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Study and design of ultra-wideband quasi-Yagi antenna based on monopole printing

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Abstract: Design of a broadband quasi-yagi antenna based on monopole printed loaded hypersurface. The antenna is fed by a microstrip line and consists of a notched rectangular monopole, a reflector loaded with branches, a pilot, and a hypersurface unit. The impedance bandwidth of the antenna is extended by increasing the length of the reflector, notching the rectangular monopole as well as the floor, and the antenna gain is enhanced by adding a high refractive index hypersurface periodic structure on the right side of the antenna. Simulation results show that the antenna has good radiation performance in the operating frequency band 2.53~4.34 GHz, VSWR<2, and the peak gain of the antenna reaches 16.9 dBi, which has the characteristics of wide bandwidth and high gain, and the designed antenna is suitable for the environment of mines and tunnels, and meets the design requirements.

1. Introduction

For the specific environment of mines and tunnels, Yagi antennas have been widely researched and applied due to their better end-fire performance. High-gain quasi-Yagi antennas can increase the coverage and transmission distance of the mine wireless communication system, improve the quality of the underground communication, and play a positive role in enhancing the overall performance of the communication network. Therefore, it has attracted many scholars at home and abroad to conduct research. Yagi antenna is a classical end-fire antenna [1-2], which is famous for its high gain and narrow beam characteristics. It was originally developed in the 1920s by Japanese engineers Hidetsugu Yagi and Taro Utada for enhancing the performance of radio and communication systems. The Yagi antenna is an end-fire antenna, consisting mainly of an active oscillator, a reflector and one or more directionals. Because of its simple structure, better directivity and easy processing, many domestic and foreign scholars have studied the application of Yagi antennas in several scenarios [3-4]. The traditional Yagi antenna has a large size, narrow bandwidth, and limited application occasions, and domestic and foreign scholars have done a lot of research to improve this defect. In literature [5], a microstrip Yagi antenna for passive temperature measurement tags is proposed to improve the impedance bandwidth of the antenna by bending the antenna. Literature [6] for S-band microstrip quasi-yagi antenna miniaturisation technology carried out simulation and experimental research h, and concluded that the use of dielectric burial and oscillator zigzag line technology can be used to a certain extent to reduce the lateral size of the quasi-yagi antenna. Literature [7] designed an ultra-wideband quasi-yagi antenna, which broadened the bandwidth at low frequencies by techniques such as bending and grooving to achieve good directional performance.

In order to solve the drawbacks in the application, based on the Yagi antenna principle, scholars at home and abroad have proposed a variety of antenna designs for broadening the bandwidth and miniaturisation, but there are fewer designs for improving the antenna gain of quasi-Yagi antennas by using the super-surface. In this paper, a design of broadband quasi-yagi antenna based on monopole-printed loaded hypersurface is proposed. The purpose of broadening the antenna operating bandwidth and improving the antenna impedance matching is achieved by optimising the antenna structure, loading branches in the reflector and opening notches in the and radiator. On the basis of ensuring the broadband characteristics of the antenna, the gain of the antenna is increased by loading the super-surface unit-cycle structure.

2. Antenna system structure design

On the realization of the enhancement of the quasi-yagi antenna gain, summed up the following methods: ① optimization of the antenna structure. Open the seam through the structure of the antenna, add a groove, or add branches and junctions to improve the gain of the antenna. Increase the size of the reflective surface.[8] The quasi-yagi antenna consists of reflector, guide and active oscillator, and increasing the size of the reflecting surface can effectively enhance the interference between the reflected wave and the direct wave of the antenna, and effectively enhance the antenna gain. (iii) Optimise the feed network [9]. Design appropriate feeding networks, such as matching circuits, couplers, etc., to improve the radiation efficiency of the antenna and thereby increase its gain. ④ Incorporate super surface structure. Introducing the super surface structure as a reflecting surface or radiator can effectively improve the antenna gain by regulating the electromagnetic wave propagation and radiation characteristics. ⑤ Adopt high dielectric constant material. Materials with high dielectric constant can effectively reduce the antenna structure and can be designed for specific electromagnetic characteristics [10], but generally the production cost is high.

