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Quad-Band CPW-fed Monopole Antenna Based on Flexible Pentangle Loop Radiator

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***Abstract*—A novel low-profile monopole antenna fabricated on flexible substrate based on pentangle loop radiator (PLR) is presented and investigated in this letter. The proposed antenna is designed to operate at GPS L2 / Bluetooth / WiMAX / WLAN frequency bands. To maintain the small size of the antenna element, an improved pentangle loop is adopted and the higher-order modes are also utilized. Also, a pair of symmetrical V-shaped parasitic radiators and a modified rectangular ground plane of coplanar waveguide (CPW) feeding structure are used to improve the impedance matching at the higher bands. The proposed antenna is fabricated on flexible substrate which can be easy to integrate in wireless system. Its experimental results shows a good agreement with the simulated results.**

***Index Terms*—Flexible substrate, parasitic radiator, pentangle loop radiator (PLR), quad-band antenna.**

I. Introduction

Modern wireless systems are required to operate at multi-frequency bands to allow various communication services. Moreover, as several communication systems are integrated into a single device, the multi-band antennas become more desirable for the reduction of real estate and manufacturing costs. Multi-band antennas for wireless system application have been investigated widely in recent years [1-11]. A quad-band taper-fed antenna with good radiation performance is put forward in [6]. In [7], a coplanar waveguide (CPW)-fed planar antenna with triple-band operation for wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX) is presented, its undesired frequencies are strictly restricted in the stopband. In [8], a miniascape-like triple-band antenna is proposed. Multi-band characteristics have been realized in these antennas. However, these proposed antennas still have large size. In [9], a multiband planar antenna is proposed. Four effective current paths are realized by the long strip, the short strip, the interconnecting strip, and the extra radiating strip but the accuracy of the resonant passband is not high and the return loss is relative large. So, a quad-band antenna based on a Hilbert self-affine prefractal geometry is proposed in [10]. The quad-band behavior is achieved by the fractal of Hilbert curve. However, despite the small size of the structure, the passbands cannot be controlled separately. This letter presents a miniature multi-band antenna where the passbands can be controlled independently to achieve good impedance matching.

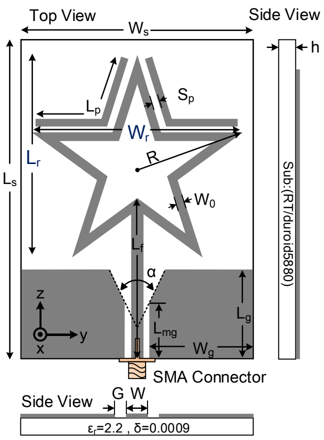

Fig. 1. Geometry of the proposed quad-band monopole antenna.

In this letter, a novel quad-band CPW-fed antenna is presented based on a flexible pentangle loop radiator (PLR). The proposed PLR can achieve the advantage of purposed size reduction, passbands controlled independently. In addition, two V-shaped parasitic radiators are used to improve the impedance matching at the third resonant band. The antenna provides four relative impedance bandwidths of 23.9%, 8.5%, 4.3%, and 7.1% with corresponding frequency bands of 0.94-1.20 GHz, 2.23-2.43 GHz, 3.58-3.74 GHz, and 4.93-5.29 GHz, respectively. Moreover, the advantages of light and flexible substrate, it makes the quad-band antenna achieve portable and conformal design, which enhances the practicability.

II. Antenna Design and Simulations

Fig. 1 shows the geometry of the proposed quad-band monopole antenna. It is consists of a main radiator of PLR, a pair of symmetrical V-shaped parasitic radiators and a modified rectangular ground plane. The PLR is derived from the conventional circular disc radiator, which was popularly used to design UWB antennas [12, 13]. Its fundamental

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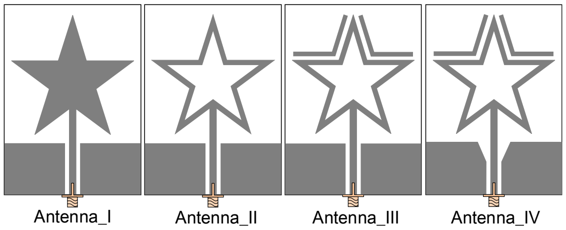

Fig. 2. Design evolution of the proposed quad-band antenna.

