists of five parts, the second part introduces the desgin of three kinds of linear polarized antennas and the third part introduces human body modeling. The fourth part analyse the polarization performance of the antennas. Finally, the performance of the linear polarization antenna in 2.45GHz body surface communication is summarized.

Lingfeng liu, Xiaonan Wang and Zhang Peng are with the Signal Information Engineering school, East China Jiaotong University, China, e-mail: lingf.liu@gmail.com.

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II. ANTENNAS DESGIN

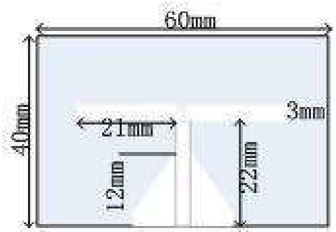
We choose IFA, MIFA and printed dipole three microstrip antennas for the study. They have small size, simple structure, low production costs and also easy to match. Their structure and initial values are shown in Fig. 1 and Tab. I. These antennas are fabricated on the PCB and operates in the 2.4GHz ISM band with the center frequency of 2.45GHz. The dielectric layer is made of the most commonly FR4 with ϵ_r=4.4 [15]. The antenna is simulated by Ansoft HFSS 13.0®. After appropriate analysis and optimization of the values of the main parameters, when *L*=16.2mm, *H*=3.8mm and *S*=5mm, the resonant frequency of IFA is 2.45GHz, the bandwidth is about 450MHz. While *L1* = 3.5 and *GndX* = 34 mm [16], the resonant frequency is around 2.45 GHz and the bandwidth is about 225 MHz. While *L2* = 21mm, *L3*= 6mm, the maximum bandwidth is 550MHz and achieve a good impedance matching at 2.45GHz.The simulation results of three antennas are shown in Fig. 2.

III. HUMAN BODY MODELING

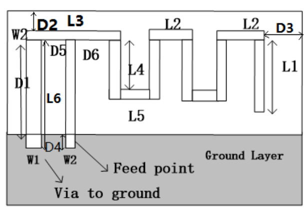
We must establish the human body model accurately in the study of the impact of human body on antenna, the human body is composed of various biological tissues with different shapes and electromagnetic properties. Most of the biological tissues are non-uniform dispersion medium and human body cant be accurately modeled. We can construct different human models to obtain multiple results as much as possible within allowable range of the error. Analysis of antenna performance in realistic environment is subjected to the body shape and environment, we simulate in the simulation state. As the antenna is not directly in vicinity of the human body, we place a cube simulated human chest at a certain distance from the antenna as shown in Fig. 3. The cube is a three layered biological tissue model [17] . As shown in Fig. 4,

Antennas	Variable	Initial Values
IFA	L	16.2
	H	3.8
	S	5
	W	1
	SubH	0.8
	GndX	50
	GndY	90
Dipole	H	11.6
	W1	3
	L1	22
	W2	3
	L2	21
	L3	10
	L4	12
	W3	3
MIFA	D1	0.5
	D2	0.3
	D3	0.3
	D4	0.5
	D5	1.4
	D6	1.7
	L1	3.3
	L2	2.7
	L3	5
	L4	2.64
	L5	2
	L6	4.9
	W1	0.9
	W2	0.5

