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Research Article

Analysis of a Compact Wideband Slotted Antenna for Ku Band Applications

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The design procedure and physical module of a compact wideband patch antenna for Ku band application are presented in this paper. Finite element method based on 3D electromagnetic field solver has been utilized for the designing and analyzing process of proposed microstrip line fed modified *E-H* shaped electrically small patch antenna. After successful completion of the design process through various simulations, the proposed antenna has been fabricated on printed circuit board (PCB) and its characteristics have been studied. The parameters of the proposed antenna prototype have been measured in standard far-field rectangular shape anechoic measurement compartment. It is apparent from the measured antenna parameters that the proposed antenna achieved almost stable variation of radiation pattern over the entire operational band with 1380 MHz of −10 dB return loss bandwidth. The maximum gain of 7.8 dBi and 89.97% average efficiency within the operating band from 17.15 GHz to 18.53 GHz ensure the suitability of the proposed antenna for Ku band applications.

1. Introduction

In conjunction with the growing development of wireless communication, wideband antennas have become a significant component where the increasing demands of antenna terminals are integrated in one compact module for wide range of application [1]. The planar patch antennas can achieve wide bandwidth along with its simple design structure, compact size, low profile, ease integration, and fabrication process, for which it is a favorable candidate for wideband applications in the field of wireless communication [2]. Advances in wireless communications have introduced tremendous demands in the antenna technology. It also paved the way for wide usage of mobile phones in modern society resulting in mounting concerns surrounding its harmful radiation [3]. In recent times, several types of planar antennas have been introduced and studied by many researchers due to their excellent properties [4]. Extensive analysis of the review process finds monopole antennas of various geometrical shapes as, for example, triangular [5], pentagonal [6], hexagonal [7], elliptical [8], ring/split ring [9], annular ring [10], circular disc [11], modified English alphabet [12–15], and the dipole antenna configuration like bow-tie antennas [16].

Furthermore, a considerable research concentration has been given into microstrip patch antennas. A $79 \times 38\,\mathrm{mm}^2$ *E-H* shaped *L*-probe microstrip patch antenna has been introduced and achieved bandwidth 440 MHz with peak gain 9.5 dBi [17], a $58 \times 58\,\mathrm{mm}^2$ wideband dual-polarized patch antenna has been proposed and obtained 1.03 GHz bandwidth with 9.3 dBi gain [18], and $12 \times 16\,\mathrm{mm}^2$ ultrawideband antenna with dual-notched band characteristics has been offered and achieved 8.3 GHz bandwidth with 3.8 dBi maximum gain [19]. Nonetheless, there is still scope of research effort to be given to improve gain, efficiency, and bandwidth alongside with the miniaturization of overall antenna size.

In this study, a $20 \times 14\,\mathrm{mm}^2$ modified *E-H* shaped compact printed antenna has been proposed and achieved low physical planar profile, adequate impedance bandwidth, and almost steady radiation pattern. The proposed slotted planar patch antenna comprises of microstrip line fed modified *E-H* shaped radiating patch and ground plane. To attain the desired resonance frequency, the patch length, cutting slots, and feeding position have been adjusted accordingly through parametric analysis during simulation process. Measured return loss, radiation pattern, gain, radiation efficiency, and impedance characteristics are presented and discussed. The measured results show good impedance matching at the operating band with reduced radiation loss which makes the proposed antenna apposite for Ku band application.

2. Designing Antenna Module

The proposed modified *E-H* shaped microstrip line fed patch antenna is designed and studied by employing finite element method based commercially available 3D electromagnetic field solver, namely, HFSS. The design configuration starts with 20 mm (1.18λ) long and 14 mm (0.82λ) planar modified *E-H* shape radiating patch. In the proposed antenna design, λ is corresponding to the wavelength at the center frequency 17.75 GHz. The modified *E-H* profile is attained by cutting two slots from rectangular shape. Since the antenna performance criteria depend on the overall size of the radiating patch, it is figured out by using mathematical model. In terms of determining bandwidth and resonance frequency, the length of the radiating element has influential effect other than the width.