In this paper, the proposed antenna design consists of a radiating patch, dielectric substrate, metal floor, and microstrip line. The antenna structure is shown in Figure 1, and the antenna design in this paper is printed on a Rogers RO (4003) dielectric substrate with dimensions W × L, thickness of 1.6 mm, dielectric constant of 3.55, and loss angle tangent of 0.0027. The quasi-Yagi antenna antenna consists of a rectangular monopole as the active oscillator, a reflector and eight leads, and a high refractive index supersurface unit periodic structure. A metal floor is printed on the lower surface of the dielectric substrate. The antenna is fed by a 50 microstrip line.

The antenna design is based on the following idea: Generally, the antenna has better radiation characteristics when the size of the monopole antenna is. The wavelength equation is as follows:

$$\lambda = c / f_r \tag{1}$$

Where c denotes the speed of light in vacuum, and f_r denotes the frequency of antenna working centre. According to the theoretical calculation, 3GHz corresponds to a quarter wavelength of 100mm. because the wave transmission passes through the free space and the medium layer, so the wavelength is between the free space and the medium. The formula for propagation in the medium is:

$$\lambda_g = \lambda / \sqrt{\varepsilon_r} \tag{2}$$

Where λ Indicates the free space wavelength, λ_g Indicates the wavelength in the medium, therefore, through the theoretical derivation, the size of the monopole radiating patch takes the value of 13.27~25mm.As shown in Figure 2(a), the antenna 1 is the initial quasi-Yagi antenna structure. Based on antenna 1, three branches are added to the right side of the reflector to increase the length of the reflector, and other structures remain unchanged as shown in Figure 2(b). The top and bottom branches are loaded for improving the impedance matching of the antenna and expanding the antenna low-frequency bandwidth, and the branch loaded in the middle of the reflector is used to reduce the effect on the antenna gain. As shown in Figure 2(c), rectangular slots are opened in the upper centre and lower centre of the monopole radiating patch, and other structures remain unchanged as a way to expand the antenna bandwidth. As shown in Figure 2(d), a rectangular slot is cut in the centre above the antenna ground plate to further widen the antenna operating frequency range.

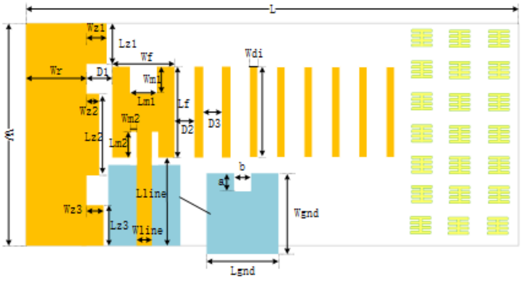


Figure 1: Antenna structure.

(a) Antenna 1 (b) Antenna 2 (c) Antenna 3 (d) Antenna 4

Figure 2: Antenna design process.

On the basis of spreading the bandwidth, in order to enhance the antenna radiation efficiency and improve the antenna gain, the electromagnetic wave can be modulated by using the super-surface structure, and Figure 3 shows the super-surface geometry. Its dielectric substrate selection is consistent with the quasi-Yagi antenna, and Rogers RO(4003) (ε_r =3.55, loss angle tangent $\tan\delta$ =0.0027) is selected to facilitate the later integration with the quasi-Yagi antenna. In this paper, we use the simulation software HFSS to simulate the hypersurface unit, and the hypersurface characteristics after the periodical arrangement of the hypersurface unit are shown in Figure 4 and Figure 5.

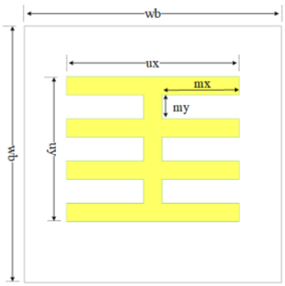


Figure 3: Structure of the hypersurface unit.