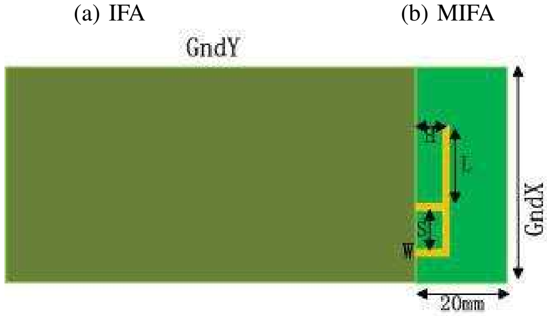
TABLE I: Variable definition



(a) IFA



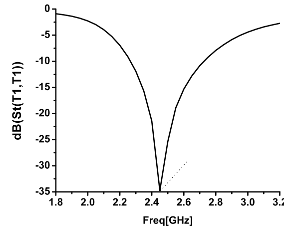
(b) MIFA



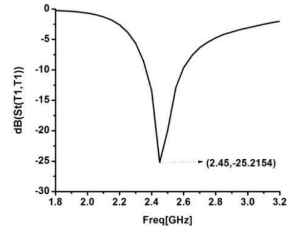
(c) Dipole

Fig. 1: Parameters of three antennas

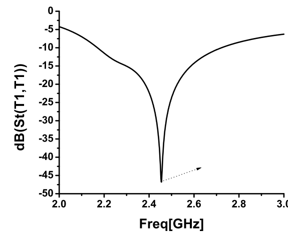
the three-layer structure of the skin layer (2 mm), fat layer (5 mm) and muscle layer (10 mm) was set from top to the bottom, and the model volume was 200 mm * 160 mm * 17 mm. Considering that the 2.4 GHz signal is rapidly attenuated in human body, this structure is considered to be able to adequately simulate the human body. Dielectric constant and other electrical characteristics [17] are derived from human body and shown in Tab. II.



(a) IFA

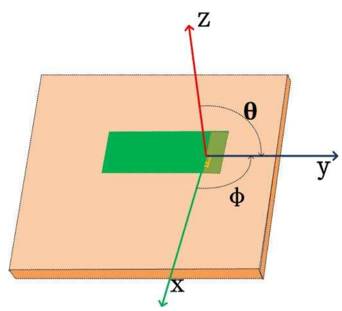


(b) MIFA

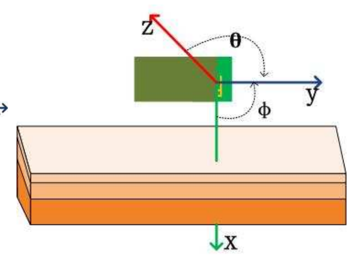


(c) Dipole

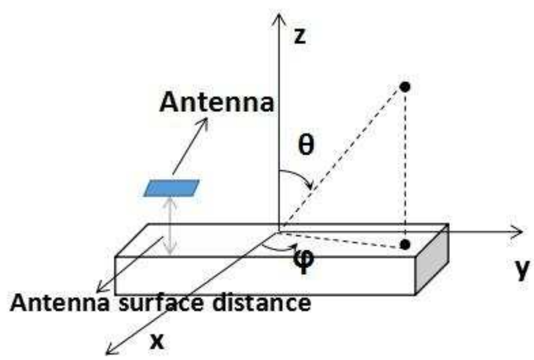
Fig. 2: Optimized S11



(a) Horizontal polarization



(b) Vertical polarization



(c) Definition of antenna and body surface distance

Fig. 3: Polarization and geometry definition

Tissue	ϵ_r	σ
Skin	38.0066	1.4638
Muscle	52.7295	1.7388
Fat	10.8206	0.2680

TABLE II: Chest model parameters at 2.45 GHZ

IV. Analysis of antenna polarization performance

The focus of this paper is to observe the antenna performance after loading human by changing the antenna place-

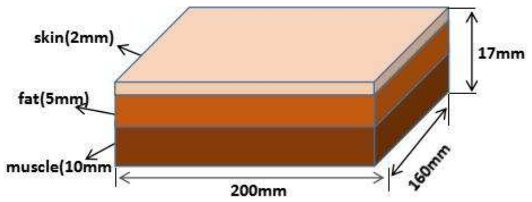


Fig. 4: Body modeling

ment. The distance between the antenna and human body surface(d) is an important factor of antenna performance. We summarize the variation of S11 and bandwidth(B) in the range of 0.5cm$<d<$6cm , and compare the changes of antenna gain pattern of different d.

