Progress In Electromagnetics Research Letters, Vol. 59, 15–20, 2016

Seven-Band Comb-Shaped Microstrip Antenna for Wireless Systems

Kaushik Mandal*

Abstract—This paper presents a very simple comb-shaped single layer microstrip patch antenna with seven operating bands for wireless systems. Eight symmetrical rectangular strips are connected by a single strip to achieve multiple operating bands. The proposed antenna provides maximum number of resonating bands compared to the antennas of its class. Effects of additional strips and the connecting strip on the antenna characteristics are studied. A prototype of the antenna is fabricated for experimental validation. The measured reflection coefficient (S_{11}) and radiation patterns are in good agreement with their simulated counterpart. Measured result shows that the proposed antenna can operate at seven different frequency bands 1.56–1.64 GHz, 1.76–1.94 GHz, 3.62–3.74 GHz, 4.43–4.48 GHz, 5.02–5.13 GHz, 5.48–5.62 GHz and 5.92–6.02 GHz. These bands cover some of the most useful bands for wireless systems such as GPS (1570.42–1580.42 MHz), DCS-1800 (1710–1880 MHz), PCS-1900 (1850–1990 MHz), WiMAX and WLAN.

1. INTRODUCTION

With growing demand of wireless communication systems, multiple-band microstrip patch antennas are now essential. There are several wireless communication standards, such as the global positioning system (GPS), DCS-1800, PCS-1900, IMT-2000/UMTS, ISM, Bluetooth, Worldwide interoperability for Microwave access (WiMAX), and Wireless Local Area Network (WLAN). It is desirable to integrate as many standards as possible into a single wireless device. The size and weight of an antenna are important for the antenna to be practical. A small-size, simple multiband antenna covering most of the wireless frequency bands is desirable.

Throughout the literature survey, different methods to achieve dual-band [1–3], tripleband [4–8] and four-band [9, 10] have been studied. To generate multiple operating bands, the most popular approach is to introduce slots on radiating patch or ground plane of the antenna or insert strips to a slot antenna. Annular-ring slot antenna suitable for 2.4/5-GHz dual-band operations with a dimension of 30 mm × 30 mm is proposed in [1]. Chakraborty et al. proposed a dual-band microstrip antenna [2] for IEEE 802.11a WLAN application using open-ended slot with slotted ground plane. A broadband U-slot patch antenna [3] converts to a triple-band (3.5–3.75 GHz, 4.85–5.2 GHz, and 5.5–5.7 GHz.) antenna by cutting two additional U-slots in the patch. An asymmetric M-shaped patch with shorting pin on the longer arm of the patch for the purposes of compactness and separating of the operational bands (2.38–2.49 GHz, 3.49–3.63 GHz and 5.57–6.20 GHz) is proposed in [4]. Liu et al. [5] proposed a triple-frequency (2.14–2.52 GHz, 2.82–3.74 GHz, and 5.15–6.02 GHz) monopole antenna that has a rectangular patch with dual inverted L-shaped strips and is fed by a cross-shaped microstrip with defected ground structure (DGS). A square slot, a pair of L-strips, and a circular shaped monopole radiator in [6] are used to produce triple band 2.14–2.52 GHz, 2.82–3.74 GHz, and 5.15–6.02 GHz with an overall dimension of 20 mm × 30 mm. A multiloop antenna [7] for triple-band operation in the sub-GHz range and a bow-tie dipole slot antenna [8] fed by coplanar waveguide (CPW) for triple-band (2.39–2.50 GHz, 3.38–3.79 GHz, and 4.87–6.23 GHz) operations are also investigated. A planar monopole four-band antenna

Received 8 January 2016, Accepted 18 February 2016, Scheduled 29 February 2016
* Corresponding author: Kaushik Mandal (kaushikrpe@gmail.com).
The author is with the Academy of Technology, West Bengal University of Technology, West Bengal, India.

(22 mm × 29 mm) consist of three radiating elements together with an additional strip to control the antenna performance is presented in Ref. [9]. More recently a four-band slot antenna [10] for the GPS, WiMAX, and WLAN systems is proposed. The antenna consists of a rectangular slot a T-shaped feed patch, an inverted T-shaped stub, and two E-shaped stubs to generate four frequency bands.

