A Wideband Harmonic Suppression Filtering Antenna with Multiple Radiation Nulls

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Abstract—In this paper, a wide harmonic suppression filtering antenna with high selectivity is designed. The filtering antenna adopts dual-layer structures. By introducing four parasitic patches around the top driven patch, the impedance bandwidth is widened. Moreover, the current directions on the driven patch and parasitic patches are opposite in some frequency, so that radiation null is introduced. In addition, a rectangular split ring DGS is etched in the middle of the ground plane, a lower sideband radiation null is introduced. Two sets of dumbbell-shaped defected ground structures are etched on the ground plane of the intermediate layer. The high-order harmonics are suppressed, and another radiation null is introduced. The experimental results show that the antenna operates at 2.46–2.66 GHz; the relative bandwidth is 7.8%; the peak gain is 3.8 dBi; and the S_{11} is more than $-3 \, \text{dB}$ at 3–13 GHz.

1. INTRODUCTION

In order to make the RF front-end more compact, a filter and an antenna are integrated into a module named filtering antenna to realize the functions of filtering and radiation at the same time. In recent years, the research of filtering antenna has become a hot spot, and various filtering antennas have been designed and reported. In [1], a compact filtering antenna is presented using a composite right/left-handed (CRLH) transmission line structure. In [2–5], the designed filtering antenna has high selectivity by etching slits on the driven patch. In [6], a branch resonator structure on a microstrip feeding line is introduced to generate multiple radiation nulls, which further improves the selectivity. In [7–9], by introducing parasitic patches, shorting vias, and loading slots, broad bandwidth is obtained. In [10, 11], by stacking patches and arranging arrays the antenna gain is improved. In [12], a miniaturized and simple power divider structure is designed, and a triple-band filtering response is realized by using a coupled line structure. So the coupled line structure can be used to improve filtering response.

In addition, the high-order odd mode of antenna will interfere surrounding antenna and consume extra energy. In order to solve this problem, different antennas with harmonics suppression are proposed. By embedding a filter [13], introducing a split ring DGS [14] and short-circuit branch [15], the harmonics of the antenna is well suppressed. Furthermore, the filtering antennas with high selectivity and harmonic suppression have great advantages simultaneously. In [16], stubs are added to a microstrip feedingline to achieve high-selectivity filtering, and the second harmonic suppression is achieved through embedding a filter structure. In [17], by utilizing the coupling of two half-wavelength stepped impedance resonators (SIRs), an antenna with good harmonic suppression and high selectivity is achieved. The magnetoelectric dipole antenna in [18] obtains high selectivity by utilizing a complementary split resonator ring (CSRR) to generate radiation null. In addition, a stepped impedance resonator is loaded on a feeding structure to achieve the third harmonic suppression.

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From the previous introduction, we can see that it is often difficult to achieve a wide harmonic suppression bandwidth of a microstrip antenna. The bandwidth of harmonic suppression is not wide enough in these previous studies.

In this paper, wide harmonic suppression bandwidth $(2f_0 \text{ to } 5f_0)$ is achieved. The wideband harmonic suppression filtering antenna adopts a dual-layer structure. By adding parasitic patches and defected ground structure, a pair of radiation nulls is introduced, which improves the selectivity of the filtering antenna. In addition, by loading the structure composed of microstrip line stubs and dumbbell-shaped defected ground structure, high-order harmonics are eliminated. A prototype working at 2.46 ~ 2.66 GHz is fabricated and measured; the relative bandwidth is 7.8%; the peak gain is 3.8 dBi; and the harmonic suppression reaches $5f_0$.

2. ANTENNA CONFIGURATION AND ANALYSIS

2.1. Geometry of the Filtering Antenna

The configuration of the proposed filtering antenna is shown in Fig. 1, which consists of three metal layers and two dielectric substrates. The driven patch is etched at the center of the top layer. Four parasitic patches are symmetrically distributed on both sides of the driven patch. A step impedance



Figure 1. Configuration of the proposed filtering antenna: (a) 3D view. (b) Feeding line and ground plane.

Parameter	H_1	H_2	L_{s1}	W_{s1}	d	d_1	L_p	W_p	l_1	w_1
values/mm	0.8	1.6	8	2	8	6	26	20	27.6	10
Parameter	s_1	r_4	la_1	la_2	la_3	w	l	w_2	l_2	w_s
values/mm	3.5	1.5	21.1	6.8	4	2.2	17	1.3	35	1.2
Parameter	l_s	w_4	d_5	w_2	sh	r_1	r_2	r_3	s	s_2
Parameter values/mm	$\frac{l_s}{11}$	$\frac{w_4}{0.8}$	$\frac{d_5}{5}$	$\frac{w_2}{1.3}$	$\frac{sh}{0.5}$	$\frac{r_1}{2}$	r_2 3	r_3 1.2	<i>s</i> 4.6	$\frac{s_2}{9.6}$
Parameter values/mm Parameter	$\frac{l_s}{11}$	w_4 0.8 l_w	$\frac{d_5}{5}$ l_{w1}	$\frac{w_2}{1.3}$	$\frac{sh}{0.5}$	r_1 2 d_3	$\frac{r_2}{3}$	r_3 1.2	<i>s</i> 4.6	$\frac{s_2}{9.6}$

Table 1. The values of the antenna.