A. IFA

Fig. 5 shows the changes of antenna matching performance and bandwidth of d. For horizontal polarization, 0.4GHz$<B<$0.52GHz, when d= 2.5cm, B reaches the maximum; for vertical polarization, the fitting equation for the bandwidth is

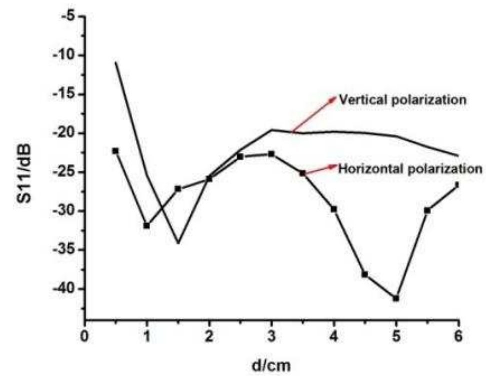
$$y[GHz] = 0.0628x + 0.1845, x[cm] \tag{1}$$

When d=0.5cm, the bandwidth is the narrowest, and the antenna is not suitable for placing on body surface this time. S11 of horizontal polarization decreases with the increase of d. When d=5cm, S11 is the smallest and the antenna matching is the best; When 0.5cm$<d<$1.5cm, S11 of vertical polarization decreases with the increase of d and when d=1.5cm, S11 reaches the minimum and the antenna matching performance is the best, when 1.5cm$<d<$4cm, S11 increases with the increase of d, and the antenna matching performance get worse. When 0.5cm$<d<$1.2cm, $d>$2cm, the horizontal polarization of S11 is always smaller than vertical polarization and the bandwidth is always wider than vertical polarization. Therefore, horizontal polarization of the antenna performance is better than vertical polarization of this range of d.

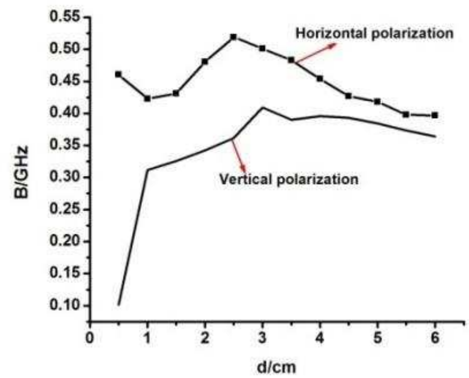
As shown in Fig. 6, E-plane pattern of horizontal polarization is stable and not sensitive to d. For H-plane pattern, when $0\,^\circ<\varphi<30\,^\circ$, $310\,^\circ<\varphi<330\,^\circ$, $S^2>5$, indicating that the difference between the gain in the same direction is great and antenna directional gain is sensitive to distance. The directional gain distribution of vertical polarization at different distances is relatively uniform and not sensitive to the d.

By comparing the antenna polarization performance at different distances, its found that the impact on antenna is not obvious of d. Therefore, 5cm and 1.5cm are selected as the research focus for horizontal polarization and vertical polarization, respectively. E-plane radiation pattern of horizontal polarization and vertical polarization after loading body model are symmetrical distribution of θ=0$\,^\circ$ and θ=90$\,^\circ$ as shown in Fig. 7. The fitted gain difference curve equation of horizontal polarization is

$$y[dB] = 0.0003797 + 0.00488x + 1.00823, x[cm] \tag{2}$$



(a) S11 changes



(b) B changes

Fig. 5: Comparison of S11 and B of horizontal polarization and vertical polarization with different d

The body model has a great influence on the antenna gain at the position of $-180\,^\circ<\theta<-125\,^\circ$, $125\,^\circ<\theta<180\,^\circ$, and when θ=140$\,^\circ$, $|G_b$-$G_f|$ is the maximum and the human body has the most obvious effects on antenna. For vertical polarization, $|G_b$-$G_f|<$6, human body has a uniform effect on antenna gain pattern over the entire range of θ. The impact of human body to vertical polarization are more obvious than horizontal polarization.

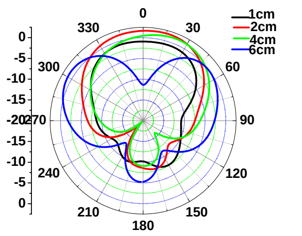
H-plane pattern of horizontal polarization after loading body model is similar to omnidirectional distribution of free space. For vertical polarization, when $0\,^\circ<\varphi<35\,^\circ$, $295\,^\circ<\varphi<320\,^\circ$, $340\,^\circ<\varphi<360\,^\circ$, $|G_b$-$G_f|>$4, human body has great effects on antenna gain pattern, when φ=17$\,^\circ$, $|G_b$-$G_f|$ reach the maximum and human body has the most obvious effects on antenna.