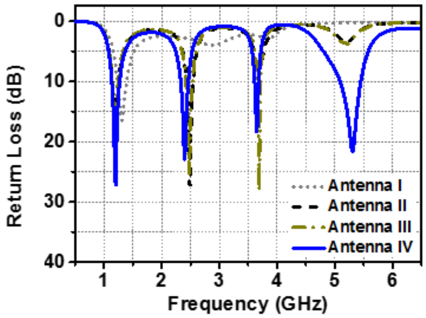

Fig. 3. Simulated return losses of the proposed quad-band antenna.

resonant frequency is determined by the physical dimensions R [14, 15]. The corresponding resonant frequency of the PLR can be defined as [16]

$$f_{\text{psp\_nm}} = \frac{pJ_{\text{nm}}c}{2\pi R\sqrt{\varepsilon_r \mu_r}} \tag{1}$$

where J_{nm} is the zeros of the derivative of the Bessel function of order n. R is the radius of the circular disc r. c is the speed of light in free space. ε_r and μ_r are the relative permittivity and relative permeability of substrate, respectively. p is the deformation factor, which is the degree of deformation about the evolution from the circular disc radiator to the pentangle loop radiator. For simplicity, the relative permeability $\mu_r = 1$ for dielectric substrate and the deformation factor $p = 0.57$ are chosen as the initial values. It is worth mentioning that, since the deformation factor p is less than 1, miniaturization can be achieved by using the PLR instead of the circular disc radiator.

The design evolution of the quad-band antenna is illustrated in Fig. 2 and the corresponding simulated return losses are presented in Fig. 3. Firstly, this initial antenna begins with a single-band pentangle patch antenna (namely Antenna I). Secondly, the pentangle patch radiator is replaced by a PLR (namely Antenna II). Its higher-order modes are excited by a large pentangle slot and it can be utilized to realize multi-band performance. Thirdly, two V-shaped parasitic elements are added to improve the impedance matching of the third band (namely Antenna III) and a triple-band antenna is achieved. Finally, a modified rectangle CPW ground structure is applied to improve the impedance matching of the fourth band (namely Antenna IV) and a quad-band antenna is realized. The proposed quad-band antenna is fed by a 50-Ω CPW feed-line structure, which is simulated by *HFSS.V13* [17].

To further investigate the characteristics of the proposed quad-band antenna, some parametric studies are carried out and the simulation results with the varied parameters are