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microstrip line with 2 arc-shaped strip stubs, which feed the antenna of top layer, is etched at the bottom layer. The ground plane is inserted at the middle of two substrates. Moreover, two sets of dumbbell-shaped DGSs and a rectangular split ring DGS are etched in the ground plane. The two dielectric substrates are fabricated of FR4 with a relative permittivity of 4.4 and a dielectric loss tangent of 0.02. The four holes at the corners are used to reinforce the upper and lower dielectric substrates. In order to facilitate the SMA connectors, a rectangular groove is subtracted from the dielectric substrate on the top layer. The geometric dimensions of the antenna are shown in Table 1.

2.2. High Selectivity and Wide Harmonic Suppression

To illustrate the design process of the antenna, three reference antennas, namely Antenna A, Antenna B, and Antenna C are given, as shown in Fig. 2. Antenna A is a classical slot coupled patch antenna. Based on antenna A, four parasitic patches are symmetrically loaded on both sides of the top patch to form antenna B. In antenna C, a rectangular split ring DGS is etched on the ground plane. Finally, two circular arc strip stubs on the feeding line are introduced, and two sets of dumbbell-shaped defected ground structures are etched on the ground plane.



Figure 2. Evolution of the proposed antenna: (a) Antenna A. (b) Antenna B. (c) Antenna C. (d) The proposed antenna.

The reflection coefficients and realized gains of the reference antennas and final designed antennas are shown in Fig. 3. From Fig. 3(a), it can be seen that antenna A works at 2.42 ~ 2.48 GHz with the relative bandwidth of 2.45%, by loading four parasitic patches symmetrically on both sides of the top patch, a new resonance f_{r2} is introduced on the right side of the passband, and the bandwidth is widened. From Fig. 3(b), it can be seen that antenna A has a low gain and a radiation null f_{n1} , and the radiation null f_{n1} is determined by the length of the feed line beyond the coupling gap. A new radiation null f_{n2} at 2.68 GHz is generated on the upper frequency band, which improves the selectivity of upper frequency band by loading four parasitic patches. The third radiation null f_{n3} is generated at 2.16 GHz, which improves the selectivity of the low frequency band, by etching a rectangular split ring DGS on the ground plane. The radiation null f_{n4} is introduced. Due to etching two circular arc strip stubs on the feeding line and two sets of dumbbell-shaped defected ground structures, a lowpass filter with wide stopband and transmission zero is realized. The frequency of f_{n4} is related to the parameter of DGS.

Figure 4 shows the current distribution of the antenna at the resonant frequency and radiation null. It can be seen that the current direction is consistent at the drive patch and parasitic patch, and the current is very strong at 2.48 GHz. However, since the length of the split ring DGS etched on the ground plane is close to a quarter of the dielectric wavelength of 2.16 GHz, most of the energy is concentrated on the split ring DGS, and the minor energy is coupled to the driven patch, as shown in



Figure 3. The S_{11} and realized gain of the reference antenna and proposed antenna: (a) S_{11} . (b) Realized gains.



Figure 4. The current distributions at the resonant frequency and the radiation null :(a) $f_{r1} = 2.48 \text{ GHz}$; (b) $f_{n3} = 2.16 \text{ GHz}$; (c) $f_{n2} = 2.68 \text{ GHz}$.

Fig. 6(b). Therefore, the radiation null f_{n3} is generated at 2.16 GHz. In addition, as shown in Fig. 6(c), the current directions on the driven patch and parasitic patches are opposite, so that the radiation null f_{n2} is generated at 2.68 GHz.

In order to suppress the higher harmonics, two sets of dumbbell-shaped defected ground structures are etched on the ground plane to realize the lowpass filter with wide stopband. It is well known that the defected ground structure can produce notch band. Fig. 5 shows the S_{21} parameters of etching different DGSs under the transmission line. It can be seen that when a set of small size or large size DGSs are loaded, two band stops are generated at 10 GHz and 4.6 GHz, respectively. When a set of larger dumbbell-shaped structures are etched in the middle of two small dumbbell-shaped structures, wide stopband appears from 4 GHz to 13 GHz. Fig. 6 shows the S_{11} parameters of etching differential DGS. It can be seen that without introducing the defected ground structure, the antenna generates high-order





Figure 5. The S_{21} of etching differential GDS.

