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CPW-Fed Stub-Loaded Slot Dipole Antenna Design for Dual-Band Operation

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Abstract—A novel uniplanar slot dipole antenna fed by a coplanar waveguide (CPW) is proposed for dual-band operation. The frequency ratio between the first spurious and fundamental modes of the slot dipole antenna can be conveniently adjusted with the use of four slot stubs introduced on its two arms. Furthermore, the radiation patterns at the first spurious mode are modified by adding four parasitic slots along its two arms to resemble those of the fundamental mode. Under the assistance of the slot stubs together with the parasitic slots, another resonant mode can be generated and merged with the first spurious mode, and therefore improve the bandwidth significantly. An antenna prototype was fabricated and measured to validate the design concept. The measured results show that dual-band operation with 10-dB impedance bandwidths of 2.99–3.83 GHz (24.6%) and 5.21–6.89 GHz (27.8%) has been obtained. The antenna has stable broadside and bidirectional radiation patterns with low cross-polarization components over the two operating bands.

1. INTRODUCTION

The demand of antennas with multiple operation bands, wide bandwidth, high efficiency, compact size, and low cost has been increasing rapidly. Coplanar waveguide (CPW)-fed slot antennas have numerous advantages such as uniplanar structure, wide bandwidth, ease of fabrication, and integration with other circuitries, and recently has attracted much attention. Consequently, various attractive multi-band CPW-fed slot antennas have been proposed [1–9]. A dual-band radial slot antenna with bandwidths of 9.7% and 23.2% was presented [1]. An aperture-coupled slot antenna was designed to achieve tri-band operation with bandwidths of 6.7%, 6.0%, and 15.2% [2]. A dual-band slot-F-shaped-monopole hybrid antenna was proposed with bandwidths of 9.1% and 11.1% [3]. A quad-band slot antenna consisting of three L-shaped slots and one rectangular slot was presented for W-WiMAX/WLAN applications [4]. The first spurious mode of the slot dipole antenna has been utilized to achieve dual-band operation [5]. Four parasitic slots were employed to modify the radiation patterns at the first harmonic mode to resemble those of the fundamental mode. Its measured bandwidths are 17.4% and 8.8%, respectively. Later, a stepped-impedance slot dipole antenna with flexible frequency ratios was investigated for dual-band operation [6]. Its measured bandwidths are 12.5% and 8.0%, respectively, for the lower and upper bands.

The aforementioned antennas, however, have relatively narrow bandwidths [1–6]. Therefore, a variety of techniques have been studied to improve bandwidth. In [7], multi-resonant modes were excited by a couple of dual-folded slots, and thus its bandwidth was greatly increased to be 66.8%. The bandwidth for the lower band, however, is as narrow as 9.5%. In [8], a novel feed mechanism composed of an arc-shaped tuning stub and a 50-Ω transformer was used to improve the bandwidths to be 30.8% and 24.0%, respectively, for the lower and upper bands. A rhombus slot antenna with rhombic ring

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feed structure and rectangular bulges was designed for dual-band operation [9]. The antenna achieved bandwidths of 24.7% and 26.3% for the lower and upper bands, respectively. Unfortunately, the co- and cross-polarization components of these antennas [7–9] have comparable intensities over the operating bands which would reduce their applications.

In this paper, a uniplanar CPW-fed stub-loaded slot dipole antenna is proposed for dual-band operation. By symmetrically introducing four slot stubs on its two arms, flexible frequency ratios between the first spurious and fundamental modes can be achieved. Four parasitic slots are further added along its two arms to tackle the null radiation problem in the broadside directions for the first spurious mode [5]. It is worth mentioning that the parasitic slots, different from [5, 6] and together with the slot stubs, also help to excite another resonant mode in the upper band. This resonant mode merges with the first spurious mode, and thus improve the bandwidth of the upper band significantly. Measured results show that dual-band operation with bandwidths of 2.99–3.83 GHz (24.6%) and 5.21–6.89 GHz (27.8%) has been obtained. Over each operating band, the antenna exhibits stable broadside and bidirectional radiation patterns and low cross-polarization components.