B. MIFA

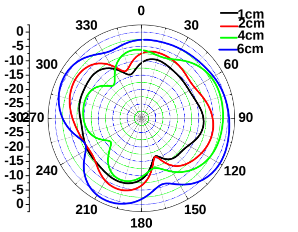
For horizontal polarization, the fitting equation for bandwidth is

$$y[GHz] = -0.00178x^2 + 0.01416x + 0.18396, x[cm] \tag{3}$$

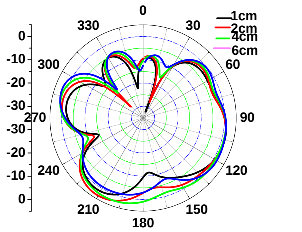
When d=1.5cm, the bandwidth is the narrowest, and the antenna is not suitable for placing on body surface. For horizontal polarization, the effect of distance on bandwidth is not



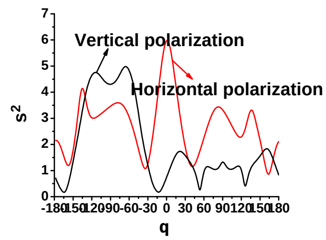
(a) E(YZ) plane of horizontal polarization



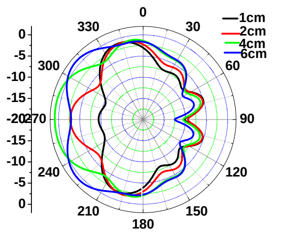
(b) E plane of vertical polarization



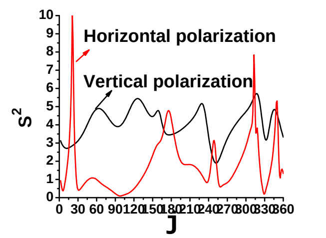
(c) H(XY) plane of horizontal polarization



(d) H plane of vertical polarization

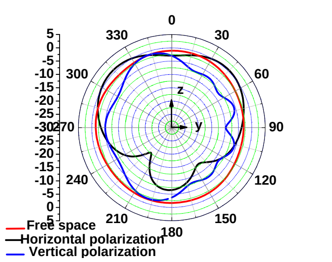


(e) E-plane

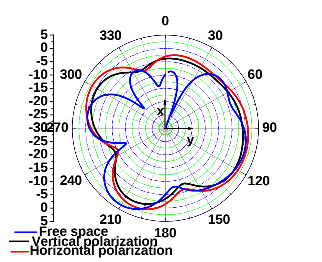


(f) H-plane

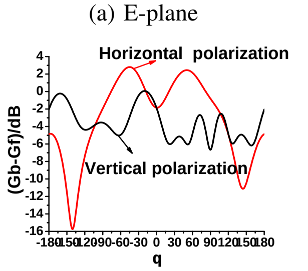
Fig. 6: Comparison of gain pattern of horizontal polarization and vertical polarization of d. $S^2 = \frac{\sum_{d=1}^{n}(G_b - G)^2}{n}$ (d=1cm, 2cm, 4cm, 6cm)



