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Design of an omnidirectional antenna with a compact size

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Abstract: An omnidirectional antenna with a compact size is presented. The diameter of the proposed antenna is 100 mm and the height is $\sim 0.1\lambda_L$ (12 mm). It consists of two dipoles and four shorting pins. With this configuration, the impedance bandwidth of the proposed antenna covers 2.4–2.6 GHz. Within the bandwidth, the proposed antenna has a stable bidirectional radiation pattern in the E-plane and the omnidirectional radiation pattern in the H-plane. The geometry of the antenna is investigated and optimised by the ANSYS high-frequency structure simulator. The fabricated antenna is compact enough to be integrated into a communication system. Measured and simulated results are also obtained and compared at the end of this work.

1 Introduction

The communication system with 360° signal coverage has attracted much attention recently. In a communication system, the factor that determines the signal coverage is not receivers or transmitters, but antennas. Designing such antennas faces quite different challenges, because it must satisfy the requirements such as large signal coverage, stable gain radiation pattern, low-profile size, and low-cost production. The omnidirectional antenna, which can provide a conical radiation pattern, is very suitable for the modern communication system. The goal of this paper is to design a vertically polarised, compact, omnidirectional, and reliable antenna that can be used for outdoor communication systems.

The classical way to realise 360° signal coverage is using monopoles. However, traditional monopoles have the disadvantage of large altitude, because of which they are not compact enough to be used in communication systems. In general, there are three ways to reduce the height of the monopole. The first way is using the top loading of the antenna. The second way is using shorting pins to the ground. The third way is meandering the monopole. For achieving a compact omnidirectional antenna, a monopolar wired patch [1] has been reported. The antenna consists of a square patch, a monopole antenna, and two shorting wires. The square patch is mounted on the top of the monopole antenna, and the patch is connected to the ground through the shorting wires. The height of the antenna is much $<0.25\lambda_C$ (λ_C is the wavelength of the centre operating frequency). In paper [2], the reduction of the antenna height is achieved by using dielectric coating. In paper [3], by using a top-loaded monopole with several shorting pins and an inductive loading, the height of the antenna is reduced to $\sim 0.3\lambda_C$. In papers [4, 5], the height of the antennas was reduced from $0.21\lambda_L$ to $0.08\lambda_L$ (λ_L is the wavelength of the lowest operating frequency). In paper [6], Aten and Haupt presented a shorted top antenna with the height of $0.14\lambda_L$. In paper [7], by meandering the monopole [7], the height of the monopole antenna was reduced to $0.23\lambda_L$.

In this paper, a promising design of a compact omnidirectional antenna with two dipoles and four shorting pins is demonstrated. By using shorting pins to the ground and placing the dipoles horizontally, the height of the antenna can be largely reduced to $0.1\lambda_L$. Stainless steel is used to make the antenna.

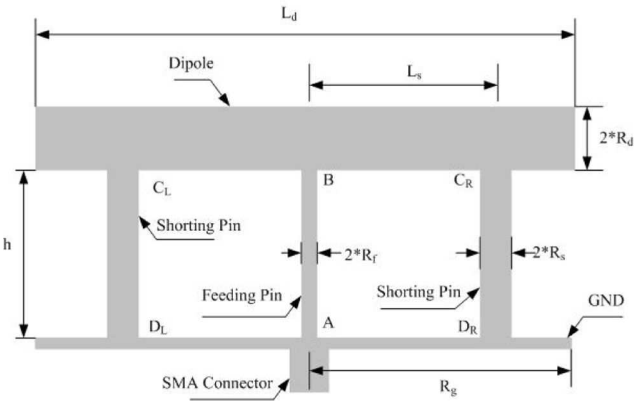


Fig. 1 *Geometry of the proposed omnidirectional antenna*

2 Antenna design

The structure of the proposed antenna presented in this paper is shown in Fig. 1. As the figure shows, the proposed antenna has a circular ground. The radius of the ground is R_g. Two mutually perpendicular dipoles are placed horizontally above the ground. The dipoles have the same radius R_d and the same length L_d, and the distance between the dipoles and ground is h (h is also the height of the shorting pins). So, the height of the whole proposed antenna is $h + 2 \times R_d$. Four shorting pins are located between the dipoles and the ground with the same distance from the centre of the ground, and the distance is L_s. The radius of the shorting pins is R_s. The ground and dipoles are connected by shorting pins. A feeding pin connects the dipoles and ground as the excitation at the centre of the proposed antenna. The radius of the feeding pin is R_f.

