

A Compact Single Layer Filtering Antenna with DGS for 5.1 GHz Application

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Abstract—A compact bandpass filtering antenna operating at 5.1 GHz is introduced. The radiation layer makes up of a U-shaped patch and a trident resonator. The U-shaped patch is both the antenna and the last stage of the filter, which is excited by the insertion coupling part of the trident resonator. To improve the impedance matching and lower stopband suppression, a defective ground structure (DGS) is used. The dimension of the antenna is $0.36\lambda_0 \times 0.36\lambda_0 \times 0.01\lambda_0$ (λ_0 is the wavelength at 5.1 GHz) without a complex external feed structure, which has enough bandwidth, a good frequency skirt selectivity, and a flat passband response. The measurement results manifest that the impedance bandwidth is 110 MHz, and the peak gain is 3.88 dBi. In addition, the filtering antenna also has a sharp roll-off rate and a satisfactory level of out-of-band suppression in the stopband.

1. INTRODUCTION

With the increasing requirement for the wireless communication system, the application of multifunctional components has been paid attention to. The traditional method is to design the antenna and filter independently and then cascade them through transmission lines to obtain the ideal passband, which will cause mismatch and extra insertion loss, leading to the degradation of antenna performance. Therefore, the concept of filtering antenna is put forward. One method is replacing the last-stage resonator of the bandpass filter with a radiation patch, which usually realizes the filtering function by multiple resonators [1, 2]. Another way is integrating the filtering function into the feeding network, which leads to a more complex feeding network and a larger antenna size [3–5]. In recent years, some researches are based on slot antennas with multi-layer substrate stacked structures; some of them use meta-surface (MS) to suppress unwanted signals [6–8]; some of them leave a certain height of air layer between two substrates to increase the impedance bandwidth [9, 10], which will increase the overall height of the antenna, thus not conducive to miniaturization. In addition, the substrate integrated waveguide filtering antenna integrated with short-circuit pins on the single-layer substrate is also studied [11, 12]. Of course, wider bandwidth and higher gain mean larger antenna size, so it is of high research value to reduce the antenna size as much as possible while ensuring antenna performance.

In this letter, a compact filtering antenna is proposed, which adopts a single-port microstrip feeding structure. A U-shaped radiation patch is used instead of the last stage of the bandpass filter. The etched slots on the U-shaped patch radiator can reduce the dimension of the antenna and improve the antenna gain. A quarter-wavelength trident resonator is combined with two open-loop resonators to improve the filtering performance. The filter and radiator are cascaded by inserting coupling, and the coupling effect depends on the gap width. In addition, a DGS is etched on the ground plate, which can lower stopband suppression and expand the bandwidth. The high frequency simulation software Ansys HFSS is used to simulate the antenna performance. Experiments indicate that the antenna has satisfactory out-of-band rejection characteristics while ensuring sufficient impedance bandwidth and antenna gain.

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2. ANTENNA DESIGN

Figure 1 displays the appearance of the antenna, which is fed by a single-port microstrip line. The antenna substrate has a thickness of 0.508 mm and is made of Rogers 4003C with a dielectric constant of 3.55. The radiation patch part consists of a U-shaped radiator and a trident resonator. The opening of the U-shaped patch is irregular, and symmetrically distributed slots are etched on it. The central branch of the trident resonator with a length of l_2 is inserted into the irregular opening of the U-shaped radiator to realize the coupling excitation. Two L-shaped arms with a length of w_2 and a width of w_1 extend from both sides of the microstrip line. The folded section at the end of each arm has a length of l_1 and a width of w_3 . The other side is the ground plane with a size of $G \times G$. A rectangle with dimension $dl \times dw$ is removed from the grounding plate to form a defective ground structure.