This paper presents a very simplely structured multiband single layer patch antenna without any DGS. Eight symmetrical rectangular strips on the opposite side of the infinite ground plane are connected by a single strip to achieve multiple operating bands. Effects of additional strips and the connecting strip on the antenna characteristics are studied. To confirm the simulated results, prototype of the antenna is fabricated and experimentally tested. The proposed antenna can operate at seven different frequency bands 1.56–1.64 GHz, 1.76–1.94 GHz, 3.62–3.74 GHz, 4.43–4.48 GHz, 5.02–5.13 GHz, 5.48–5.62 GHz and 5.92–6.02 GHz. The proposed antenna provides maximum number of resonating band compare to the antennas of its class [1–10].

This paper is organized as follows. Section 2 briefly describes the design scheme of the proposed antenna structure and associated parameters. Section 3 compares simulated results to measured results to prove the design concept. Finally, the concluding remarks are given in Section 4.

2. ANTENNA GEOMETRY

The geometry and dimensions of the proposed seven-band antenna is shown in Figure 1 where all the dimensions are in mm. An inexpensive FR4 substrate (79 mm × 65 mm) with dielectric constant $\varepsilon_r = 4.4$, thickness $h = 1.6$ mm and loss tangent = 0.02 is used for the design purpose. The objective is to design a multi-band antenna, so an array of multiple resonators of the same dimension has been considered. Eight symmetrical rectangular strips of dimension 4 mm × 25 mm are printed with an internal gap of 1 mm between them. These strips are connected with the help of a strip line of thickness 2 mm as shown in the Figure 1. When they are connected by another strip different current flow paths have been formed at different frequencies. These path lengths are not identical so it can provide multiple operating frequencies. The overall area of the patch is 39 mm × 25 mm. The antenna is fed by a co-axial probe at the 4th strip of the radiating patch. Dimensions, mentioned in Figure 1, are optimized after a large number of simulations, and finally the prototype is fabricated for the experimental verification. A photograph of the fabricated prototype is shown in Figure 1(c).

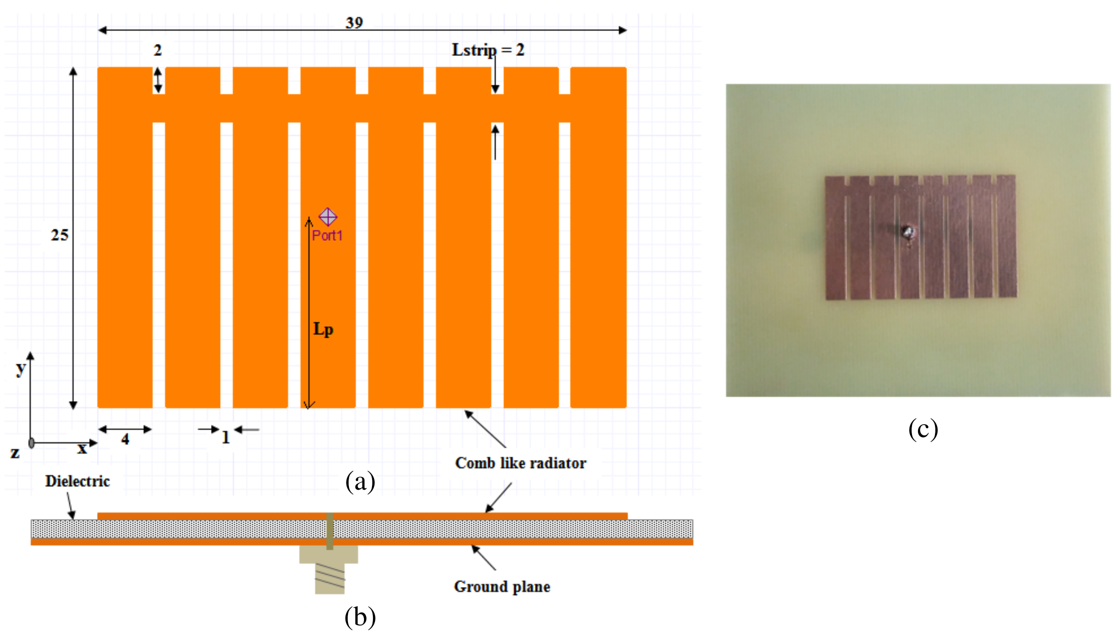

Figure 1. Geometry of the proposed seven-band antenna. (a) Top view, (b) side view and (c) photograph of the fabricated prototype. ($L_P = 14$ mm and $L_{\text{strip}} = 2$ mm).