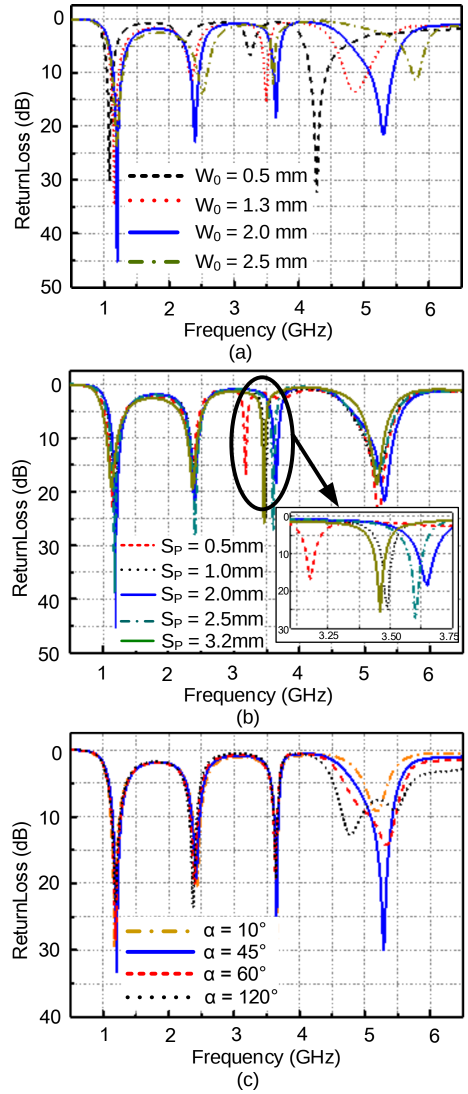

Fig. 4. Simulated return losses of the proposed quad-band antenna with (a) $S_P = 2.0$ mm, $\alpha = 45°$ with varied W_0; (b) $W_0 = 2.0$ mm, $\alpha = 45°$with varied S_P; (c) $W_0 = 2.0$ mm, $S_P = 2.0$ mm with varied α.

illustrated in Fig. 4.The fundamental radiation frequencies of the proposed quad-band antenna are mainly determined by the physical dimensions of the pentangle patch radiator. Fig. 4 (a) shows the simulated return loss of the proposed quad-band antenna versus the different values of W_0. Obviously, the radiation frequencies is shifted to higher operating frequency when W_0 changes from 0.5 mm to 2.5 mm. Therefore, we can adjust the operating frequencies by tuning W_0 and make them convenient for practice. Fig. 4(b) illustrates the effects of the parameter S_P. S_P is the coupling distance between the main radiator and the two V-shaped parasitic radiators. It is used to adjust the impedance matching of the third radiation band. When varying S_P with other parameters fixed, the third radiation band moves from 3.2GHz to 3.6GHz with S_p increasing from 0.5mm to 2.0mm and the other resonant modes almost keep unchanged. It is found that the parameter S_P mainly affects the third radiation band. That is to say, we can control the radiation frequency and bandwidth of the third

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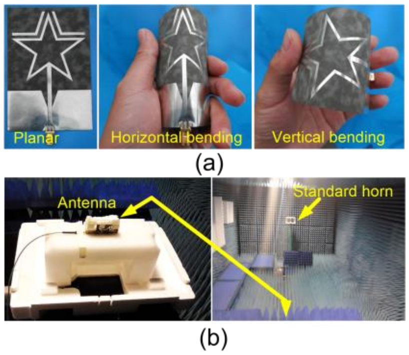

Fig. 5. Practical prototype of the flexible quad-band antenna. (a) Under planar, horizontal bending and vertical bending. (b) Under test on a rotating polystyrene arm in anechoic chamber.

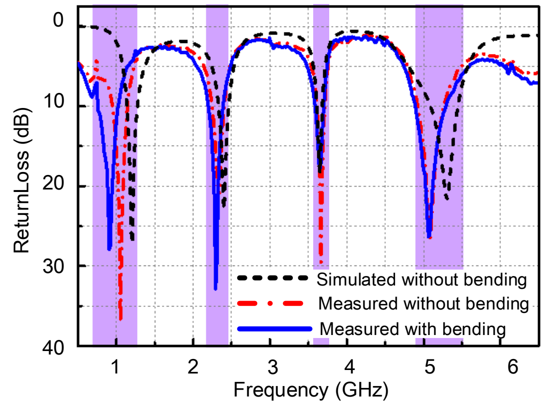

Fig. 6. Measured and simulated return losses of the quad-band antenna.

radiation band by tuning S_P. It makes the quad-band antenna owns multiple degrees of controlling each band separately. As indicated in Fig. 4(c), the modifying factor α has a great effect on impedance bandwidths of the fourth radiation band. Obviously, the corresponding impedance bandwidth becomes broaden when α increases. Therefore, the fourth radiation band can be tuned and optimized by the parameter α.