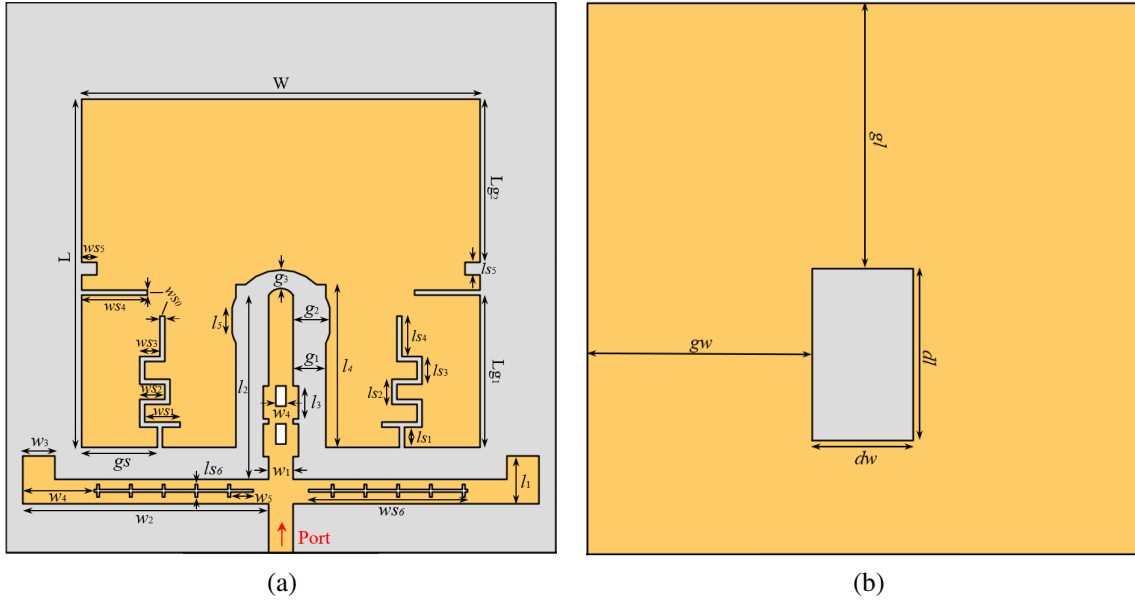


Figure 1. The appearance of the antenna, (a) radiation patch, (b) ground plane.

2.1. Design of U-Shaped Radiation Patch

The length and width of the patch mainly determine the radiation resistance and resonance frequency, which can be determined according to the following formula:

$$W = \frac{c}{f} \left(\frac{\epsilon_r + 1}{2} \right)^{-\frac{1}{2}} \quad (1)$$

$$L = \frac{c}{f\sqrt{\epsilon_e}} - 2\Delta L \quad (2)$$

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + 12 \frac{H}{w} \right)^{-\frac{1}{2}} \quad (3)$$

$$\Delta L = 0.412H \frac{(\epsilon_e + 0.3) \left(\frac{w}{H} + 0.264 \right)}{(\epsilon_e - 0.253) \left(\frac{w}{H} + 0.3 \right)} \quad (4)$$

In which ΔL is the equivalent slot radiation length, and ϵ_e represents the effective dielectric constant of the medium. Based on the traditional U-shaped microstrip antenna, the continuous U-shaped slots distributed symmetrically are set. Since the direct introduction of the continuous U-shaped slots will

cause an impedance mismatch, the continuous U-shaped slots are etched based on the straight slots. Two slots with different lengths and widths are etched on both sides of the patch. Therefore, the optimized antenna size $W \times L$ can be obtained under the condition of good antenna impedance matching. While the length of antenna surface current increases, the current intensity near the slot is enhanced, which can make up for the antenna gain loss caused by the reduction of antenna size.

2.2. Design of Trident Resonator

The design idea of a trident resonator comes from a quarter-wavelength microstrip bandpass filter, which has good performance, small size, and easy processing. Due to the microstrip line structure and dielectric substrate, the length $(l_2 + w_2 - w_1 + l_1)$ is slightly larger than the calculated quarter wavelength at the working frequency. Combining the main branch of the trident resonator with two open-loop resonant units and etching some crossed straight lines on the two arms can optimize impedance matching and stabilize the filtering effect. The width of etched slots is 0.1 mm; the length of long slots is wg ; the length of short slots is lg . The short slots are equally divided by the long slots and distributed at equal intervals with a distance of 1.19 mm. Fig. 2 shows the comparison of the results before and after changing the resonator structure. After changing the structure, a continuous impedance bandwidth (S_{11} below -10 dB), a higher passband gain, and a lower stopband suppression level can be obtained.

