A Filtering Patch Antenna With Flexibly Controllable Radiation Nulls

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Abstract

In this paper, a filtering patch antenna with flexibly controllable radiation nulls is presented. The patch antenna is fed by an F-shaped probe consisting of two arms along the Y-axis and a metal column along the Z-axis. A broadside radiation null on the lower band is generated by cross-coupling. Meanwhile, a folded defected ground structure (DGS) is introduced to generate an upper band radiation null. By adjusting the parameters of F-probe and DGS, two radiation nulls can be controlled independently to achieve great out-of-band suppression. For demonstration, a prototype is fabricated and measured. The simulation results agree well with the measured ones. A flat in-band realized gain of filtering antenna is about 7.1dBi. The proposed filtering antenna operating at 2.33 GHz achieves a wide relative bandwidth of 9.8% and out-of-band suppression level is more than 24dB.

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Introduction: With the rapid development of wireless system, the requirements of RF front-end are more and more strict. The demand for compact antennas with good filtering performance is increasing. As important components of the front-end of the communication system, antennas and filters are usually designed separately, resulting in wasting of resources [1]. In the past few years, filtering antennas have been a typical solution to achieve both filtering and radiating characteristics, this solution can reduce circuit size and improving system performance.

The existing filtering antenna design methods can be classified into three categories. The first technique is to combine the filter structure with the antenna. However, the interface impedance needs to be optimized or additional impedance converters are required, which brings additional damage to the insertion. Another way is to use antenna to replace the last stage resonator of the filter [2]. The filter structure is usually made up of multiple resonators, and the additional resonators also introduce insertion losses and reduce antenna radiation efficiency. The third method is to construct the design of the filter and the radiator at the same time, the novel feeding structure is used to construct new coupling paths to produce radiation and high selectivity [3], such as the T-circuit, H-circuit and F-circuit type probe [4]. Using the parasitic element such as the etching slot lines, the short circuit point and DGS is another effective method for the radiator to generate radiation nulls [5]. In addition, the reported antennas need to improve the independent control of radiation nulls. Therefore, designing a flexible and controllable filtering antenna is a challenging task.

In this letter, a filtering antenna with flexibly independent controllable radiation nulls is developed. The patch antenna is fed by F-circuit probe, which establishes cross-coupling to generate radiation null. In the design of development, DGS is used to enhance bandwidth and promote filtering performance. For demonstrate, the prototype of proposed antenna is designed and fabricated.

(a)

(b)

Fig. 1 *Configuration of the wideband filtering patch antenna. (a) Perspective view. (b) Side view. g=80mm, l=52.3mm, w=47.2mm, lp=44.3mm, wp=39.2mm, ws1=1mm, ws2=1.3mm, ld=8.5mm, wd=6mm, s1=0.5mm, s2=2mm, s3=1mm, s4=7.5mm, ht=3mm, hs=0.8mm, h1=5mm, h=16mm, ls1=34mm, l1=24mm, l2=20mm.*

Antenna design and analysis: The structure of the proposed filtering antenna is exhibited in Fig. 1, consisting of a rectangular microstrip patch excited by F-probe and a folded DGS on the metal ground. The antenna is designed on Rogers RO4003 substrate with a relative permittivity of 3.38, length l, width w and thickness of 1.5 mm. The specific dimensions of the proposed filtering antenna are shown in Fig.1. To further understand the working mechanism, as shown in Fig.2, the design evolution process is divided into three steps. Antenna I is a rectangular patch fed by L-shaped probe.

