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Dual-Band Patch Antenna with Filtering Performance and Harmonic Suppression

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***Abstract*— A novel design of dual-band antenna with integrated filtering performance is proposed. A low-profile aperture-coupled U-slot patch antenna is employed for dual-band operation with a uniform polarization, which is fed by a dual-mode stub-loaded resonator (SLR). The U-slot patch works as a dual-mode resonator of the dual-band filter as well as the radiation element. The odd- and even-mode of the SLR are coupled and tuned with the U-slot patch, generating two 2nd-order operation bands at 3.6 and 5.2 GHz. Compared with the traditional patch antenna, the proposed antenna exhibits improved bandwidth and frequency selectivity. In addition, the bandwidths can be controlled by adjusting the coupling strength between the SLR and the patch. Furthermore, the higher-order harmonics can be suppressed over a broadband without increasing the footprint of the design. Measured and simulated results agree well with each other, showing an excellent performance in terms of impedance matching, bandwidths, 2nd-order filtering, out-of-band rejection, cross polarization discrimination (XPD) and gain at both bands.**

***Index Terms*— Dual-band, bandwidth, 2nd-order, filtering, U-slot patch, harmonic suppression.**

I. Introduction

MODERN wireless communication systems demand RF front-ends with features of compactness, highly integration, multiband and multifunction. Patch antenna is considered as one of the most widely used antennas owing to its low profile, low cost, unidirectional and compatibility with backend circuits. Significant effort has gone into designing dual-band or multi-band patch antennas [1]-[4]. Dual-band operation can be obtained by manipulating the fundamental mode and higher order modes of the patch [5], [6].

To reduce the volume and complexity of RF front-ends and meet the demand for multifunctional operation, integrated passive devices such as power dividers, filters and antennas have been considered as a promising solution. The integration has the added benefits of improving the frequency response and removing the 50 Ω interconnections and matching networks [8]. In [9], multiplexers were proposed based solely on resonators to eliminate traditional transmission-line based distribution networks. The integration of filter and antenna has shown advantages such as reduction of RF front-end [10], improved bandwidth and frequency selectivity [11] and harmonic suppression [12]-[13]. Nevertheless, many challenges remain in the design and optimization of filtering antennas such as multiband operation and tunable bandwidth. To the best of the author's knowledge, the problems haven't been fully considered and solved. In [14] - [15], two dual-band filtering patch antennas were proposed. However, the rectangular patch in [14] works in two orthogonal polarizations at the two bands and very complicated matching structures were needed. Besides, the peak gains were only -1.8 dBi and 1.1 dBi at the two bands and many unwanted harmonics appeared between the two bands. In [15], the TM_{10} and TM_{30} modes of the patch were employed, but the gain was only -4 dBi and the feeding network was also complex. In [16], a tri-band filtering antenna was proposed by cascading a triband filtering with a wideband antenna.

In this communication, a novel dual-band filtering antenna with broadband harmonic suppression performance is proposed for 3.6/5.2 GHz WiMAX and WLAN applications. A U-slot patch antenna is integrated with a dual-mode stub loaded resonator (SLR) through electromagnetic coupling, producing a 2nd-order dual-band filtering antenna. Compared with tradition patch, the bandwidth, filtering and harmonics suppression are significantly improved. In addition, the bandwidths of the antenna can be adjusted in the designing process. Both the simulated and measured results exhibit improved bandwidth and radiation performances.