2. ANTENNA DESIGN AND DISCUSSIONS

2.1. Antenna Configuration

Figure 1 presents the configuration of the proposed dual-band CPW-fed slot dipole antenna, which consists of a conventional 50-Ω CPW-fed slot dipole and a couple of twin slots including four slot stubs and four parasitic slots. The antenna is etched on FR-4 substrate with relative permittivity $\varepsilon_r = 4.3$, loss tangent $\tan\delta = 0.02$, thickness $h = 1.6$ mm, and size $W \times L = 40\,\text{mm} \times 80\,\text{mm}$. The widths of the strip and gap (S and G) of the 50-Ω CPW feed line are 3.0 mm and 0.3 mm, respectively. The length of the slot dipole L_D equals to a half guided-wavelength of its fundamental mode, and the width W_D of the slot dipole can be used to tune the input impedance of the antenna. Four slot stubs with length L_S, width W_S, and position D_S are symmetrically introduced on the two arms of the slot dipole. Furthermore, four parasitic slots with length L_P and width W_P are added symmetrically along the two arms of the slot dipole. Unlike [5], the length L_P of the parasitic slots does not necessarily equal to half of the slot dipole length L_D. The parasitic slots should be placed as closely as possible to the slot dipole arms, and therefore the width of the gap D is selected to be 0.2 mm. The parameters of the antenna were optimized using CST Microwave Studio and determined as follows (mm): $L_D = 26.5$, $L_S = 4.8$, $L_P = 14.8$, $W_D = 3.5$, $W_S = 1.9$, $W_P = 4.6$, $D = 0.2$, and $D_S = 15.0$.

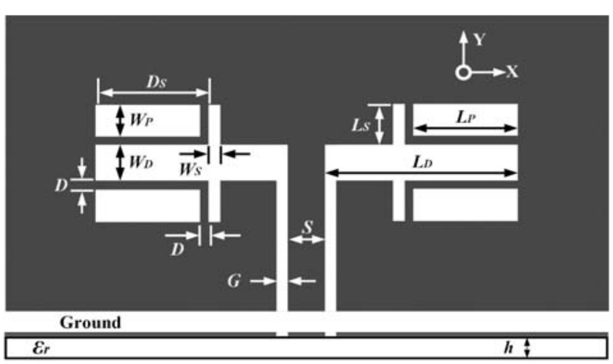

Figure 1. Configuration of the proposed dual-band CPW-fed slot dipole antenna.

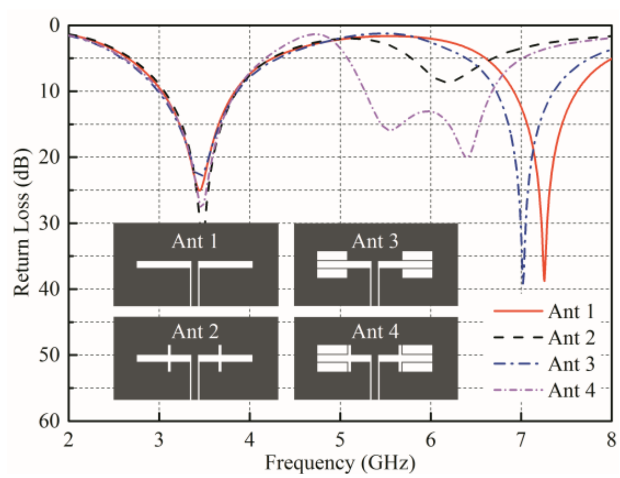

Figure 2. Simulated return loss for the proposed antenna with different slot embedment.