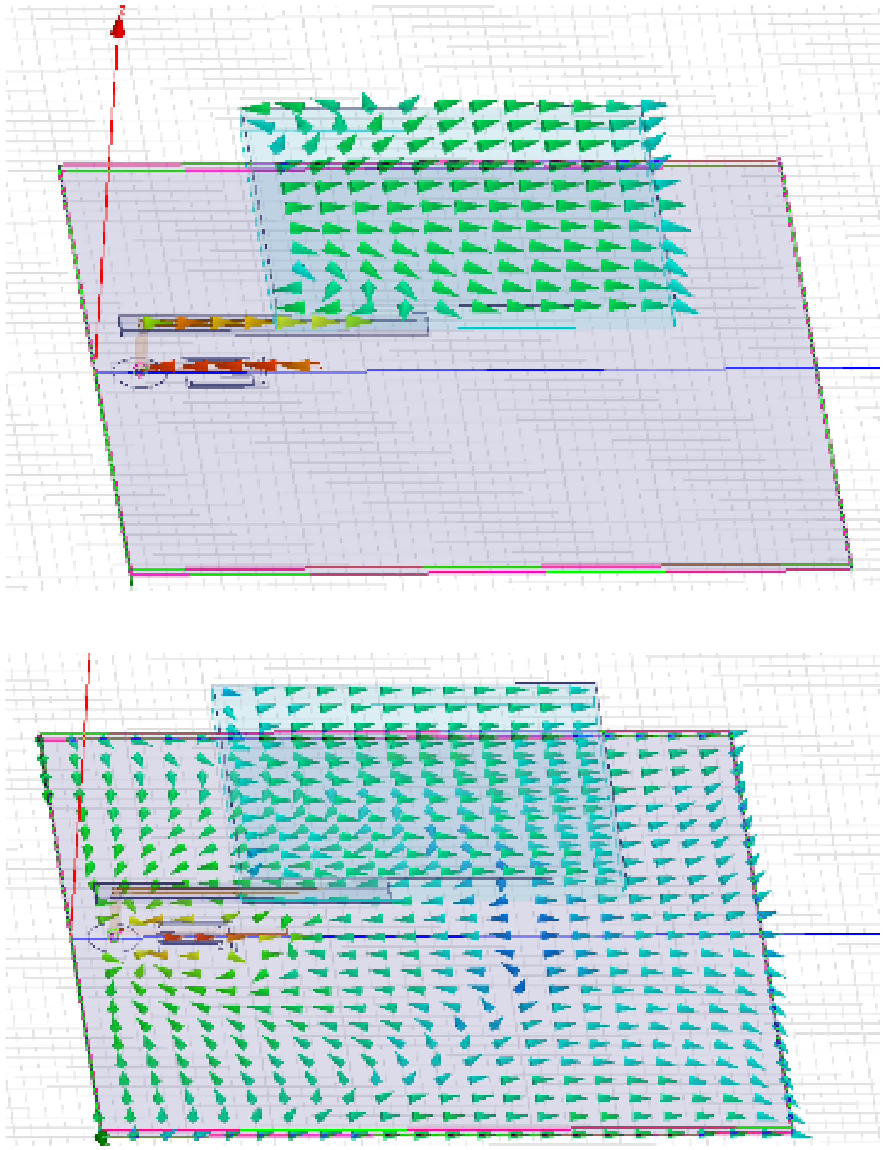
The developed Antenna II uses F-probe instead of L-probe. As seen from Fig.2, the F-probe structure consists of two arms along the Y-axis and a metal column along the Z-axis. Along the Z-axis, the upper arm is called Arm1, and the lower one is called Arm2. The arms are printed on two Roger RO4003 substrates of different sizes. Multiple coupling paths are constructed between the F-probe and patch, forming a cross-coupling in the antenna. Fig.3 demonstrates a coupling project for the F-probe feeding structure. Arm1 and Arm2 are on behalf of the functions of P1 and P2 respectively. The phase difference between two coupling paths can be controlled by the length of the arms and the interval between them. Then the radiation null is generated on one side of the passband.

(a) (b) (c)

Fig. 2 *Perspective view of the evolution process. (a)AntennaI. (b)Antenna II. (c) Antenna III.*

Fig. 3 *General coupling scheme for a filtering antenna*

Fig. 4 *Simulated results of the designedAntenna I, II and III*



(a) (b)

Fig. 5 *Simulated current distributions on the proposed antenna at radiation null frequencies. (a) 2.09 GHz. (b) 2.69 GHz.*

In order to achieve the filter frequency selection function and generate a radiation null in the upper band. The DGS is constructed to form Antenna III. By changing the current distribution and current direction, the DGS changes the effective dielectric constant, equivalent capacitance and inductance to change the transmission characteristics. This method does not affect the resonance characteristics of the F-probe guaranteeing the flexible control of the filter function.