As is known, at the end of the dipole, the impedance of the dipole is close to 0 Ω. So, the size reduction can be achieved by connecting shorting pins from the end of the dipole to the ground. The electric currents flow from $A \to B \to C_R \to D_R$ and $A \to B \to C_L \to D_L$, and the path lengths of the current determine the operating frequency of the antenna. As Fig. 1 shows, the current flowing from $B \to C_R$ and the current flowing from $B \to C_L$ are in the opposite directions, the radiations caused by the dipoles can be counteracted in far field. The lengths of $B \to C_R$ and $B \to C_L$ must be tuned to achieve an omnidirectional radiation pattern. When the currents flowing on the feeding pin and shorting pins are in the same directions, their radiations can be superimposed in the far field, which makes the feeding and shorting pins work like an array. The simulated current distribution of the proposed antenna at the centre frequency (2.5 GHz) is shown in Fig. 2. The current is concentrated at the region of the feeding and shorting pins.

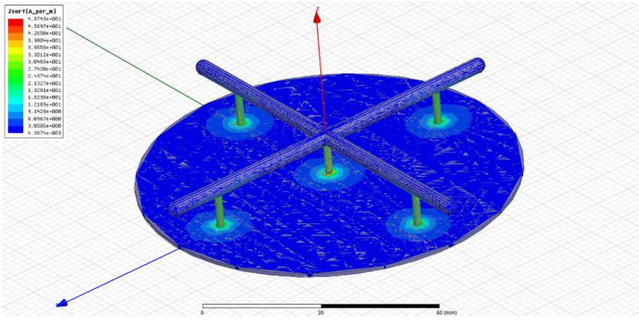


Fig. 2 *Simulated current density distribution at the centre frequency (2.5 GHz) of the proposed antenna*

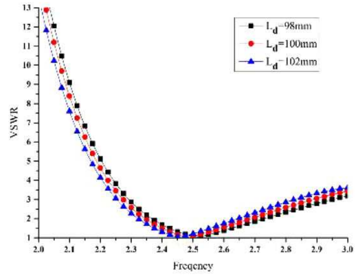


Fig. 3 *Simulated results of VSWR with various values of L_d*

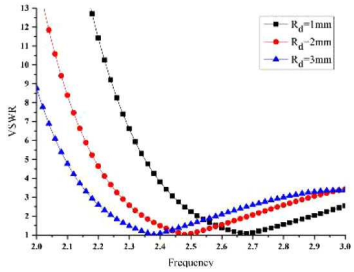


Fig. 4 *Simulated results of VSWR with various values of L_s*

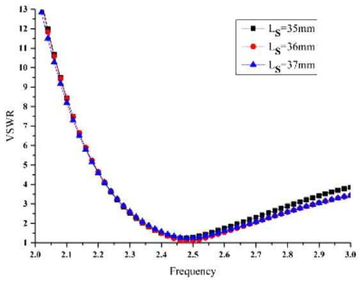


Fig. 5 *Simulated results of VSWR with various values of R_f*

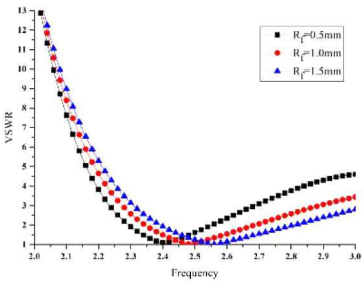


Fig. 6 *Simulated results of VSWR with various values of h*

To study the effect of different structures, all parameters have been studied in this paper. Figs. 3–8 show the effects of the different parameters on the voltage standing wave ratio (VSWR) of the proposed antenna. As can be seen, the changes in the parameters h and R_d mainly affect the low-frequency segment of the impedance bandwidth, whereas the changes in the parameter R_f mainly affect the high-frequency segment of the impedance bandwidth. This is because changing the parameters h, R_d, and R_f is equivalent to changing equivalent current length. The changes in the parameters L_d and L_S have little effect on the impedance bandwidth. R_S is a very important parameter of the proposed antenna. By tuning R_S, the bandwidth with a good impedance can be achieved.

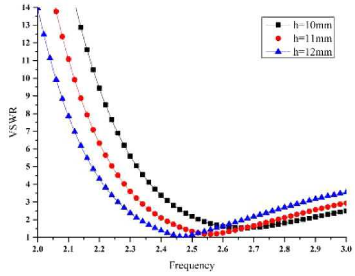


Fig. 7 *Simulated results of VSWR with various values of R_d*

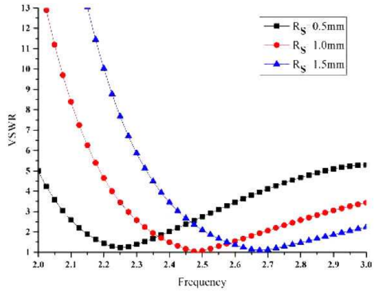


Fig. 8 *Simulated results of VSWR with various values of R_s*

Table 1 Dimensions of proposed antenna

Parameter	Value, mm	Parameter	Value, mm
h	9	L_s	36
R_g	50	Rs	1
R_d	2	R_f	1
L_d	104	—	—