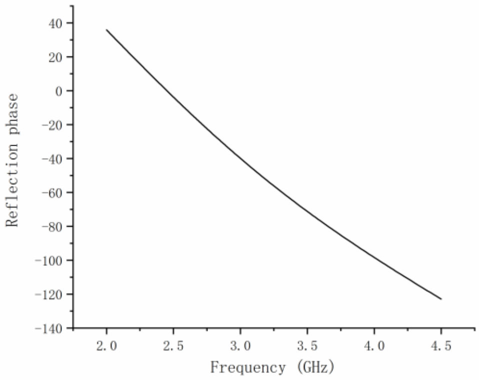


Figure 4: Phase distribution.

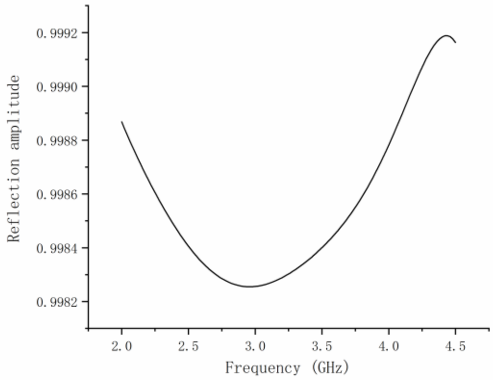


Figure 5: Amplitude distribution.

From Figure 4 and 5, the phase and reflection amplitude of the reflected wave under the structure of the super-surface unit can be seen, and it can be seen that the amplitude stays above 0.99 in the whole working frequency band, which has good reflection characteristics.

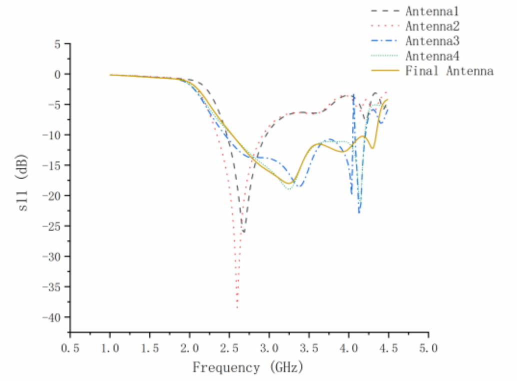
In the right side of the antenna guide integrates the periodic structure of the super surface unit, regulating the antenna electromagnetic wave reflection, thus playing the effect of increasing the antenna gain. The final structure of the antenna is shown in Figure 1. After optimisation by HFSS electromagnetic simulation software, the design parameters of the antenna are shown in Table 1.

Table 1: Antenna reference dimensions. (unit: mm)

Parameter	Size	Parameter	Size	Parameter S	Size
W	50	Lline	20	Lm1	8
L	102	D1	5	Wm2	2
H	1.6	D2	4	Lm2	5
Wr	16	D3	4	a	3.3
Wf	16	Wz1	3	b	2.5
Lf	22	Lz1	7	ux	2.1
Wdi	2	Wz2	3	uy	1.7
Ldi	20.5	Lz2	22	mx	0.95
Wgnd	19.4	Wz3	1.875	my	0.3
Lgnd	20	Lz3	7	Wb	5
Wline	2.5	Wm1	6		

3. Antenna simulation results and analysis

In this paper, the antenna is simulated and analyzed using the simulation software HFSS. As shown in Figure 6, the reflection coefficient (s11) of different structures of this antenna is compared, from which it can be seen that the working bandwidth of antenna 1 is 2.47-2.97 GHz, and the working bandwidth of antenna 2 after loading the branch on the reflector is 2.34-2.92 GHz, and the working frequency band is moved to the low frequency. The operating bandwidth of the antenna 3 after opening rectangular notches on the monopole is 2.44-4.05 GHz, 4.08-4.21 GHz, and trapping occurs, which improves the impedance matching of the antenna at the high frequencies and broadens the operating bandwidth of the antenna. Based on this, the bandwidth of the final antenna reaches 2.53-4.34 GHz by giving rectangular notches to the floor and by adding a super-surface periodic structure.Comparing with antenna 1, the final antenna greatly broadens the operating bandwidth of the antenna, and the relative bandwidth is improved from 16.7% to 60.3%.