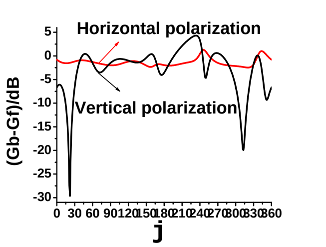
(a) E-plane



(b) H-plane

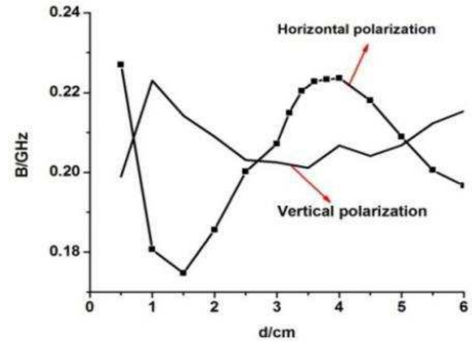


(c) Differential gain of E-plane

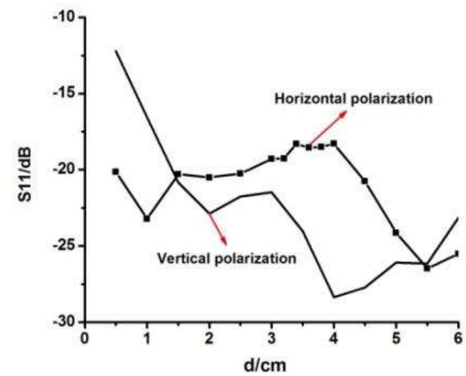


(d) Differential gain of H-plane

Fig. 7: Gain pattern of IFA. G_b: Gain of antenna on body surface, G_f: Gain of antenna in free space



(a) S11 changes



(b) B changes

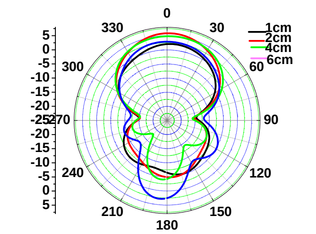
Fig. 8: Comparison of S11 and B of horizontal polarization and vertical polarization with different d

obvious. When d=1cm, B=225GHz, reaching the maximum. The fitting equation for S11 of vertical polarization is

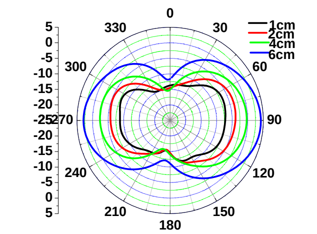
$$y[dB] = 2.02866x - 16.01, x[cm] \tag{4}$$

When d=5.5cm, S11 takes the minimum. When 1cm< d <2.5cm, S11 of vertically polarized is always smaller than horizontal polarization, and the bandwidth is always wider than horizontal polarization. In this range, the antenna is more suitable for placing on the surface of the human body in vertically polarized. When d=0.5cm, S11 of vertical polarization take the maximum and the bandwidth is the narrowest, so the antenna is not suitable for placing on human body surface. The S11 curve of horizontal polarization is flat and when d=4cm, B reaches the maximum, so the antenna is most suitable to place on human body surface.

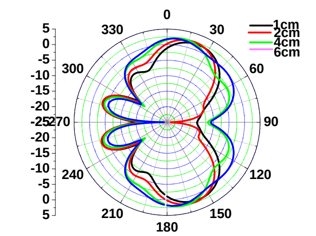
For the horizontal polarization, the square gain distributions at different distances are relatively uniform and not sensitive to distance. For E-plane pattern of vertical polarization, when $30^\circ < \varphi < 150^\circ$, $S^2 > 4$, The gain difference at different distances is relatively large, the antenna direction gain is more sensitive to the distance factor than the other position. For H-plane pattern, when $130^\circ < \varphi < 180^\circ$, $0^\circ < \varphi < 30^\circ$, $225^\circ < \varphi < 240^\circ$, $330^\circ < \varphi < 360^\circ$, $S^2 > 4$, the antenna direction gain is more sensitive to the distance factor. fig. 9 shows the radiation pattern of the antenna in free space and after loading