3. RESULTS AND DISCUSSIONS

For proper impedance matching and optimizing various dimensions of the proposed antenna, a large number of simulations have been carried out using Method of Moments (MoM) based ANSOFT Designer. Knowledge about different parameters is very important because it provides the detailed insight into understanding the characteristics of the antenna. Some sensitive parameters have been investigated and the influences of such parameters on the antenna performance studied. Their effects are explained as follows.

3.1. Design Steps

Design of the proposed multiband antenna starts with a single rectangular strip (4 mm × 25 mm), and it provides a single band, centered at 3.1 GHz. As per the dimension of a single resonator, it should resonate at 3.091 GHz. In this case, it resonates at 3.1 GHz. Gradually more symmetrical rectangular

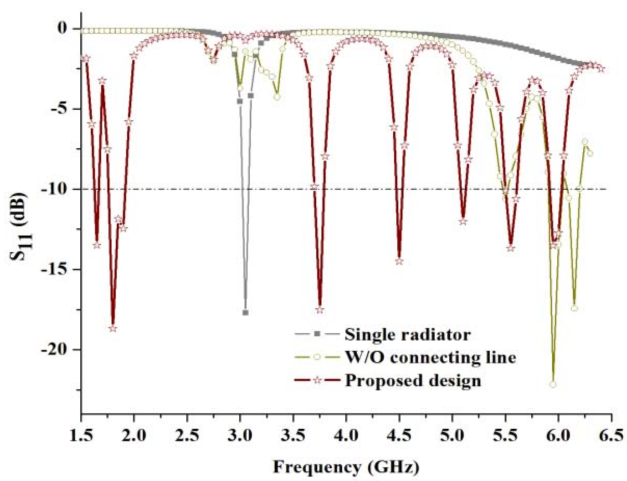

Figure 2. Stepwise improvement of reflection coefficient (S_{11}).

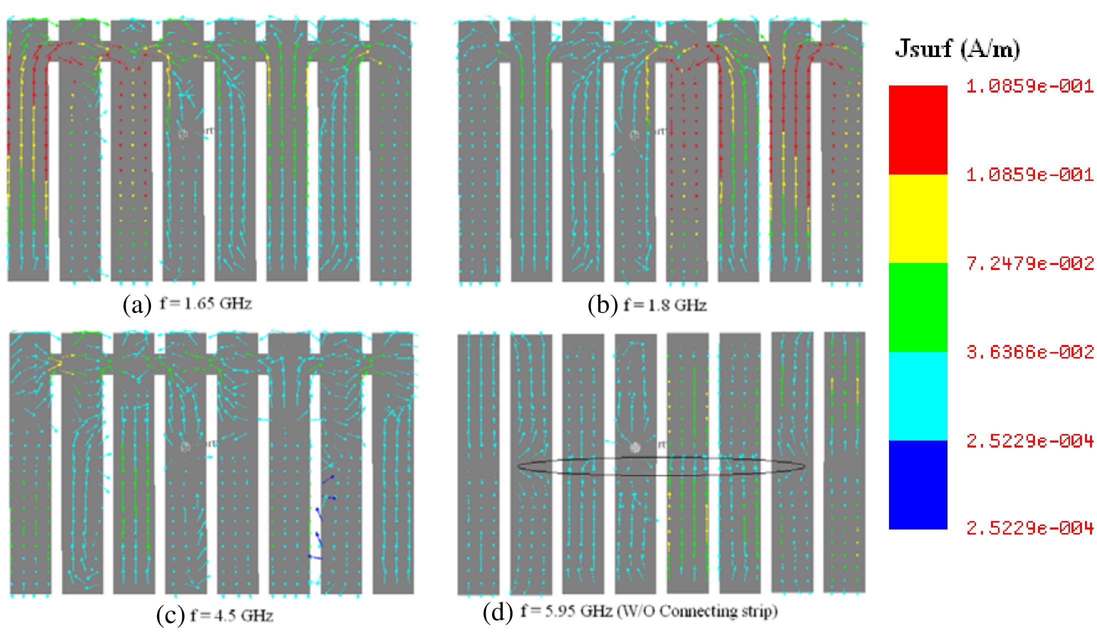

Figure 3. Surface current distributions on the antenna for (a) $f = 1.65$ GHz, (b) $f = 1.65$ GHz, (c) $f = 4.5$ GHz, and (d) design without connecting strip at $f = 5.95$ GHz.

strips are added on both sides of the main strip. With eight symmetrical strips but without connecting line, it provides only two bands as presented in Figure 2. Finally, the strips are connected by a strip line, and it provides seven operating bands. The stepwise improvement of reflection coefficient (S_{11}) is shown in Figure 2.