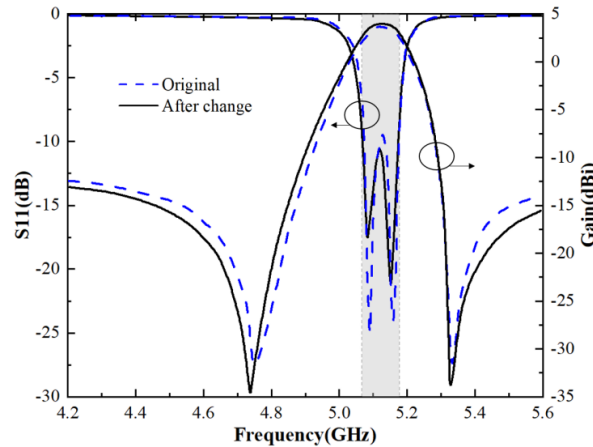


Figure 2. Comparison of the results before and after changing the resonator structure.

2.3. Synthesis of Resonator and Radiator

As the radiation patch is used as the last stage of the filter, the electrical coupling generated by the microstrip line inserted into the U-shaped patch is replaced by admittance inverter J , which can integrate the antenna and resonator. The gap width of the coupling structure will affect the coupling effect and further affect the antenna performance. Adjust the widths of the gaps g_1 and g_3 to get the best coupling effect, and change only one g value at a time while keeping other parameters unchanged. Fig. 3 shows the influence of gap width on S_{11} . According to the best coupling effect, g_1 is determined to be 1.3 mm, and g_3 is determined to be 0.73 mm. It is worth noting that when $g_3 = 0.78$ mm, the center frequency has a large deviation, which may be due to the serious impedance mismatch.

2.4. Design of DGS

The DGS can be achieved by etching different shapes on the ground plate, which can change the current distribution to achieve the desired effect [8]. By removing the ground at the coupling part of the U-shaped radiator and trident resonator, the coupling with the ground plane can be weakened, thus increase the coupling between the two parts. In this way, the impedance bandwidth can be further expanded, and the gain can be improved. Fig. 4 is a comparison of the simulation results of S_{11} and

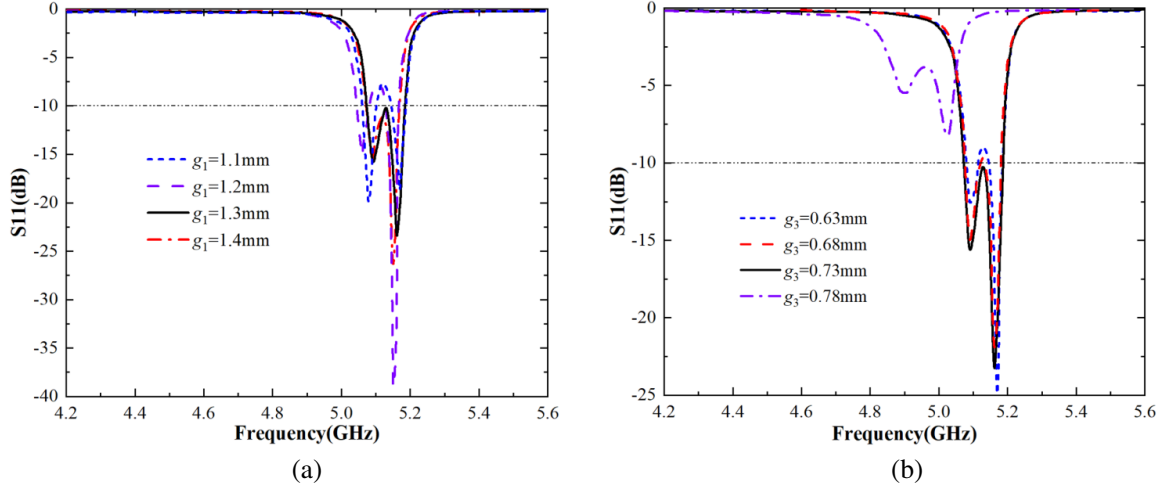


Figure 3. S_{11} results under different g . (a) g_1 , (b) g_3 .