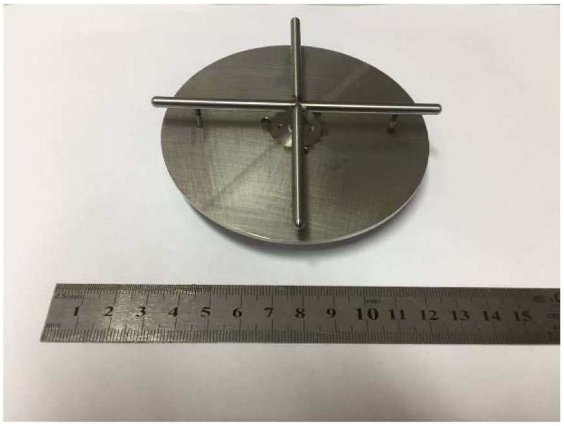


Fig. 9 *Prototype of the proposed antenna*

3 Results

Table 1 shows the final optimal parameters of the proposed antenna. Its height is only $\sim 0.1\lambda_L$. A prototype of the proposed antenna based on these parameters was fabricated. The picture of the proposed antenna is Fig. 9. The impedance bandwidth (VSWR ≤ 2.0) and the gain of the proposed antenna are obtained by using an Aglilent E8363b network analyser and a microwave anechoic chamber, respectively. The simulated VSWR and measured VSWR

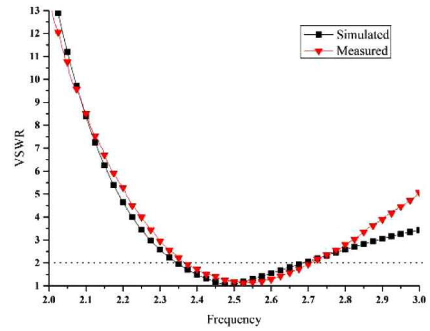
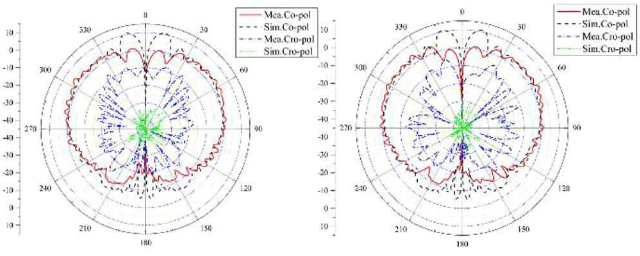
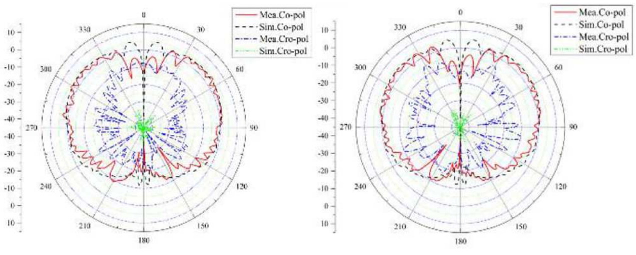


Fig. 10 *Measured and simulated VSWR of the proposed antenna*



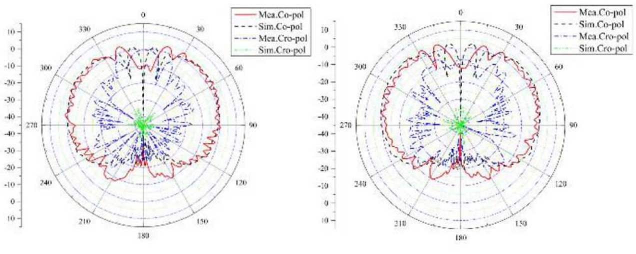
a *b*

Fig. 11 *Measured and simulated E-plane radiation patterns at 2.4 GHz*
(a) *x–o–z* plane, ***(b)*** *y–o–z* plane



a *b*

Fig. 12 *Measured and simulated E-plane radiation patterns at 2.5 GHz*
(a) *x–o–z* plane, ***(b)*** *y–o–z* plane



a *b*

Fig. 13 *Measured and simulated E-plane radiation patterns at 2.6 GHz*
(a) *x–o–z* plane, ***(b)*** *y–o–z* plane

against frequency of the designed antenna are shown in Fig. 10. It can be observed that the measured results are in reasonable agreement with the simulated results, and the frequency discrepancy is acceptable. For VSWR $\leq$ 2.0, the measured impedance bandwidth is ∼350 MHz. The bandwidth of the proposed antenna has already met the requirements of the wireless system.