The surface electrical currents for different frequencies and design steps are shown in Figure 3, to clarify the phenomenon behind this multiple operating bands. For the proposed design, the first resonating frequency is 1.65 GHz which is little higher than half of 3.1 GHz. It is seen in Figure 3(a) that the current flows through the inverted U-shaped path formed by the first and third strips and connecting strip. The total length of the inverted U-shaped path is roughly double of a single strip; as a result, the first resonating frequency (1.65 GHz) is slightly higher than half of 3.1 GHz.

The second operating band ($f = 1.8$ GHz) is mainly due to the higher order strips as shown in the Figure 3(b). Discontinuity in the current distribution is highlighted by a circle for the design without connecting strip in Figure 3(d). By connecting eight strips, the surface currents distribution becomes regular. It is understood that by using this connecting strip, additional resonant modes can be excited as the electrical path length is increasing.

3.2. Width (L_{strip}) Variation of Connecting Line

The width of connecting line (L_{strip}) plays a significant role in antenna performance. With $L_{\text{strip}} = 1$ mm, the first and last bands are prominent, and the middle bands are negligible. For $L_{\text{strip}} = 3$ mm, the

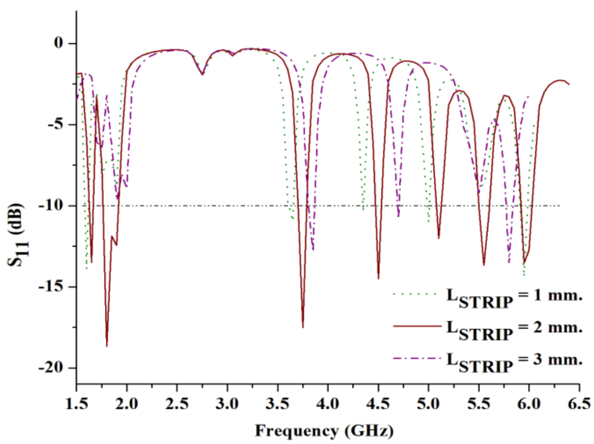

Figure 4. Variation of S_{11} characteristics with different L_{strip}.

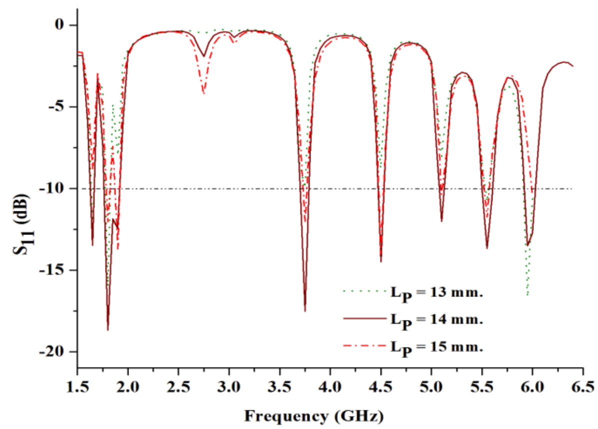

Figure 5. Variation of S_{11} characteristics with different L_P.

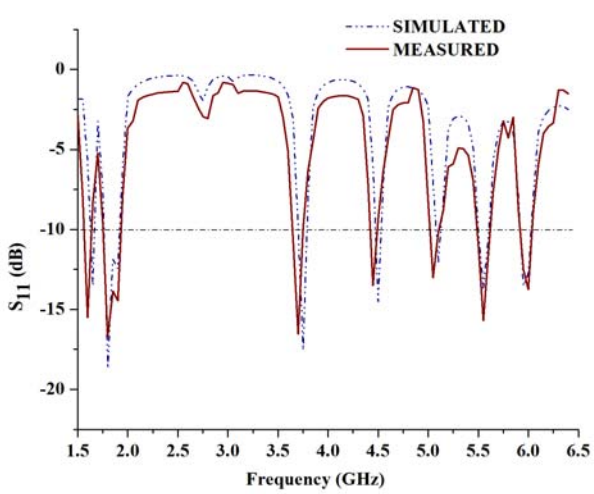

Figure 6. Comparison between simulated and measured S_{11} characteristics.

second and fourth bands are prominent, but for $L_{\text{strip}} = 3\,\text{mm}$, impedance matching is better and provides seven operating bands. This is summarized in Figure 4.