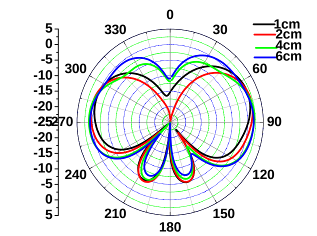
(a) Horizontal polarization of E-plane



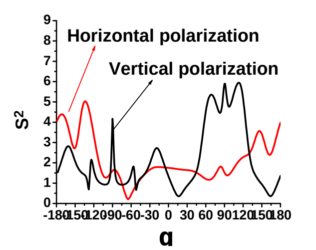
(b) Vertical polarization of E-plane



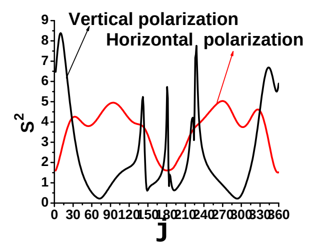
(c) Horizontal polarization of H-plane



(d) Vertical polarization of H-plane

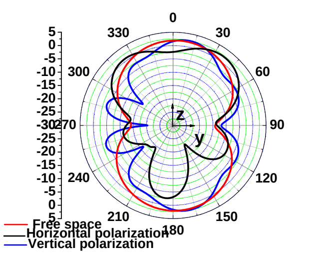


(e) E-plane

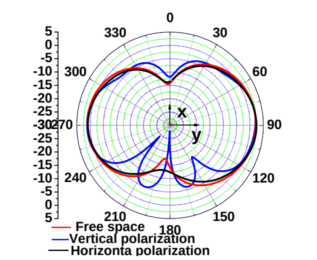


(f) H-plane

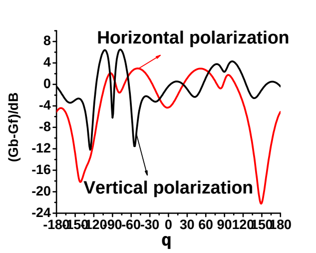
Fig. 9: Directional gain changes at different distances



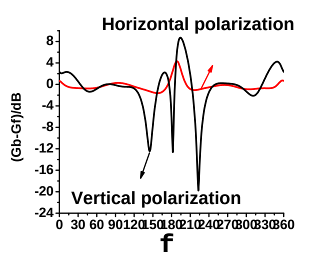
(a) E-plane



(b) H-plane



(c) Differential gain of E-plane



(d) Differential gain of H-plane

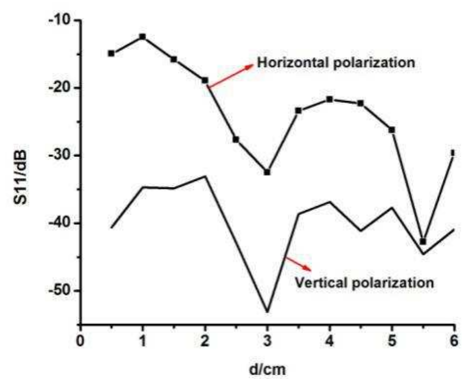
Fig. 10: Antenna gain pattern

body model. Horizontal polarization and vertical polarization were selected 5.5cm and 4cm respectively as the research focus. The gain pattern of horizontal polarization and vertical polarization after loading human body model is symmetrically distributed with 0° and 90° respectively. For horizontal polarization, the fitted curve equation of gain difference is

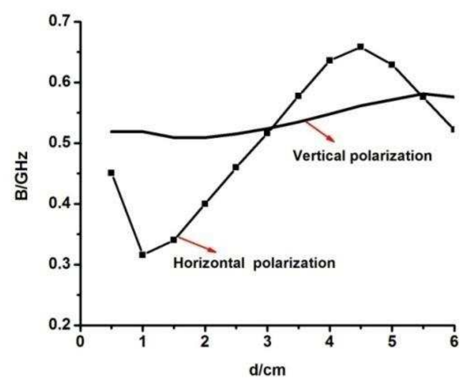
$$y[dB] = -4.5676x^2 - 0.0018x + 1.1592, x[cm] \tag{5}$$

At the position of $-180^\circ<\theta<-110^\circ$, $110^\circ<\theta<180^\circ$, $|G_b$-$G_f|>4$, the human body has a significant effect on antenna gain pattern. When $\theta=150^\circ$, $|G_b$-$G_f|$ takes the maximum, the human body has the greatest effect on antenna gain pattern. For vertical polarization, at the position of$-135^\circ<\theta<120^\circ$, $-65^\circ<\theta<-45^\circ$, $|G_b$-$G_f|>6$, the effect of the body on antenna gain pattern is obvious; when $\theta=130^\circ$and $\theta=550^\circ$, $|G_b$-$G_f|=12$, reaches the maximum, human body has the greatest effect on antenna gain pattern.