2.2. Design Evolution

To analyze the effects of the embedded slots on the performance of the antenna, the simulated return loss with different slot embedment are presented in Figure 2. It can be seen that, without the slot stubs and parasitic slots, the conventional CPW-fed slot dipole (denoted as Ant 1) has two resonant modes around 3.5 and 7.2 GHz, corresponding to its fundamental and first spurious modes, respectively. The frequency ratio between these two resonant modes is predictable and unchangeable, i.e., equal to two. As for the case with the slot stubs only (denoted as Ant 2), the first spurious mode of the slot dipole is reduced to be around 6.2 GHz with poor matching, whereas the fundamental mode is unchanged. We should note that flexible frequency ratios between the first spurious and fundamental modes can be achieved by varying the length and position of the slot stubs as shown in next section. The efficacy of the slot stubs can also be founded in [10]. Without the slot stubs, the parasitic slots (denoted as Ant 3) have negligible effect on the fundamental and first spurious modes of the slot dipole. The parasitic slots were firstly introduced to modify the radiation patterns at the first spurious mode [5], which will not be presented here for brevity. Finally, the proposed antenna (denoted as Ant 4), with the combination of the slot stubs and parasitic slots, has two closely generated resonant modes for the upper band, and therefore its bandwidth is significantly improved. Furthermore, among these two resonant modes, the upper mode corresponds to the first spurious mode of the slot dipole, whereas the lower mode is excited under the combined effect of the slot stubs and parasitic slots. In addition, the fundamental mode of the slot dipole is kept unchanged.

2.3. Parametric Studies

Parametric studies performed by simulations have been carried out to investigate the effects of the geometrical parameters on the performance of the proposed antenna. The simulated return loss when the length of the slot stubs L_S varies from 3.8 to 5.8 mm are shown in Figure 3. As L_S varies, the width of the parasitic slots is also changed as $W_P = L_S - D$ accordingly. Clearly, we can observe that the two resonant modes in the upper band are decreased with increasing L_S, achieving flexible frequency ratios between the upper and lower bands. The effect of the length L_P of the parasitic slots on the performance of the antenna is exhibited in Figure 4, wherein L_P is decreased from 14.8 to 13.2 mm. It is found that L_P should be as long as possible to effectively generate the second resonant mode and achieve a wider bandwidth in the upper band. Therefore, L_P is determined to be 14.8 mm, which means the width of the gap $(D_S - L_P)$ between the parasitic slots and slot stubs is $D = 0.2$ mm. Further examinations on the above parametric studies demonstrate that the performance of the lower band in terms of resonant frequency, bandwidth, radiation pattern, and gain remains constant. This implies that the proposed antenna allows one to allocate the two operating bands independently.

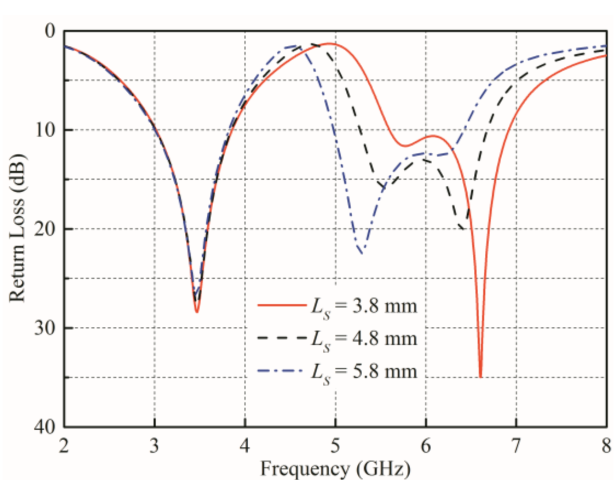

Figure 3. Simulated return loss for the proposed antenna with varying length L_S of the slot stubs

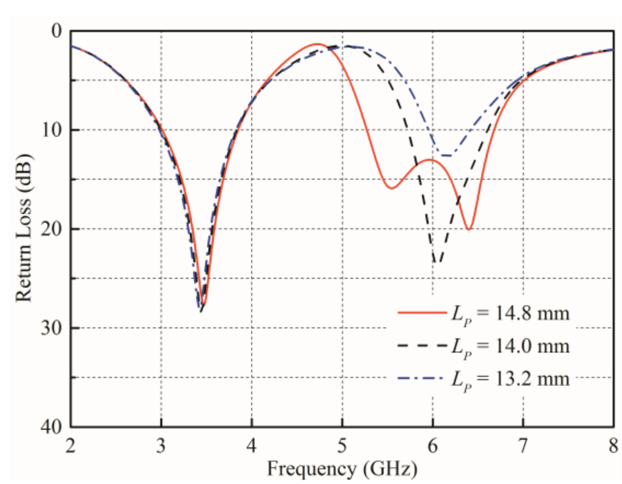

Figure 4. Simulated return loss for the proposed antenna with varying length L_P of the parasitic slots.