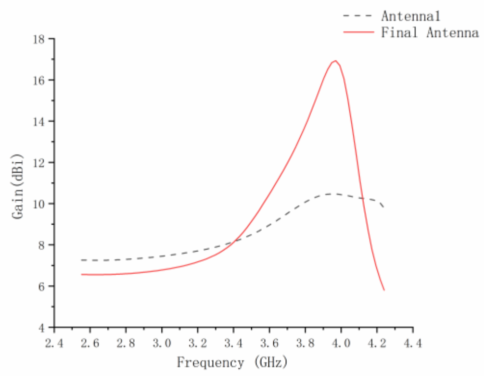
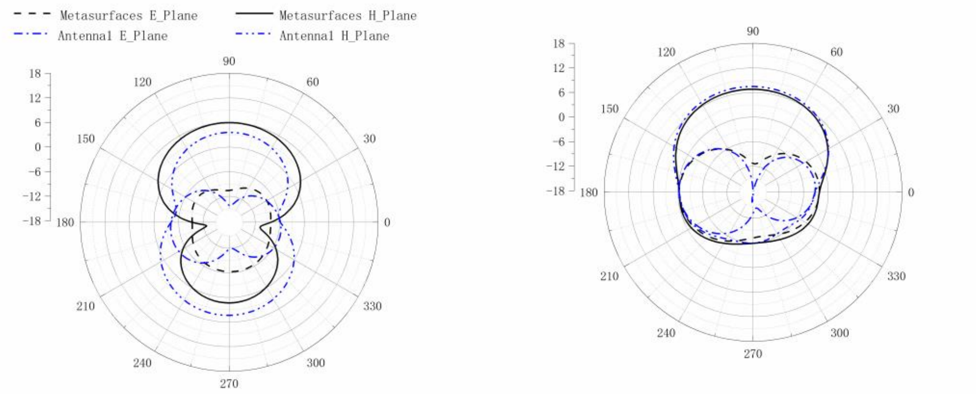


Figure 6: Comparison of different structures of antenna s11. Figure 7: Antenna Gain Comparison.

From Figure 6, it can be seen that there is little effect on the antenna bandwidth during the process of increasing the hypersurface. The comparison of the gain of the initial antenna and the final antenna is given in Figure 7. From the Figure, it can be seen that by integrating the structure of the hypersurface unit, the antenna gain is substantially improved by up to 6.47 dB in the operating band of 3.4-4.1 GHz, and the final antenna gain is 4.5-16.9 dBi.



(a) 2 GHz direction map. (b) 3 GHz direction map.

Figure 8: Antenna normalised orientation diagram.

Figure 8 shows the normalized directional plots of the initial antenna 1 and the final antenna loaded with the hypersurface in the E and H planes at 2 and 3 GHz, from which it can be seen that the loading of the hypersurface unit makes the antenna's radiated energy concentrated, reduces the width of the back flap, and improves the antenna's radiation performance.

4. Conclusion

In this paper, a quasi-Yagi antenna based on branch loading, open rectangular notch and loaded hypersurface is proposed. The bandwidth of the antenna is increased by opening a rectangular notch to the monopole radiating patch and the impedance matching at high frequencies is improved. Also branch loading to the reflector increases the low frequency bandwidth and reduces the effect on the gain. The gain of the antenna at high frequencies is increased by integrating a super surface periodic structure. The designed antenna can be well suited for special environments such as mines and tunnels to meet the requirements of underground antenna communication.

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