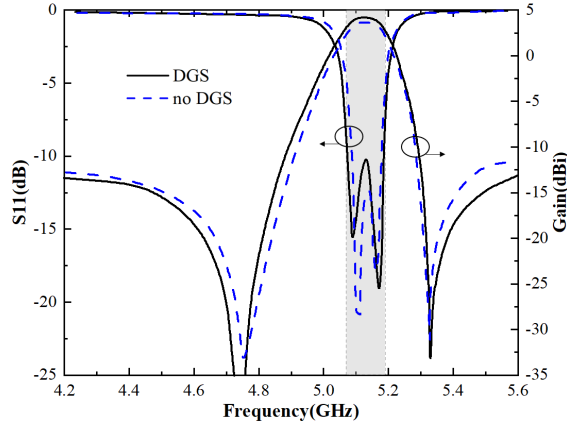


Figure 4. Comparison of S_{11} and gain results before and after adding DGS.

gain before and after adding DGS while other parameters are unchanged. The use of DGS can not only expand the bandwidth and increase the gain but also improve the stopband suppression level.

3. RESULTS AND DISCUSSIONS

Figure 5(a) shows the manufactured antenna. The simulation and measurement results of S_{11} and gain under the optimal parameters are displayed in Fig. 5(b), showing that the antenna has a sharp edge roll-off rate, and the out-of-band rejection can reach -30 dB. Due to the roughness of the manufacturing process, the actual loss of materials and the influence of the measurement operation process, there are some differences between the measurement and simulation results, but they are basically similar. Fig. 5(c) reveals the current intensity distribution on the antenna surface at two radiation nulls of 4.75 GHz and 5.33 GHz. At 4.75 GHz, the current intensity is mainly concentrated upon the trident resonator, and the flow direction is opposite. Therefore, the cross-polarization counteracts in the broadside direction, and nearly no energy is radiated out, forming the radiation null at low frequency. At 5.33 GHz, besides the current on the trident resonator, a small amount of current is distributed on the radiation patch. Benefiting from the high symmetry of the patch structure, the two co-polarized radiation sources at the edge of the U-shaped patch and the end of the feed line are in the opposite directions with equal amplitude, thus forming the radiation null. This is why the gain of high-frequency radiation zero point is slightly higher than that of low-frequency radiation zero point. Fig. 5(d) shows the co-polarized (co-pol)