3. EXPERIMENTAL RESULTS

To validate the design concept, an antenna prototype shown in Figure 5 was implemented and measured using an Agilent E8363B network analyzer. Figure 6 presents the measured and simulated return loss of the proposed antenna. Clearly, very good agreement between the measured and simulated results has been obtained. The measured bandwidths (defined by $|S_{11}| \leq -10\,\mathrm{dB}$) are 24.6% (2.99–3.83 GHz) and 27.8% (5.21–6.89 GHz) for the lower and upper bands, respectively. Discrepancies are most likely due to the fact that the antenna was measured with a soldered subminiature A version (SMA) connector, whereas a waveguide port was used to feed the antenna during the simulations. In addition, the fabrication tolerances as well as the nonideal uniform substrate may also contribute to the differences.

Figure 7 illustrates the measured and simulated realized peak gains of the proposed dual-band slot dipole antenna. An average gain of 5.2 dBi (4.7–5.6 dBi) and 4.9 dBi (2.1–6.2 dBi) has been achieved for the lower and upper bands, respectively. In the upper band, especially beyond 6.2 GHz, it can be noticeably observed that the gain is decreased linearly when the frequency increases. This primarily results from the cross-polarization components produced by the radiations from the introduced slot stubs. The magnetic currents distributed along the twin slot stubs are out of phase, which cancel

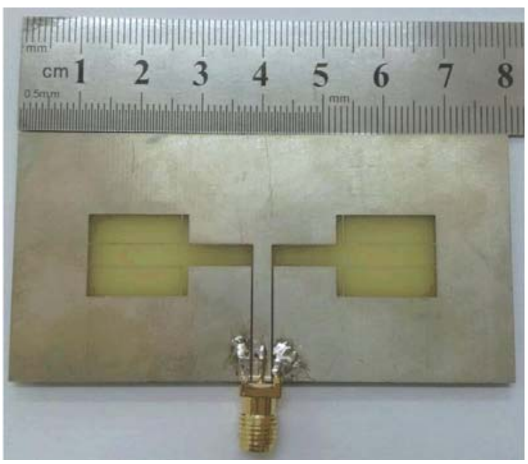

Figure 5. Photograph of the fabricated dual-band slot dipole antenna.

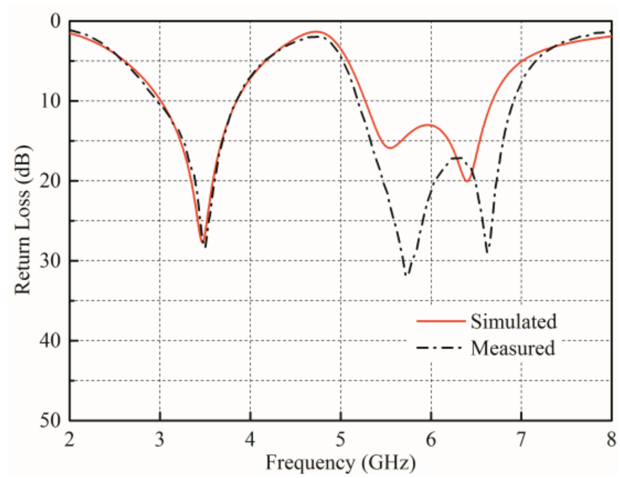

Figure 6. Simulated and measured return loss of the proposed antenna.