III. Experimental Results and Discussion

By optimizing the geometry parameters of the main radiator and two parasitic radiators, the optimal dimensions of the antenna are finally obtained as follows: L_s =90mm, W_s = 60mm, L_g = 28.5mm, W_g = 28.3mm, L_r = 54mm, W_r = 52mm, L_{mg} = 16.5mm, R = 27mm, W_0 = 2mm, S_p = 2.2mm, L_p = 34mm, L_f = 46mm, α = 45°, W = 3mm and G = 0.2mm. The proposed quad-band antenna is printed on a flexible Rogers RT/duroid 5880 substrate with relative permittivity ε_r = 2.2, loss tangent $tan\delta$ = 0.0009, thickness h = 0.127 mm. This substrate allows fold, rolling and bending for substantial flexibility. The overall size is 90 × 60 mm^2.

Fig. 5(a) shows a photograph of the fabricated quad-band antenna with flexible substrate. Measurements were carried out by using Agilent E5230A vector network analyzer. The radiation patterns and peak gains were measured in an anechoic chamber by a linearly polarized UWB standard gain horn antenna and an automated positioning system with full rotation angle capability, as shown in Fig. 5(b).

Measured return loss of the antenna is shown in Fig. 6. It demonstrates that the impedance bandwidths of the flexible quad-band antenna are about 260 MHz (0.94-1.20 GHz), 200 MHz (2.23-2.43 GHz), 160 MHz (3.58-3.74 GHz), and 360 MHz (4.93-5.29 GHz), corresponding to the impedance bandwidth of 23.9%, 8.5%, 4.3%, and 7.1% with respect to the appropriate resonant frequencies over the four radiation bands. Some frequency shifts in the first radiation band and the fourth radiation band are maybe caused by the poor smoothness property of the flexible substrate. Furthermore, it also can be found that the antenna under bending conditions exhibits a low susceptibility to impedance mismatching and resonant frequency shift to lower. It clarifies that the flexible quad-band antenna is practical in both flat and bending conditions.

TABLE I
Comparison Between The Proposed Multi-band Antenna And The Others

Ref.	Resonant band (GHz)	ε_r	Peak gain (dB)	Radiator size (λ_g×λ_g)
[7]	2.4/5.2/5.8	4.4	2.1/2.1/3.8	0.42×0.42
[9]	2.4/3.5/5.2/5.8	3	1.3/3.2/1.5/1.8	0.28×0.40
[11]	2.4/3.5/5.2/5.8	4.6	2.5/2.6/3.5/3.1	0.34×0.43
Proposed	1.2/2.4/3.5/5.2	2.2	5.47/5.88/1.97/3.56	0.31×0.32

Fig. 7 indicates the measured normalized far-field radiation patterns in E-plane and H-plane of the proposed quad-band antenna in flat and bending condition at 1.2, 2.4, 3.5, and 5.2 GHz, respectively. It is observed that the fabricated antenna shows a dipole-shaped radiation pattern in the E-plane and an omnidirectional radiation pattern in the H-plane for the four operating frequency bands. In addition, depending on the type of the dominant radiation mode, there is a little variation in the shape of the E-plane radiation pattern. Furthermore, Fig. 7 also shows the achieved normalized co- and cross-polarization patterns of the proposed quad-band antenna at four operating frequencies. It can be observed that the cross-polarization level is less than −20 dB across the entire operating frequency bands.

The antenna peak gains were measured by applying the gain comparison method, in which a pre-calibrated reference standard gain antenna is used to determine the absolute gain of the antenna under test. The measured results are shown in Fig. 8. The obtained average gains are about 5.47, 5.88, 1.97, and 3.56 dBi for the 1.2, 2.4, 3.5, and 5.2 GHz bands, respectively. As shown in Fig. 8, the proposed quad-band antenna has a little loss under bending condition compare with the antenna under flat condition.

Table I compares the performance of the proposed quad-band antenna with several previous works. It shows that the proposed design achieves excellent performance with the miniature size.