The simulated results of the reference and proposed antennas are compared in Fig.4. From the graph, the resonant frequency point is increased because of the introduction of the F-probe feeding circuit. Meanwhile, due to the principle of cross-coupling, a radiation null is generated in the lower band. With the introduction of DGS, the bandwidth is optimized and expanded. Another radiation null is generated in the upper band because of the high impedance characteristics of DGS. The center frequency of the filtering antenna is 2.33GHz. Two radiation nulls are at 2.09GHz and 2.69GHz, respectively. Rejection level is more than 24dB. The average realized gain is 7.25dBi and the relative bandwidth is 9.87% (2.22GHz ˜ 2.45GHz). The filter frequency selection and basic radiation function of the filtering antenna are realized.

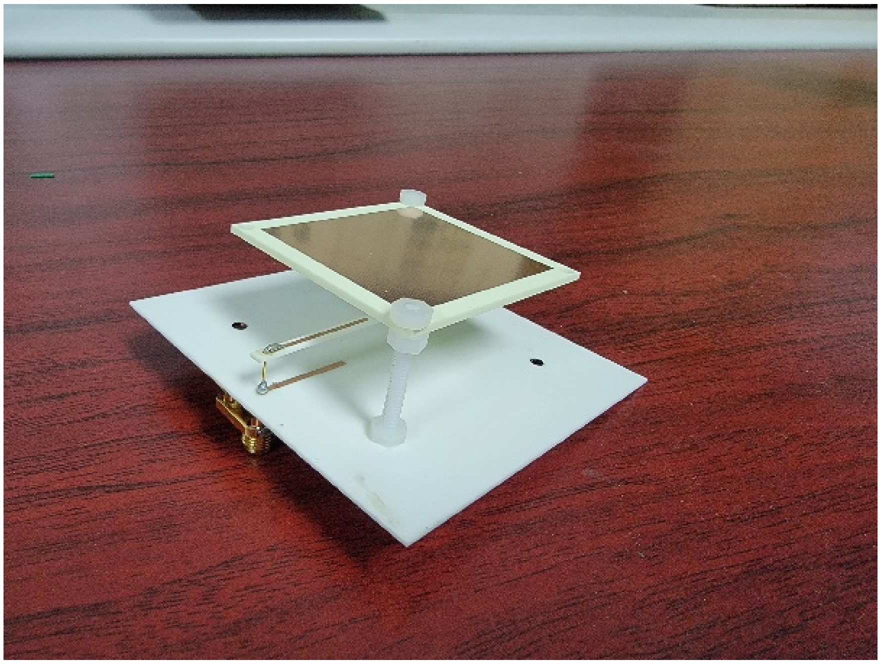
In Fig.5, the current distribution of the filtering antenna can be observed at two radiating nulls frequencies. At 2.09GHz, the current is mainly concentrated in the Arm2, the phase difference caused by cross-coupling makes the current on the arms to cancel out. The current on the patch is so little, creating a radiation null. At 2.69GHz, the current is most concentrated in the DGS slots on the ground and offsets in the direction causing the current on the patch is rarely excited. Low patch radiation efficiency forms another radiation null.

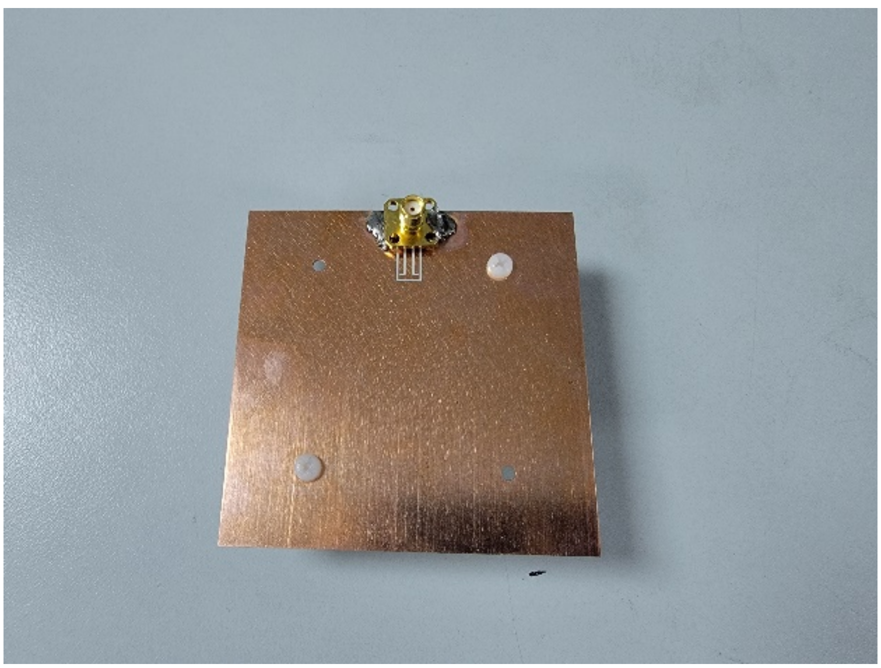
F-probe structure and DGS sharpen the band-edge rill-off better and realize the great rejection level. Importantly, the radiation nulls can be flexibly adjusted independently. The length of *l2* affects the phase difference of the cross-coupling path. As shown in Fig.6, the increase in the length of *l2* causes the lower radiation null to move to lower frequency direction, and the upper radiation null has a negligible effect. The total length of the folded DGS is established to approximately half the wavelength of the null frequency. From Fig.6(b), the effect of *wd* on the upper radiation null point is shown. As a result, the introduction of folded DGS enables the filter function to be adjusted more flexibly to realize the desired filter response.