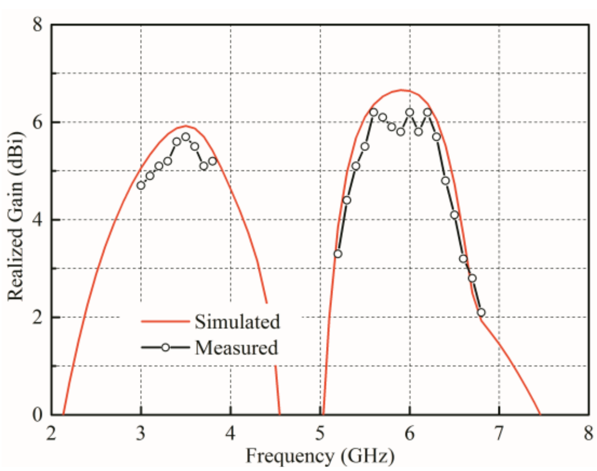

Figure 7. Simulated and measured realized gain of the proposed antenna.

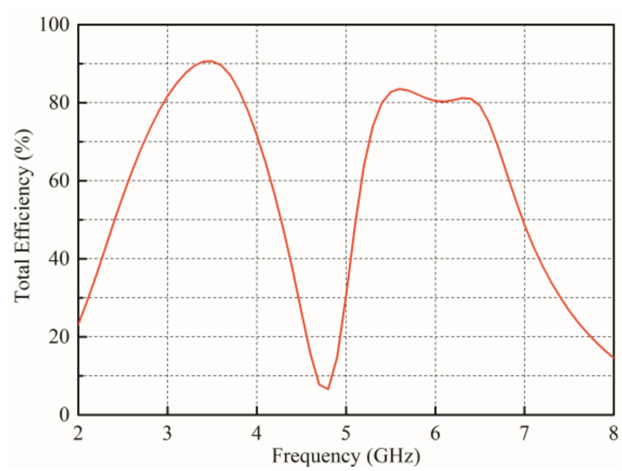

Figure 8. Simulated total efficiency of the proposed antenna.

out each other in the far-field, leaving the remaining in-phase magnetic currents along the slot dipole arms to radiate. As shown in Figure 8, the total radiation efficiencies obtained from the simulations maintain above 80% and 60% for the lower and upper bands, respectively. We further note that the gains measured at 3.5, 5.7, and 6.6 GHz are 5.7, 6.1, and 3.2 dBi, respectively, while the simulated total radiation efficiencies are 90%, 83%, and 74%, respectively.

The measured and simulated far-field radiation patterns of the proposed antenna at 3.5, 5.7, and 6.6 GHz are normalized and plotted in Figure 9. The measured radiation patterns agree well with the simulated ones. Across both operating bands, stable broadside and bidirectional radiation patterns have been obtained. Most importantly, we can clearly observe that all the radiation patterns have very low cross-polarization components. Note that the well-known null radiation problem in the broadside directions for the first spurious mode of the slot dipole has been simultaneously tackled by using the parasitic slots. Although the radiation patterns in the H-plane (x-z plane) should be symmetric, slightly asymmetric patterns were measured owing to the inevitable scattering from the feeding coaxial cable. Theoretically, no cross-polarization in the E-plane (y-z plane) ought to be radiated if the antenna is ideally symmetric with respect to the center line of the feeding CPW, which was also validated by