3.3. Variation of Feeding Position (L_P)

The position of co-axial feed also plays an important role for better impedance matching. With $L_P = 13\,\text{mm}$, the second and last two bands appear. For $L_P = 15\,\text{mm}$, all bands appear, but impedance matching is poor. Finally, for $L_P = 14\,\text{mm}$, impedance matching is maximum and provides seven

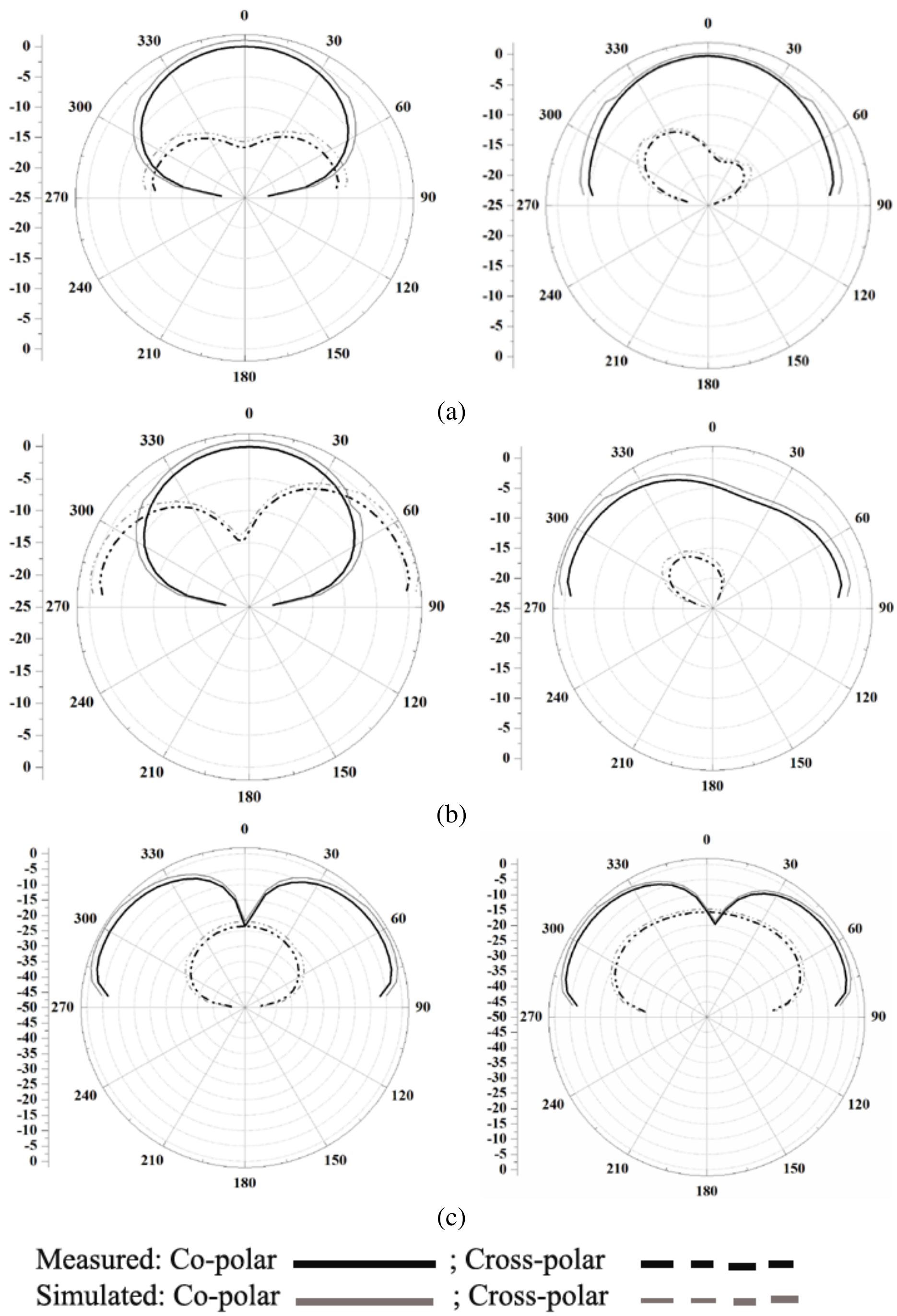

Figure 7. The simulated and measured radiation patterns, E-plane (left) and H-plane (right), for the proposed antenna. (a) 1.65 GHz, (b) 1.8 GHz and (c) 5.95 GHz.

operating bands. This is summarized in Figure 5.