Figure 6. The S_{11} parameters of etching differential DGS.

harmonics of TM₃₀, TM₃₂, and TM₅₀. When a pair of small-sized dumbbell-shaped structures is etched on the ground plane, TM₃₂ is suppressed, and TM₃₀ is slightly suppressed and shifted towards low frequency. At the same time, a new resonant TM₂₀ is excited at 4.6 GHz. When a group of larger dumbbell-shaped structures is etched between two small dumbbell-shaped structures, TM₂₀ can be well suppressed. In addition, two open-circuit branches are loaded on both sides of the feeding line. The harmonic TM₅₀ is well suppressed, and the S_{11} of the final antenna is more than $-3 \, \text{dB}$ from 3 to 13 GHz. Moreover, from Fig. 3(b), it can be seen that the fourth radiation null f_{n4} appears at 3.2 GHz, which further improves the selectivity of the antenna.

2.3. Parametric Analysis

Figure 7 shows the effect of length of parasitic patch l_1 and length of split ring DGS l_{a1} on radiation null. It can be seen that as l_1 increases, the radiation null gradually shifts toward the low frequency band,



Figure 7. The realized gain at differential l_1 and l_{a1} , (a) different l_1 , (b) different l_{a1} .

while the radiation null at the low frequency band remains unchanged. In addition, as l_{a1} decreases, the radiation null gradually shifts toward the high frequency band, while the radiation null at the high frequency band remains unchanged. So the radiation null f_{n2} and f_{n3} of the proposed filtering antenna can be independently controlled by the length l_1 of the parasitic patches and the length l_{a1} of split ring DGS.

3. MEASUREMENT VERIFICATION AND RESULTS

To verify this design, the designed filtering antenna was finally manufactured and tested. Fig. 8 is the prototype of the designed filtering antenna. The overall size is $80 \text{ mm} \times 60 \text{ mm} \times 2.4 \text{ mm}$.



Figure 8. Photograph of the fabricated filtering antenna: (a) The top layer. (b) The middle layer. (c) The bottom layer.

Figure 9 shows the simulated and measured S_{11} and gains of the proposed filtering antenna. It can be seen that the proposed filtering antenna has a bandwidth from 2.46 GHz to 2.66 GHz with the maximum gain of 3.8 dBi and two radiation nulls at 2.18 GHz and 2.70 GHz. In the stopband from 3 GHz to 13 GHz, the high-order harmonics are suppressed, and the wide stopband suppression of $5f_0$ is achieved. The measured results are basically consistent with the simulated ones.

Figure 10 presents the simulated and measured radiation patterns of the designed filtering antenna at 2.48 GHz. It can be seen that simulated and measured co-polarized field and cross-polarized field results are almost identical, and the cross-polarization is lower than $-35 \,dBi$.

A detailed comparison about this paper with some similar reported filtering antennas on some key indicators is shown in Table 2. It can be clearly found that this antenna can have a wider harmonic

Refs.	Operating	Relative	Radiation	Realized	Cost	Harmonic
	frequency (GHz)	bandwidth	nulls	gain (dBi)		Suppression
[4]	4.84-6.04	22.6%	2	7.4	High	Up to $2f_0$
[11]	5.12 - 5.35	4.4%	2	15.5	High	Up to $2f_0$
[12]	1.70 - 2.81	49%	0	7.2	High	Up to $4f_0$
[14]	3.10 - 3.16	1.9%	0	/	Low	Up to $5f_0$
[16]	2.34 – 2.72	15.2%	2	7.2	High	Up to $2f_0$
[17]	3.43 - 3.62	6.6%	1	7.4	High	Up to $3f_0$
[18]	1.44 - 2.79	63.8%	2	7.3	High	Up to $4f_0$
This work	2.46 - 2.66	7.8%	4	3.8	Low	Up to $5f_0$

Table 2. Comparisons between the proposed filtering antenna and other works.



Figure 9. Simulated and measured results: (a) S_{11} , (b) realized gain, (c) S_{11} and realized gain for 1–4 GHz.



Figure 10. Radiation pattern of the proposed filtering antenna at 2.48 GHz: (a) *E*-plane, (b) *H*-plane.

suppression and four radiation nulls compared to most involved antennas despite the limitation of low realized gain. The reason for the low realized gain is that a low cost FR4 dielectric substrate is adopted. Due to the high dielectric loss tangent of FR4, the antenna gain is decreased. In addition, the half power beamwidth of 80° also results in relatively low antenna gain.

4. CONCLUSION

In this paper, a filtering antenna with high selectivity and harmonic suppression is designed. By adding the parasitic patches and DGS, the impedance bandwidth is extended, and two radiation nulls are introduced. Moreover, by adopting the defected ground structure and the stub, the high-order harmonics is suppressed. The proposed filtering antenna works at 2.46 GHz–2.66 GHz with four radiation nulls. And the harmonic suppression is up to $5f_0$.

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