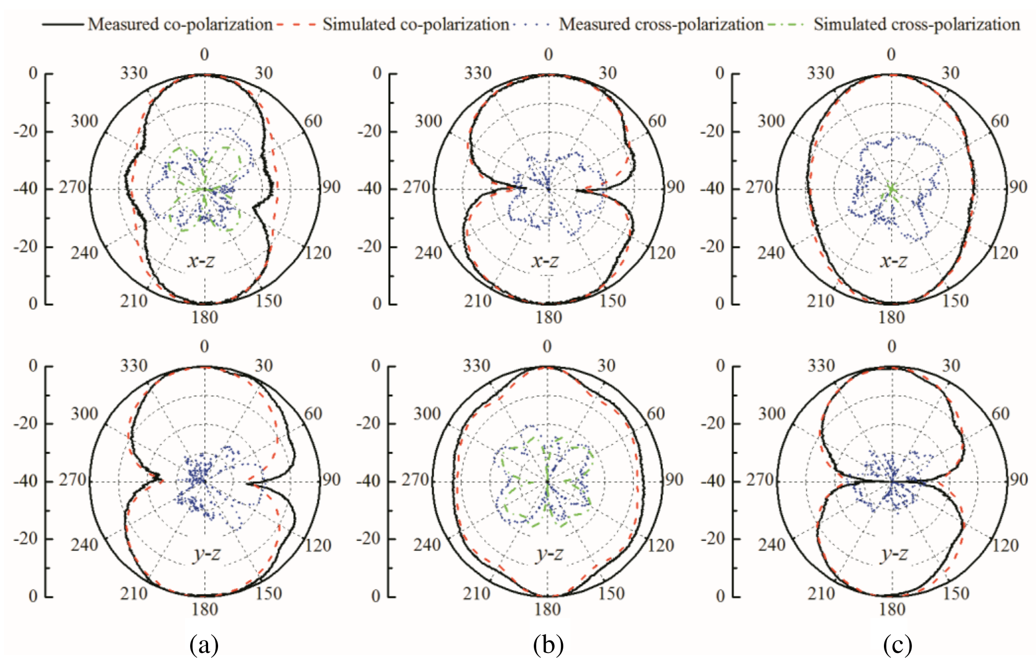

Figure 9. Simulated and measured radiation patterns of the antenna. (a) 3.5 GHz. (b) 5.7 GHz. (b) 6.6 GHz.

Table 1. Comparison of the proposed antenna with other reported CPW-fed dual-band slot antennas.

Ref.	Size (λ_0^2)	f_L (MHz)	BW (MHz, %)	f_H (MHz)	BW (MHz, %)	X-pol.
[1]	- - -	- - -	- - -, 9.7	- - -	- - -, 23.3	L
[3]	- - -	2482	226, 9.1	5408	599, 11.1	L
[5]	1.022×0.438	2190	380, 17.4	4675	410, 8.8	L
[6]	0.915×0.407	1525	190, 12.5	3500	280, 8.0	L
[7]	0.242×0.202	2420	210, 9.5	7210	4820, 66.8	H
[8]	0.648×0.648	2775	854, 30.8	5026	1206, 24.0	H
[9]	0.408×0.408	2450	607, 24.7	5500	1451, 26.3	H
This work	**0.909×0.455**	**3410**	**840, 24.6**	**6050**	**1680, 27.8**	**L**

simulations. Nonetheless, there may exist some fabrication errors, resulting in the unwanted slotline mode besides the dominant CPW mode [2]. The excited slotline mode gives rise to the magnetic current component along the y-axis, thus leading to cross-polarization radiation in the E-plane. It can be seen from Figure 9 that the cross-polarization radiation, however, are still maintained in rather lower levels in the E-plane within the two operating bands.

The advantages of the proposed antenna compared with other reported CPW-fed dual-band slot antennas are depicted in Table 1, where λ_0 is the wavelength of the center frequency in the lower band. When compared with the antennas reported in [1, 3, 5, 6], the proposed antenna obtains much wider bandwidths both in the lower and upper bands. Note that in [1, 3], several detailed data were not provided, and thus are marked with '- - -'. The antennas investigated in [7–9] have achieved similar bandwidth to that of the proposed antenna within a much more compact dimension. The proposed antenna, however, possesses much lower cross-polarization components, i.e., less than -20 dB, due to its highly symmetric structure. Note that the measured data regarding to the cross-polarization components were not given in the references, and hence, are compared qualitatively. The 'L' denotes that the cross-polarization components are no more than -15 dB, whereas 'H' denotes that the cross-polarization components are comparable with the co-polarization components.

4. CONCLUSION

A novel dual-band stub-loaded CPW-fed slot dipole antenna is proposed and discussed in this paper. It exhibits broad bandwidths, stable broadside and bidirectional radiation patterns, and low cross-polarization radiation within the two operating bands. In addition to its simple and uniplanar structure, the antenna also features that the lower and upper bands can be tuned independently. The measured bandwidths of the antenna are 840 MHz (24.6%) from 2.99 to 3.83 GHz in the lower band and 1.68 GHz (27.8%) from 5.21 to 6.89 GHz in the upper band. Therefore, the proposed antenna is much more suitable for modern practical multi-band applications.

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