IV. Conclusions

In this letter, a novel quad-band CPW-fed monopole antenna is designed and analyzed. By using the flexible PLR,

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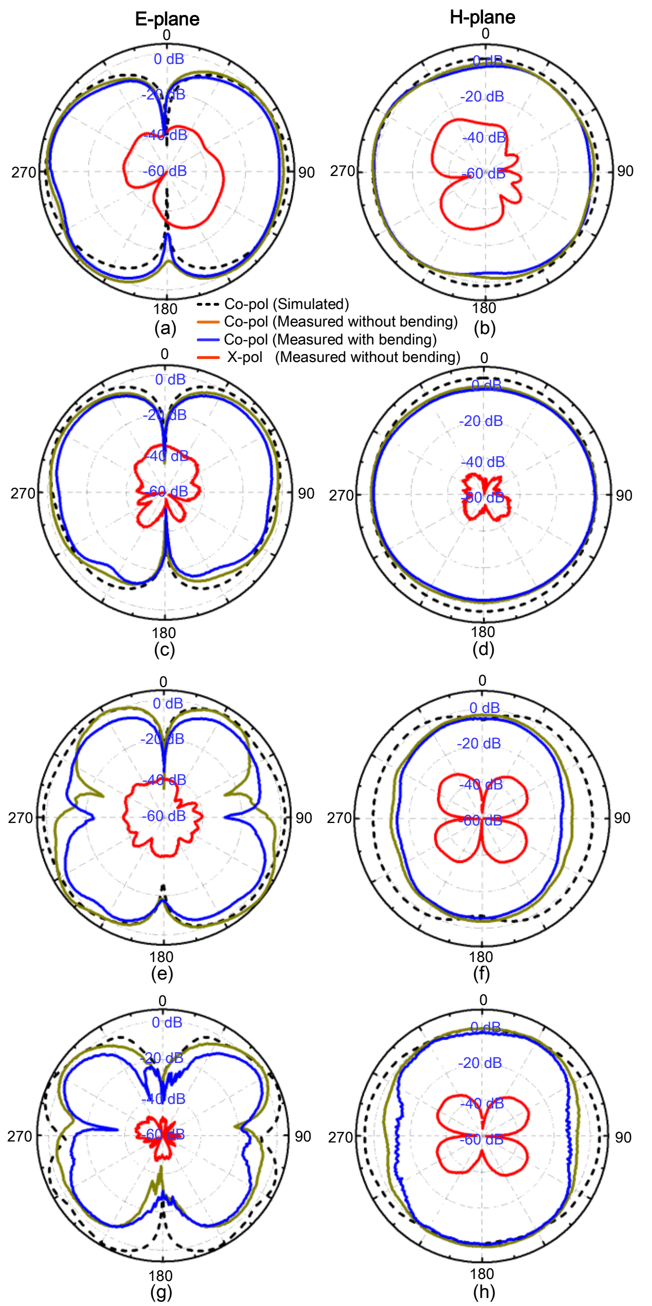

Fig. 7. Simulated and measured normalized radiation patterns of the proposed quad-band antenna in flat and bending condition at (a) 1.2 GHz E-plane, (b) 1.2 GHz H-plane, (c) 2.4 GHz E-plane, (d) 2.4 GHz H-plane, (e) 3.5 GHz E-plane, (f) 3.5 GHz H-plane, (g) 5.2 GHz E-plane, (h) 5.2 GHz H-plane.

a pair of V-shaped parasitic radiators and a modified CPW-fed structure, four operating bands covering GPS-L2, WiMAX, and WLAN antenna have been achieved. The measured return loss and radiation patterns are agreed reasonably well with simulated ones. Also, the antenna has a good performance under bending conditions. It could be a better candidate for multiband terminal design in conformal wireless applications.

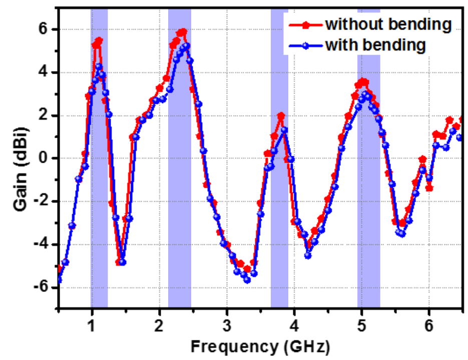

Fig. 8. Measured peak gains of the proposed quad-band antenna.