For H-plane gain pattern of the horizontal polarization, the gain curve is always gentle and the body has little effect on antenna gain pattern. For vertical polarization, the curve fluctuates obviously at the position of $145^\circ<\theta<230^\circ$, the human body has great effect on antenna. $|G_b$-$G_f|$ takes the maximum and the human body has the most obvious effect on antenna. subsectionPrinted dipole For horizontal polarization,



(a) S11 changes



(b) B changes

Fig. 11: Comparison of S11 and B of horizontal polarization and vertical polarization with different d

the fitting curve equation of bandwidth is

$$y[dB] = 0.014x + 0.4937, x[cm] \tag{6}$$

When d=1cm, the bandwidth is narrowest, the antenna is not suitable for placing on body surface at this time. For vertical polarization, the fitted curve equation of bandwidth is

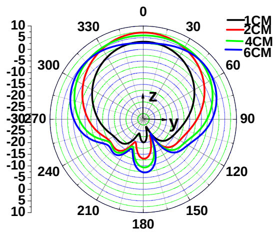
$$y[dB] = -0.0153x^2 - 0.2802x + 0.52222, x[cm] \quad (7)$$

At the range of all distances, when d=3cm, S11 takes the minimum, so when the antenna placed 3cm near the body surface in vertical polarization, the antenna performance is the best. We can see form the S11 curve, the trend of vertical polarization and horizontal polarization is consistent, and the fitting curve equation is

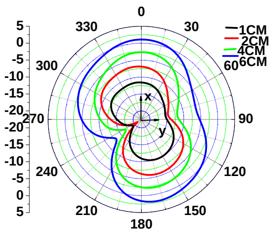
$$y[dB] = -0.838x - 37.197, x[cm] \quad (8)$$

$$y[dB] = -3.4777X - 12.723, x[cm] \quad (9)$$

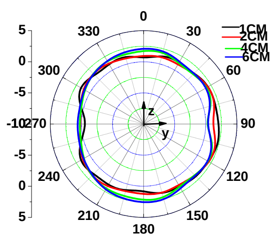
Horizontal polarization and vertical polarization take the



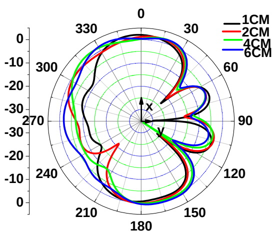
(a) Horizontal polarization of E-plane



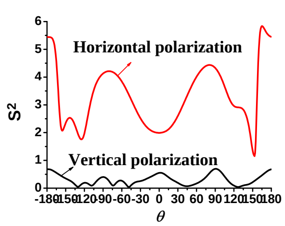
(b) Horizontal polarization H-plane



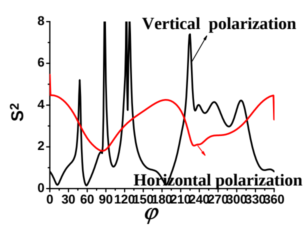
(c) Vertical polarization E-plane



(d) Vertical polarization of H-plane



(e) E-plane



(f) H-plane

Fig. 12: Comparison of gain pattern of horizontal polarization and vertical polarization of d

minimum and maximum at d=3cm and d=5.5cm respectively. S11 of horizontal polarization is always greater than vertical polarization. When 0cm< d <3cm, the bandwidth of vertical polarization is always greater than horizontal Polarization. Therefore, in this range of d, the antenna is more suitable for vertical polarization. For horizontal polarization, as shown in fig. 12a and fig. 12d, the directional gain distributions at different distances are relatively uniform and are not sensitive to d; but within the range of θ and φ, $2<S^2<7$, S^2 is large and the difference in gain is relatively large at different distances in the same direction.

For vertical polarization, as shown in fig. 12b and fig. 12e, the E-plane pattern is stable and is not sensitive to d. At the position of $85°<\varphi<90°$, $120°<\varphi<130°$, $220°<\varphi<230°$, $S^2>7$, the difference of H-plane pattern of d is relatively great, the antenna direction gain is more sensitive to d.

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