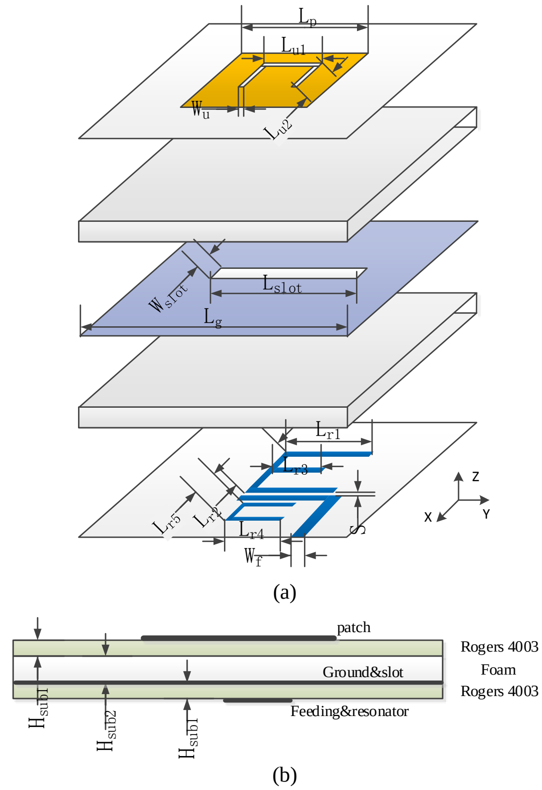

Fig.1. Configuration of the proposed dual-band filtering antenna: (a) exploded perspective view, (b) the stacked structure.

This manuscript is submitted on October 31, 2015. This work is supported by the project "DIFFERENT" funded by EC FP7 (grant no. 6069923). YW is supported by UK EPSRC under Contract EP/M013529/1.

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II. Antenna Design

A. Configuration

Fig. 1 shows the configuration of the proposed dual-band filtering antenna. The design is a stacked structure composed of two substrates separated by a thin foam (1 mm). The square patch is printed on the upper layer of the top substrate with a U-shaped slot is etched in it for dual-band operation. The mechanism and the design method has been detailed in [3]. The feeding line and the dual-mode E-shaped SLR are printed on the bottom layer of the lower substrate. The patch and the feeding network share a same ground plane in the middle layer with an aperture etched in it. Fig. 1(b) illustrates the stacked structure of the proposed design. Rogers 4003 substrate with a dielectric constant of 3.55 and a loss tangent of 0.0027 was used. All simulations were performed using High Frequency Simulation Software (HFSS 15) and the optimized parameters are listed in Table I.

B. Stub-Loaded Resonator

To achieve the dual-band patch antenna with filtering performance, a dual-mode SLR is employed to couple and synthetically tune with the U-slot patch. In contrast with the traditional method of cascading a filter with an antenna [12], the filtering and radiating components are seamlessly integrated in this work. The U-slot patch here serves as the last-order dual-mode resonator of the 1st-order dual-band passband filter (SLR) as well as the radiating element. This contributes to a higher order filtering performance (2nd-order) while maintaining a compact footprint.

Owing to the high freedom in controlling the modes, the E-shaped SLR is widely used as a dual-mode resonator in filter design. The SLR can be analyzed using the odd- and even-mode method, as previously detailed in [15]-[17]. When the odd-mode is excited, the center part of the SLR is equivalent to a shorted end and the resonant frequency can be approximately derived as,

$$f_{odd} = \frac{c}{2\sqrt{\varepsilon_r}\,(2L_{r1} + L_{r2})} \tag{1}$$

When the even-mode is excited, the symmetrical plane can be viewed as an opened end and the resonant frequency can be expressed as,

$$f_{even} = \frac{c}{2\sqrt{\varepsilon_r}\,(L_{r1} + L_{r2}/2 + L_{r3})} \tag{2}$$

where the f_{odd} and f_{even} are the odd- and even-mode resonant frequencies of the SLR. c is the light velocity in free space and ε_r is the effective permittivity. Thus, the odd-mode and even-mode resonant frequencies can be tuned easily by adjusting the dimensions of the SLR.

TABLE I
PARAMETERS OF THE PROPOSED ANTENNA: (MM)

L_p	L_{u1}	L_{u2}	W_u	L_g	L_{slot}	W_{slot}	L_{r1}
27.2	7.5	8	0.45	60	9.4	0.7	8.2
L_{r2}	L_{r3}	L_{r4}	L_{r5}	S	W_f	H_{sub1}	H_{sub2}
8	6.15	4.2	2.8	0.3	1.8	0.813	1