The analytical study shows that the width of the patch has insignificant effect on obtaining resonance and through mathematical modeling the patch width for desired frequency can be calculated by utilizing the already established mathematical equations [21]. The available equations are applicable for conventional rectangular radiating patch; however, the geometric shape and dimension of the proposed antenna have been achieved by modifying, testing, and running the method:

$$W = \frac{c}{2f_o}\sqrt{\frac{\varepsilon_r + 1}{2}}, \quad (1)$$

$$L = \frac{c}{2f_o\sqrt{\varepsilon_r}} - 2\Delta l. \quad (2)$$

The usual symbol W is the width and L is the length of the radiating patch in (1) and (2), respectively; whereas c is the speed of light, f_o is the center frequency, ε_r is the relative dielectric constant, and Δl is the change in length. The effective dielectric constant ε_{eff} can be formulated as

$$\varepsilon_{\text{eff}} = \frac{1}{2}(\varepsilon_r + 1) + \frac{1}{2}(\varepsilon_r - 1)\sqrt{\left(1 + \frac{10h}{W}\right)}, \quad (3)$$

where h denotes the thickness of the substrate used.

Because of the effect of fringing field surrounding the radiating patch, the electrical dimension of the antenna seems to be bigger than the physical dimension. The change of length of Δl due to the effect of fringing field can be presented by the following:

$$\Delta l = 0.412h\frac{(\varepsilon_e + 0.3)[w/h + 0.8]}{(\varepsilon_e - 0.258)[w/h + 0.8]}. \quad (4)$$

The dimension of the microstrip line is optimized through design and simulation to obtain enhanced impedance matching over the operating frequency bands. The designing process of the antenna is started with the estimating of the overall dimension of radiating patch which is chosen to be of inverted A shape that is responsible for providing compact size of the antenna.

The parametric study has been conducted on width and length of 2 slots. Four combinations $W3 = W6 \times L3 = L6$

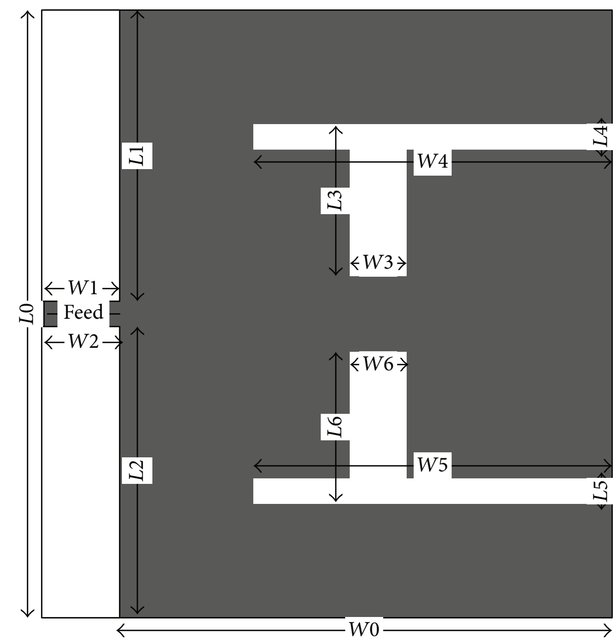
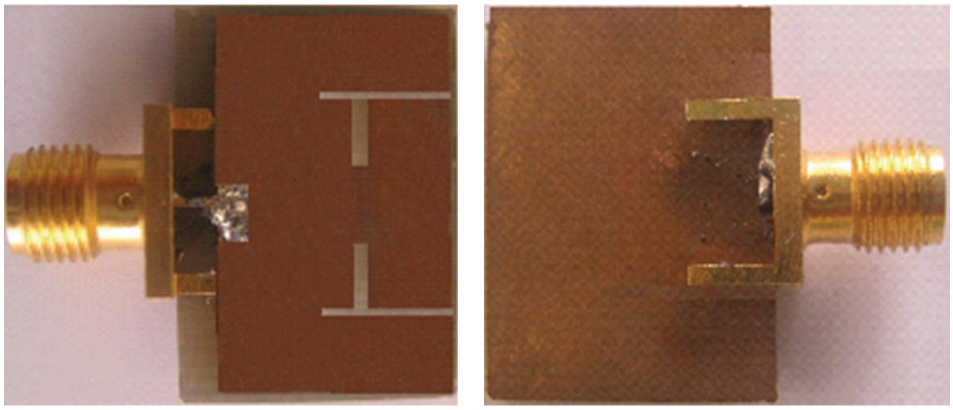