(a) (b)

Fig. 6 *Simulated broadside realized gains of the proposed filtering antenna when the total length of the slot varies. (a) the lower-band edge null. (b) the upper-band edge null.*

Experimental verification: An operating at 2.33GHz filtering antenna is fabricated. The prototype with an overall size of 1.15 $\times$1.15 $\times$ 0.30 (80mm $\times$ 80 mm $\times$ 21 mm) is shown in Fig.7. The reflection coefficient (S_{11}) is measured by Agilent Network Analyzer. The radiation patterns and realized gain are measured by Satimo Near-field Measure System. Simulated and measured results of the proposed filtering antenna are demonstrated in Fig.8. The average realized gain achieves 7.1dBi and the relative bandwidth is 9.7%. Two radiation nulls, at 2.13 and 2.67 GHz, are observed on both sides of the passband resulting in a high selectivity. Rejection level of the proposed filtering antenna is more than 24dB. The radiation patterns in two cut planes for co- and cross-polarization at 2.33 GHz are presented in Fig.9. The measured co-polarizations at broadside direction in both E-plane and H-plane are at least 20dB higher than the corresponding cross-polarizations. Due to manufacturing and measuring errors, a slight difference between the simulated and measured results is demonstrated.





(a) (b)

Fig. 7 *The photograph of the proposed filtering antenna prototype (a) Perspective view. (b) Bottom view.*

Fig. 8 *Simulated/measured results of the proposed filtering antenna*

The performance of the proposed antenna and other reported filtering antennas is listed in Table I. These antennas achieve filtering function by a novel type feeding structure or other parasitic elements. In [3], L-shaped probe feeds stacked patches, the level of out-of-band suppression is not high. In [4], two F-probe feeding structures generate two radiation nulls, but producing resonant interference. The radiation nulls could not be controlled flexibly. In [5], DGS is introduced but the stopband level has not been raised. The proposed filtering antenna is designed by multi-degree to generate radiation nulls, increasing the flexibility of design. Meanwhile, the realized gain of radiation is greater than 7.1dBi and out-of-band suppression is more than 24dB.

(a) (b)

Fig. 9 *Simulated and measured radiation patterns of the antenna in E-plane and H-plane at 2.33 GHz: (a) Co-polarization. (b) Cross-polarization.*

Table 1. Performance comparison with other reported wideband filtering antennas

	Bandwidth	Gain	Suppression level	Suppression level	Controllable radiation nulls	Controllable radia
[3]	16					
[4]	21					
[5]	9.2					
Our work	9.8					

Conclusion: In this letter, the F-shaped probe and folded DGS are applied to design the filtering antenna with great frequency selectivity. Cross-coupled routes of F-shaped probe and the high impedance characteristics of DGS are established in the antenna. Two radiation nulls can be controlled independently to achieve great out-of-band suppression. The proposed filtering patch antenna achieves average gain of 7.1dBi with a bandwidth of 9.8%. In general, the proposed filtering antenna implements flexibly controllable radiation nulls and rejection suppression levels is more than 24dB.

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