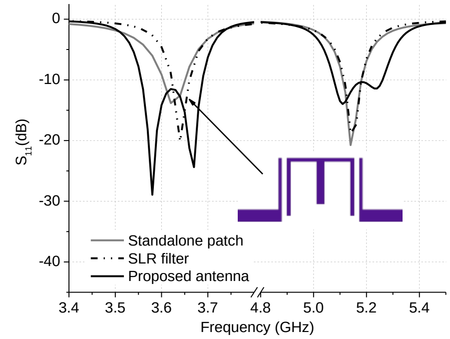
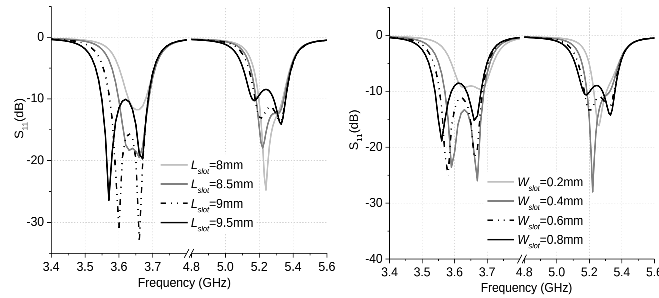


Fig. 2. The S_{11} comparison among standalone U-slot patch, SLR filter and proposed filtering antenna.



(a) (b)

Fig. 3. The variation of bandwidth with different: (a) L_{slot}, (b) W_{slot}.

C. Improved Frequency Response

The bandwidth of the dual-band U-slot patch antenna is usually narrow, especially when the profile is low. Methods such as increasing the profile of the design or loading the parasitic are commonly used to increase the bandwidth at the expense of a higher profile. In this design, a new method for enhancing the two bandwidths of the patch antenna is presented. By using a dual-mode resonator to feed a U-slot patch through electromagnetic coupling, higher-order frequency responses at the two bands can be achieved without increasing the profile of the antenna.

Fig. 2 compares the simulated S_{11} of standalone U-slot patch, SLR filter and the proposed filtering antenna. It is observed that the proposed antenna exhibits improved bandwidths of 4% at both bands with 2nd-order filtering performance. In each band, two reflection zeros can be identified, contributing to sharp roll-offs at both bands. In contrast, the traditional U-slot patch only shows one pole in each band and the bandwidths at both bands are only about 1.8%.

D. Tunable Bandwidth

Bandwidth is one of the key issues to be concerned in filtering antenna design. In bandpass filter design, the bandwidth can be tuned by adjusting the coupling strength between the resonators [16]. In our previous work [17], similar approach was adopted to tune the bandwidth of the antenna.

Fig. 3(a)-(b) shows the bandwidths of the two operation bands with different lengths and widths of the aperture. It is observed that when the length of aperture L_{slot} is shorter than 8 mm, the two reflection zeros merge together, leading to a narrow bandwidth of less than 50 MHz (FBW = 1.4%). As L_{slot} increases, indicating that the coupling strength between the SLR and the U-slot patch increases, the two reflection zeros are divided and a wider bandwidth of over 150 MHz (4.2%) is

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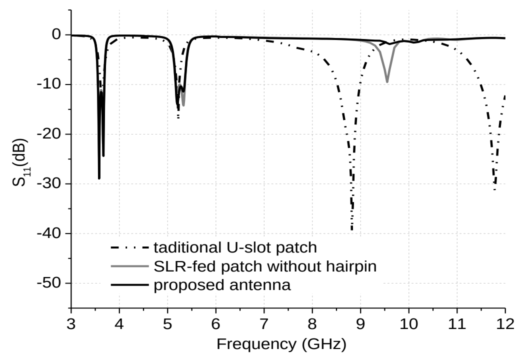


Fig. 4. The harmonic response of traditional U-slot patch, SLR-fed patch without hairpin and proposed filtering antenna over a wideband.