Figs. 11–13 plot the measured and simulated radiation patterns for the three operating frequencies at 2.4, 2.5, and 2.6 GHz. The measured results agree well with the simulated results. From the results, it can be demonstrated that the antenna has a good bidirectional radiation pattern in the E-plane at all the operating frequencies.

The measured *x–o–y* plane (H-plane) radiation patterns of the proposed antenna at 2.4, 2.5, and 2.6 GHz are shown in Figs. 14,

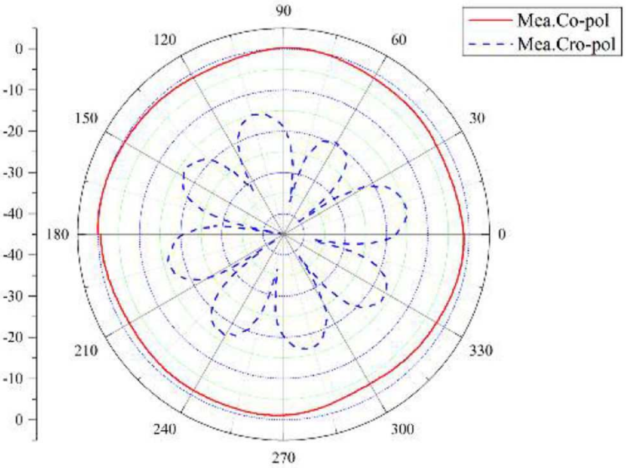


Fig. 14 *Measured x–o–y plane (H-plane) radiation patterns at 2.4 GHz*

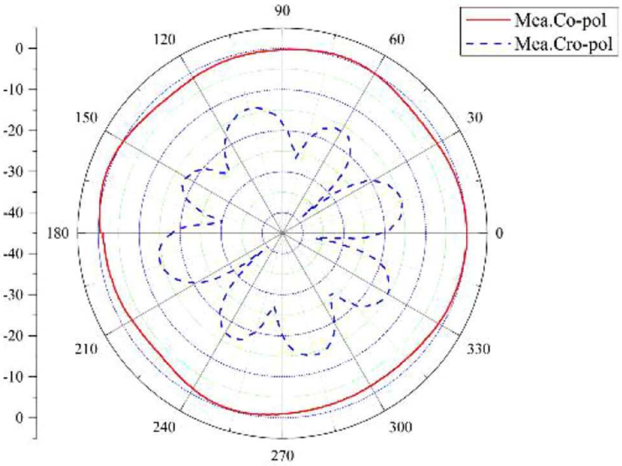


Fig. 15 *Measured x–o–y plane (H-plane) radiation patterns at 2.5 GHz*

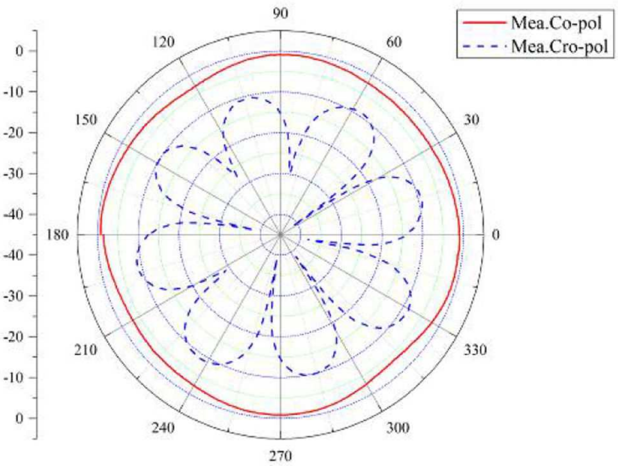


Fig. 16 *Measured x–o–y plane (H-plane) radiation patterns at 2.6 GHz*

15, and 16, respectively. As can be seen, the highest gain of the antenna is ∼0 dB, and the fluctuation of gain is <4 dB. Within the impedance bandwidth from 2.4 to 2.6 GHz, the proposed antenna has an omnidirectional radiation pattern in the *x–o–y* plane with the low cross-polarisation level.

4 Conclusion

In this paper, an omnidirectional antenna with a compact size is proposed. Simulated and measured results show that it possesses an impedance bandwidth (VSWR $\leq$ 2.0) of 2.35–2.7 GHz. The antenna can provide a stable bidirectional radiation pattern in the

E-plane and an omnidirectional radiation pattern in the H-plane within the impedance bandwidth. By connecting the end of the dipole to the ground though shorting pins and placing the dipoles horizontally, the height of the antenna can be largely reduced to $0.1\lambda_L$. Owning to these characteristics, the antenna has wide and potential applications in wireless communication applications.

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