Figure 1: Geometry and configuration of the proposed antenna.

Table 1: Design specification of the proposed antenna.

Parameter	Value (mm)
$L0$	20
$L1$	9
$L2$	9
$L3$	4
$L4$	0.25
$L5$	0.25
$L6$	4
$W0$	14
$W1$	2
$W2$	2
$W3$	1
$W4$	9
$W5$	9
$W6$	1



(a) (b)

Figure 2: Prototype of the proposed antenna. (a) Radiating patch. (b) Ground plane.

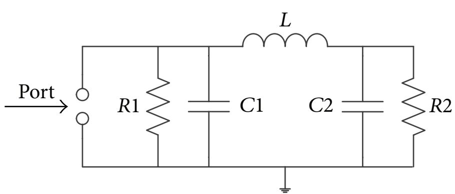


Figure 3: RLC equivalent circuit model of the proposed antenna.

(1×4, 1×2, 2×4, and 2×2) of slot dimension have been considered. From the analysis, the lowest return loss value and the widest bandwidth obtained from slot dimension 1×4 have been clearly seen. The microstrip feed line with $2 \times 1\,\text{mm}^2$ dimension is placed at the center of Y-axis to achieve 50 ohm impedance characteristics. The detailed antenna configuration is tabulated in Table 1. The detailed geometrical configuration of the proposed antenna is exhibited in Figure 1. The proposed antenna is fabricated on widely available, inexpensive, durable FR4 substrate (thickness = 1.6 mm, relative permittivity = 4.6, and loss tangent = 0.02) using in-house PCB prototyping machine. The modified E-H slotted rectangular radiating patch is fed by microstrip line which is terminated through a subminiature A (SMA) connector for measurement purpose. The fabricated prototype of the proposed modified E-H slotted patch antenna is displayed in Figure 2.

3. Equivalent Circuit Model

For equivalent circuit configurations such as the C- and Π-network topologies, for which the circuit branch functions are uniquely given in terms of the associated network parameters, each branch can be separately augmented by parallel and series branch elements. The Z parameter responses of this antenna are obtained using IE3D EM simulator based on method of moments (MoM) and from equivalent circuit modeling using only single augmentation. The approximate equivalent RLC circuit of the proposed antenna is presented in Figure 3, where $R1 = 343.358\,\Omega$, $R2 = 852.207\,\Omega$, $C1 = 0.00566\,\text{pF}$, $C2 = 0.2191\,\text{pF}$, and $L = 0.0835\,\text{nH}$. Without the presence of inductor L, the equivalent circuit with the lumped parameters poses the characteristics of a high pass filter. The induction element L plays a vital role in determining the resonant frequency.