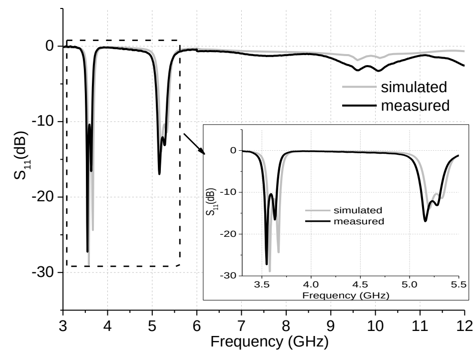


Fig. 5. Simulated and measured S_{11} of the proposed dualband filtering patch antenna.

achieved for the low-band. The length of the aperture has a similar but less significant effect on the high-band operation. The effects of the width of the aperture on the bandwidth are shown in Fig. 3(b). When the width of the aperture decreases from 0.8 to 0.2 mm, the bandwidths of the low-band and high-band decrease from 4.2% to 1.8% and from 3.8% to 1.2%, respectively. Different from the traditional patch antenna, where the bandwidth is usually tuned by adjusting the profile of the antenna, this work provides a new method to tune the bandwidth of the antenna while keeping the profile of the antenna unchanged.

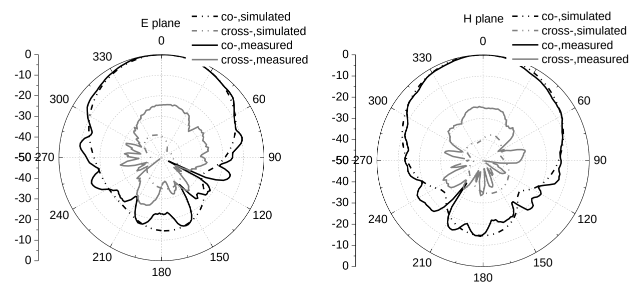
E. Harmonic Suppression

Harmonics is a serious problem to be concerned in wireless communication systems. Traditionally, harmonics are often eliminated by cascading a filter at the backend [12]. However this increases the complexity and the volume of the RF front-end. In this integrated filtering antenna, harmonic suppression is taken into consideration. Fig. 4 shows the harmonic response of a traditional U-slot patch, a SLR-fed patch without hairpin and the proposed filtering antenna. It is observed that the traditional patch antenna has two strong harmonics at 8.75 and 11.7 GHz. However, when the U-slot patch is fed and coupled by a SLR, the two harmonics are eliminated. This is attributed to the fact that the dual-mode SLR and the dual-band U-slot patch have the same fundamental resonant frequencies but different higher order harmonics. As a result, these two components are detuned at the high band and the higher order harmonics can be suppressed.

It should also be noted that the SLR itself also introduces an unwanted harmonic at 9.5 GHz. To overcome this interference, a hairpin resonator with its fundamental resonant frequency at 9.5 GHz is shunted at the feed line, as presented in the proposed antenna. The hairpin resonator introduces a notch-band at 9.5 GHz, which is used to eliminate the interference at that band. As a result, this antenna can achieve an excellent out-of-band rejection up to 12 GHz. Compared with the traditional method in [12], the harmonics are suppressed without increasing the footprint of the antenna. In addition, the frequency response, including the bandwidth and the frequency selectivity, are significantly improved.

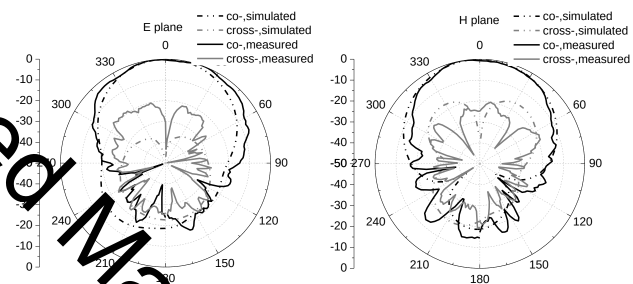
III. RESULTS AND DISCUSSION

The simulated and measured S_{11} of the proposed filtering antenna are presented in Fig. 5. A broad frequency range from 3 to 12 GHz was tested to show the harmonic suppression performance. The measured result agrees very well with the simulation with dual operation bands from 3.5 to 3.65 GHz and 5.1 to 5.3 GHz were achieved. The minor discrepancy between the simulation and the measurement is attributed to the fabrication errors. At the both bands, 2^{nd}-order response with two reflection zeros are identifiable. This results in improved bandwidth and filtering performance. Out of the bands, the antenna exhibits wideband harmonic suppression up to 12 GHz.