With these parametric studies, the dimensions of the proposed antenna are finalized, and a prototype is fabricated for experimental verification. Figure 6 shows the comparative plot of simulated and measured reflection coefficients (S_{11}). S_{11} is measured by using a vector network analyzer. Measured result shows that the proposed antenna can operate at seven different frequency bands 1.56–1.64 GHz, 1.76–1.94 GHz, 3.62–3.74 GHz, 4.43–4.48 GHz, 5.02–5.13 GHz, 5.48–5.62 GHz and 5.92–6.02 GHz. These bands cover some of the most useful bands for wireless systems such as GPS (1570.42–1580.42 MHz), DCS-1800 (1710–1880 MHz), PCS-1900 (1850–1990 MHz), WiMAX and WLAN. Comparison shows that the measured result reasonably agrees with the simulated one throughout the band. However, the measured result displays a slight difference at operating frequencies. The disagreement between simulation and measurement results may be mainly due to the measured environment effect and effect of the SMA connector.

Figure 7 shows the simulated and measured radiation patterns including the co- and cross-polarizations in two principal planes — namely, E-plane (y-z plane) and H-plane (x-z). More significantly, the radiation patterns in both planes have low cross-polarization values, and there are no back lobes. At higher frequencies, cross-polarization level is higher, and maximum radiation takes place in the directions of $+50^\circ$ and -50°. The proposed antenna provides a favorable radiation pattern.

4. CONCLUSIONS

A very simple coaxial probe fed comb-shaped seven-band patch antenna is presented. The presence of connecting strip and number of rectangular strips appear as critical parameters. The proposed antenna successfully operates at seven different bands without any additional layers, complicated structure and DGS. The proposed antenna provides maximum number of resonating bands compare to the antennas of its class. Favorable radiation pattern and sufficient reflection coefficient at the operating bands make this antenna a suitable candidate for the multifunction wireless devices.

REFERENCES

1. Sze, J.-Y., C.-I. G. Hsu, and S.-C. Hsu, "Design of a compact dual-band annular-ring slot antenna," *IEEE Antennas and Wireless Propagation Letters*, Vol. 6, 423–426, 2007.
2. Chakraborty, U., A. Kundu, S. K. Chowdhury, and A. K. Bhattacharjee, "Compact dual-band microstrip antenna for IEEE 802.11a WLAN application," *IEEE Antennas and Wireless Propagation Letters*, Vol. 13, 407–410, 2014.
3. Mok, W. C., S. H. Wong, K. M. Luk, and K. F. Lee, "Single-layer single-patch dual-band and triple-band patch antennas," *IEEE Trans. Antennas and Propagation*, Vol. 61, 4341–4344, 2013.
4. Peng, L., C.-L. Ruan, and X.-H. Wu, "Design and operation of dual/triple-band asymmetric M-shaped microstrip patch antennas," *IEEE Antennas and Wireless Propagation Letters*, Vol. 9, 1069–1072, 2010.
5. Liu, W.-C., C.-M. Wu, and Y. Dai, "Design of triple-frequency microstrip-fed monopole antenna using defected ground structure," *IEEE Trans. Antennas and Propagation*, Vol. 59, 2457–2463, 2011.
6. Hu, W., Y.-Z. Yin, P. Fei, and X. Yang, "Compact triband square-slot antenna with symmetrical L-strips for WLAN/WiMAX applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, 462–465, 2011.
7. Genovesi, S., A. Monorchio, and S. Saponara, "Compact triple-frequency antenna for sub-GHz wireless communications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, 14–17, 2012.
8. Ge, J. and L. Jin, "A compact multiband bow-tie dipole slot antenna for WLAN and WiMAX applications," *Progress In Electromagnetics Research Letters*, Vol. 56, 17–23, 2015.
9. Mehdipour, A., 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 and Wireless Propagation Letters*, Vol. 11, 144–147, 2012.
10. Cao, Y. F., S. W. Cheung, and T. I. Yuk, "A multiband slot antenna for GPS/WiMAX/WLAN systems," *IEEE Trans. Antennas and Propagation*, Vol. 63, 952–958, 2015.