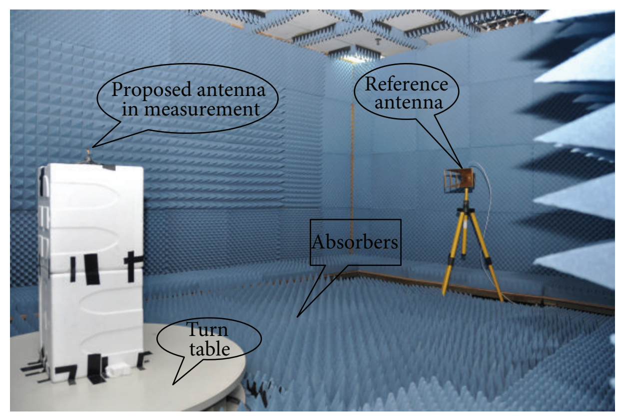


Figure 4: Illustration of the anechoic measurement chamber.

4. Experimental Results and Analysis

To validate the performance of the proposed planar antenna, a prototype has been fabricated and measured in a standard far-field testing environment. A rectangular shape anechoic measurement chamber footprint of $5.5 \times 4.5\,\text{m}^2$ and 4 m height has been used to measure the result parameters of the proposed antenna prototype. The distance between the reference antenna and the antenna under test is 3 meters. A double ridge guide horn antenna has been used as reference antenna. Figure 4 presents the photographic view of the anechoic measurement chamber. The wall, ceiling, and floor of the chamber are covered by pyramidal shaped foam absorber which has less than −60 dB reflectivity at normal incidence. A 360° revolving table (diameter = 1.2 meter) is used to rotate the test antenna at 1 rpm rotational speed connected by 10-meter microwave coaxial cable to the controllers.

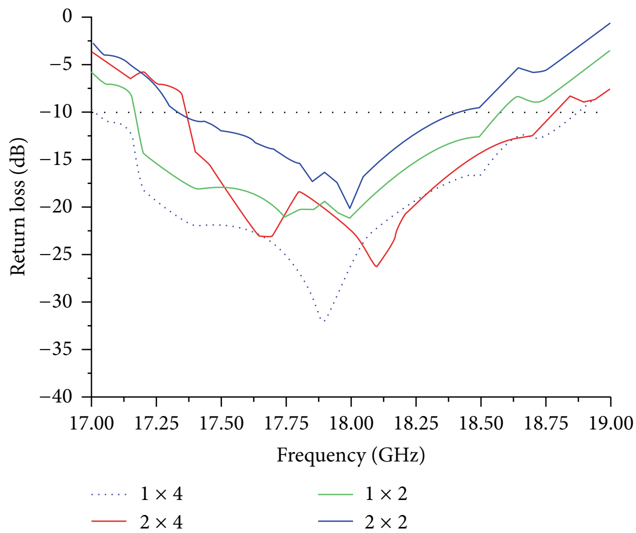


FIGURE 5: Return loss analysis of the antenna with four different dimensions of $W3 = W6 \times L3 = L6$.

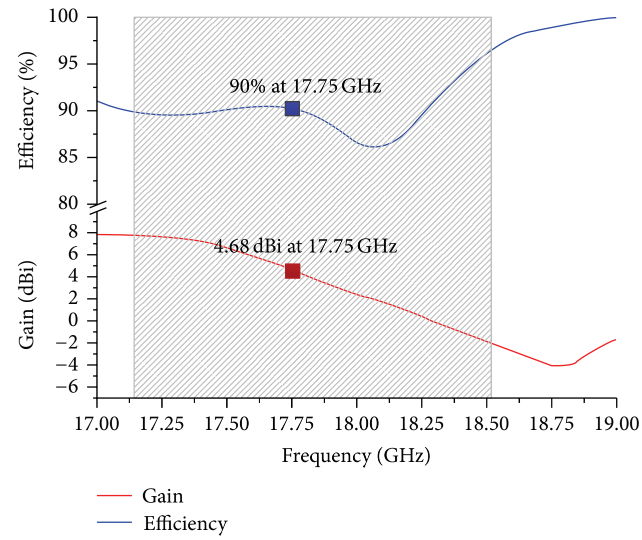


FIGURE 7: Achieved gain and efficiency of the proposed antenna.