(a) (b)

Fig. 6. The normalized simulated and measured radiation patterns at 3.6 GHz: (a) E plane, (b) H plane.



(a) (b)

Fig. 7. The normalized simulated and measured radiation patterns at 5.2 GHz: (a) E plane, (b) H plane.

Fig. 6(a)-(b) shows the normalized simulated and measured co- and cross-polarization radiation patterns at 3.6 GHz in the E (XOZ) and H plane (YOZ), respectively. The antenna exhibits a radiation in broadside direction with a cross polarization discrimination (XPD) of -25 dB in both planes. The E and H plane radiation patterns at 5.2 GHz are presented in Fig. 7. It is observed that the measured results agree well with simulations. Compared with the U-slot antenna in [3], the XPD of this antenna is significantly improved, especially in the directions offset the broadside. The discrepancy between the simulated and measured patterns, especially the nulls in the backward

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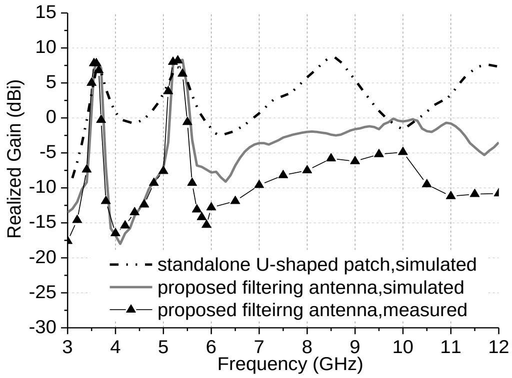

Fig. 8. The simulated and measured gain of the proposed dual-band filtering antenna.

TABLE II
COMPARISON WITH OTHER DUALBAND PATCH ANTENNAS

Types of antennas	Harmonics suppression	Polarization at two bands	Gain (dBi) (f_L/f_H)	XPD (dB) (f_L/f_H)
Ref. [13]	No	different	-1.8/1.1	-10/-22
Ref. [14]	No	consistent	-4.0/3.8	NA
This work	Yes	consistent	7.5/8.0	-40/-30

radiation, is mainly attributed to the influence of measurement devices and the cables behind the antenna.

Fig. 8 shows the simulated and measured realized gains of the proposed dual-band filtering antenna from 3 to 12 GHz. For comparison, the simulated gain of a standalone U-slot patch antenna is also included. The proposed antenna achieves the gains of 6.5 and 7 dBi at low- and high-band, respectively. At the harmonics of 8.5 and 11.7 GHz, the traditional U-slot patch antenna has a gain of 7.5 dBi. However for the proposed filtering antenna, the gain drops sharply to below -7.5 dBi as the frequency offsets by 5.6% from the two central frequencies. At the two harmonic bands, the simulated and measured gains are significantly reduced to below -2 and -5 dBi, respectively. This demonstrates that the proposed antenna has excellent frequency selectivity and out-of-band harmonic suppression over a wideband.

Table II compares the proposed dual-band filtering antenna with the other two reported dual-band filtering antennas in [13] and [14]. The comparison focuses on the harmonic suppression, polarization, gain and XPD at the two bands. This comparison shows that this work exhibits an improved gain and XPD at the two operation bands. The works in [13] and [14] lack the investigation of harmonic suppression and the gains are relatively lower than a traditional patch antenna. In addition, the design in [13] exhibits different polarizations at the two bands, and thus the technical contribution may be insufficient.

IV. Conclusion

In this communication, a novel dual-band filtering antenna has been proposed by integrating a dual-mode resonator in the U-slot patch antenna design. The U-slot antenna as well as the resonator have been investigated. The proposed antenna exhibits an improved 2nd-order filtering response with two reflection zeros in both bands, which results in enhanced bandwidth and frequency selectivity. The bandwidth can be tuned by adjusting the coupling strength between the SLR and the patch. In addition, the harmonic suppression over a broadband has been studied. Simulated and measured results agree very well, showing an excellent frequency response in terms of impedance matching, bandwidth, frequency selectivity, out-of-band rejection, radiation and gain.

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