REFERENCES

[1] Q. Rao and W. Geyi, “Compact multi-band antenna for handheld devices,” *IEEE Trans. Antennas Propag*., vol. 57, no. 10, pp. 3337-3339, Oct. 2009.

[2] P. Wu, Z. Kuai, and X. Zhu, “Multi-band antennas comprising multiple frame-printed dipoles,” *IEEE Trans. Antennas Propag*., vol. 57, no. 10, pp. 3313-3316, Oct. 2009.

[3] H. Kanj and S. M. Ali, “Compact multi-band folded 3D monopole antenna,” *IEEE Antennas Wireless Propag. Lett*., vol. 8, pp. 185-188, 2009.

[4] J. Zhu, M. A. Antoniades, and G. V. Eleftheriades, “A compact tri-band monopole antenna with single-cell metamaterial loading,” *IEEE Trans. Antennas Propag*., vol. 58, no. 4, pp. 1031-1038, Apr. 2010.

[5] X. Wang, Y. Yu, and W. Q. Che, “A novel dual-band printed monopole antenna based on planar inverted-cone antenna (PICA),” *IEEE Antennas Wireless Propag. Lett*., vol. 13, pp. 217-220, 2014.

[6] C.-C. Chen, C.-Y.-D. Sim, and F.-S. Chen, “A novel compact quad-band narrow strip-loaded printed monopole antenna,” *IEEE Antennas Wireless Propag. Lett.*, vol. 8, pp. 974–976, 2009.

[7] H.-W. Liu, C.-H. Ku, and C.-F. Yang, “Novel CPW-fed planar monopole antenna for WiMAX/WLAN applications,” *IEEE Antennas Wireless Propag. Lett.*, vol. 9, pp. 240–243, 2010.

[8] C.-P. Deng, X.-Y. Liu, Z.-K. Zhang, and M. M. Tentzeris, “A miniascape-like triple-band monopole antenna for WBAN applications,” *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 1330–1333, 2012.

[9] A. Mehdipour, A.-R. Sebak, C. W. Trueman, and T. A. Denidni, “Compact multiband planar antenna for 2.4/3.5/5.2/5.8-GHz wireless applications,” *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 144–147, 2012.

[10] R. Azaro, F. Viani, L. Lizzi, E. Zeni, and A. Massa, “A monopole quad-band antenna based on a Hilbert self-affine prefractal geometry,” *IEEE Antennas Wireless Propag. Lett.*, vol. 8, pp. 177–180, 2009.

[11] X. Sun, G. Zeng, H. -C. Yang and Y. Li, A compact quad-band CPW-fed slot antenna for M-WIMAX/WLAN applications,” *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 395–398, 2012.

[12] K. Zhang, T. Wang, and L. L. Cheng, “Analysis of band-notched UWB printed monopole antennas using a novel segmented structure,” *Progress In Electromagnetics Research C*, vol. 34, pp. 13-27, 2013.

[13] C. -W. Zhang, Y. -Z, Yin, P. -A. Liu, and J. -J. Xie, “Compact dual band-notched UWB antenna with hexagonal slotted ground plane,” *Journal of Electromagnetic Waves and Applications*, vol. 27, pp. 215-223, 2013.

[14] J. Watkins, “Circular resonant structure in microstrip,” *Electron. Lett.*, vol. 5, no. 21, pp. 524–525, Sep. 1969.

[15] L.-M. Si, X. Lv, “CPW-fed multi-band omni-directional planar microstrip antenna using composite metamaterial resonators for wireless communication,” *Progress In Electromagnetics Research*, vol. 83, pp. 133–146, 2008.

[16] K. Chang, *Microwave Ring Circuits and Antenna*. New York: Wiley, 1996.

[17] High Frequency Structure Simulator. Ver. 13.0, ANSYS, Inc., Canonsburg, PA, USA, 2010