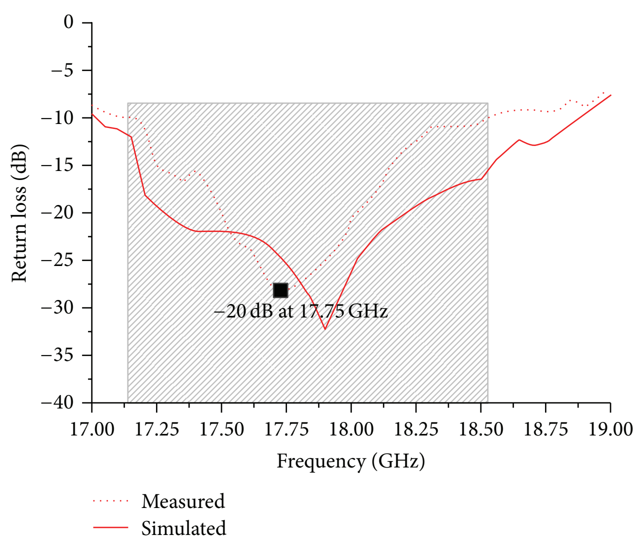


FIGURE 6: Simulated and measured return loss of the proposed antenna.

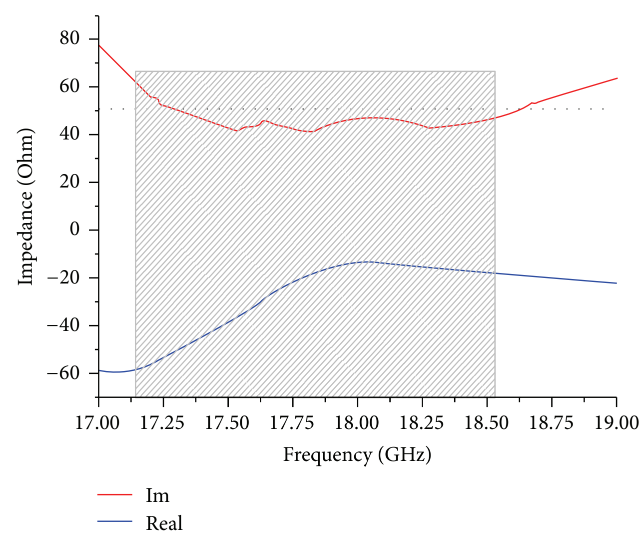


FIGURE 8: Input impedance over the radiating patch of the proposed antenna.

The parametric study has been conducted on width and length of two cutting slots. Four combinations $W3 = W6 \times L3 = L6$ (1×4, 1×2, 2×4, and 2×2) of slot dimension have been considered. Figure 5 illustrates the simulated return loss of the proposed antenna for four different slot dimensions. From the analysis, it can be clearly concluded that the slot dimension of $1 \times 4\,\text{mm}^2$ has achieved the lowest return loss value and the widest bandwidth among four combinations.

The simulated and measured return loss of the proposed antenna prototype is shown in Figure 6. It is clearly visible that the measured bandwidth is achieved at 1380 MHz (17.15 GHz to 18.53 GHz) defined by less than −10 dB return loss. Top portion of Figure 7 presents the antenna efficiency and the bottom part shows the achieved gain of the proposed antenna. The gain of 4.8 dBi and 90% efficiency were achieved at the resonance 17.75 GHz. The average gain and efficiency obtained in the entire operating band from 17.25 GHz to 18.25 GHz are 3.89 dBi and 89.2%, respectively. The input impedance (real and imaginary part) of the proposed antenna is illustrated in Figure 8. It is apparent from the figure that the real part of the input impedance tends to remain as close as the 50 Ω line and over the entire operating band.