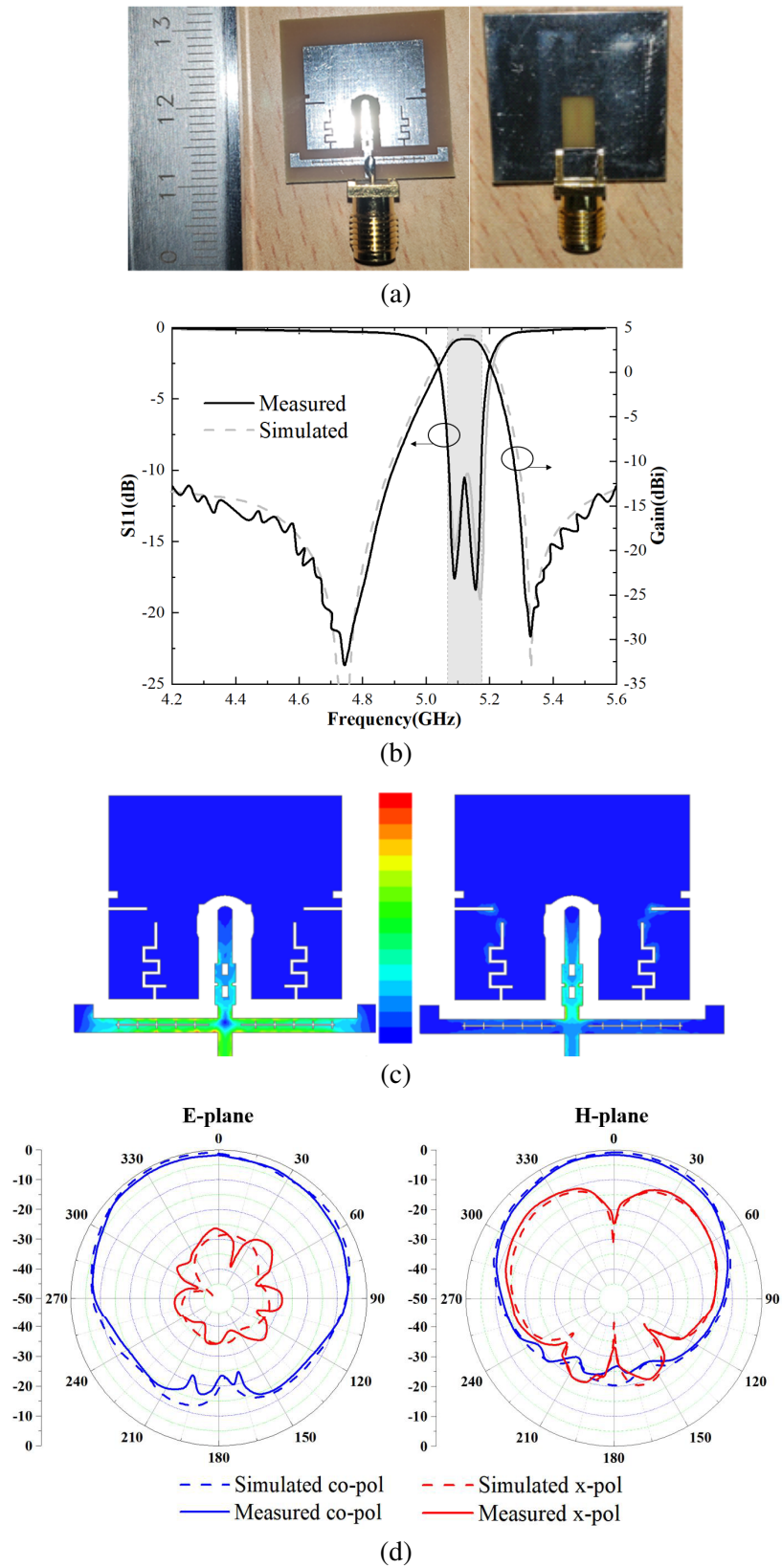


Figure 5. (a) The manufactured antenna, (b) results of S_{11} and gain, (c) surface current intensity of antenna at 4.75 GHz and 5.33 GHz, (d) radiation patterns of the fabricated filtering antenna.

and cross-polarized (x-pol) radiation patterns of the antenna. The cross-polarization suppression level of the E -plane is good in the passband. However, the suppression level of the H -plane is poor, which can be improved by using different feeding techniques [13]. The optimal parameters of the antenna are listed in Table 1. Table 2 shows the comparison between the proposed antenna and other similar antennas.

Table 1. The dimensions of the parameters. (Unit: mm).

Parameter	G	W	L	g_1	g_2	g_3	l_1	l_2	l_3
Dimension	21.8	15.8	13.8	1.3	1.45	0.73	1.9	7.3	1.3
Parameter	l_4	l_5	w_1	w_2	w_3	w_4	w_5	dw	dl
Dimension	6.45	1	0.97	9.75	1.27	2.83	0.9	4	6.8
Parameter	ws_0	ws_1	ws_2	ws_3	ws_4	ws_5	ws_6	Lg_1	Lg_2
Dimension	0.2	1.4	1	0.8	2.6	0.6	6.3	6.02	6.46
Parameter	gl	gw	gs	ls_1	ls_2	ls_3	ls_4	ls_5	ls_6
Dimension	10.49	8.89	2.9	0.8	1	1.1	1.6	0.5	0.5

Table 2. Comparison of similar works.

Reference	Layers	Size ($\lambda_0 \times \lambda_0 \times \lambda_0$)	Gain (dBi)	Freq (GHz)
1	1	$0.5 \times 0.5 \times 0.01$	3.33	5
7	2	$1.3 \times 1.3 \times 0.06$	8.2	5
11	1	$1.06 \times 1.02 \times 0.025$	7.9/8.55	2.52/3.42
Proposed	1	$0.36 \times 0.36 \times 0.01$	3.88	5.1

4. CONCLUSION

A compact single layer filtering antenna is introduced. The 5.1 GHz antenna can be used in broadband wireless access system for indoor applications [14]. By adjusting the insertion coupling part of the U-shaped patch radiator and quarter-wavelength trident resonator, a good coupling effect is obtained. By modifying the patch structure, the size of the antenna can be effectively reduced without affecting its performance. Besides, a DGS is used to adjust impedance matching to obtain enough bandwidth and lower stopband suppression. The simulation and measurement results verify its good performance. The proposed filtering antenna has smaller size, wider impedance bandwidth, and higher gain than similar works on the premise of keeping good antenna performance, and its performance in actual test can meet the requirements of practical application.

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