Figure 9 represents the simulated and measured radiation patterns in *E*-*H* plane for the proposed antenna. It is noticeable that the cross polar effect is much lesser than copolar in both cases of simulated and measured radiation pattern which is preferred. The measured cross polarization value is not more than −13 dB in both *E* and *H* plane. The very nearly steady radiation pattern guaranteed the antenna to be a competitive candidate for future use. A comparative analysis between the proposed modified *E*-*H* slotted antenna

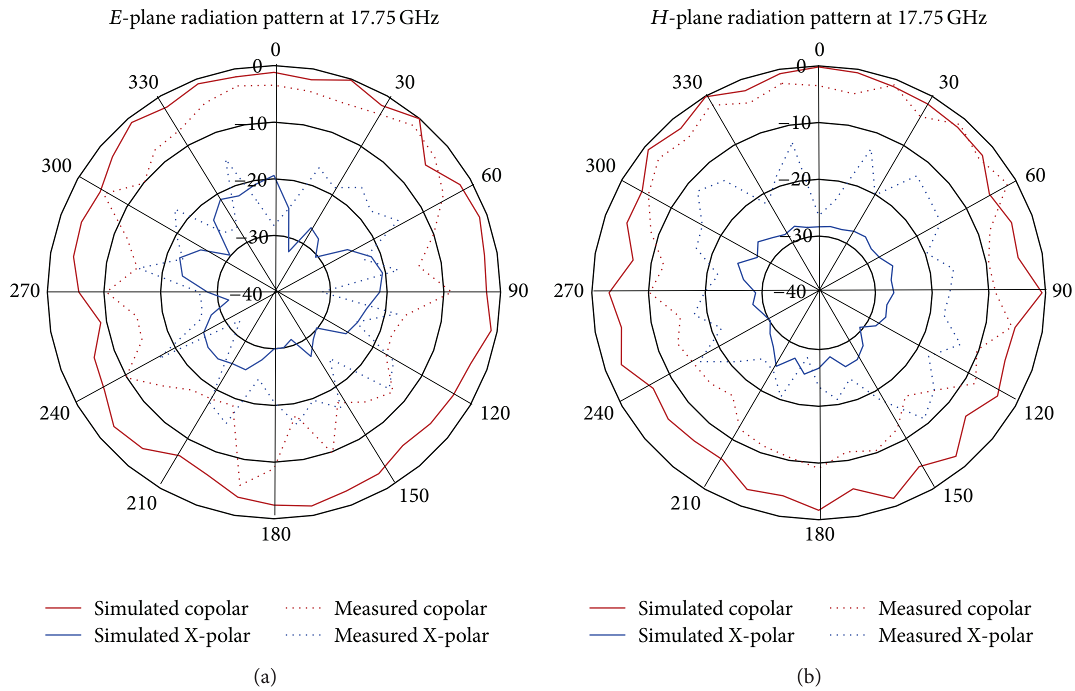


Figure 9: Simulated and measured radiation pattern. (a) *E*-plane and (b) *H*-plane of the proposed antenna.

Table 2: Comparison of the proposed antenna with some recently reported antennas.

Author	Dimension	Bandwidth	Gain
Proposed	$20 \times 14\,\mathrm{mm}^2$	1.38 GHz	7.8 dBi
[20]	$80 \times 12\,\mathrm{mm}^2$	1.62 GHz	7.8 dBi
[4]	$40 \times 40\,\mathrm{mm}^2$	950 MHz	7.6 dBi
[2]	$15 \times 15\,\mathrm{mm}^2$	870 MHz	6.2 dBi

and some recently available antennas for Ku band application is presented in Table 2. By analyzing the tabulated data, it can be spotted that the proposed antenna has achieved broader bandwidth and higher gain with comparatively smaller dimension.

5. Conclusion

A $20 \times 14\,\mathrm{mm}^2$ modified *E-H* shaped microstrip line fed wideband planar patch antenna has been designed, fabricated, and measured in $5.5 \times 4.5 \times 4\,\mathrm{m}^3$ anechoic antenna measurement chamber. The operating bandwidth of 1.38 GHz (ranging from 17.15 GHz to 18.53 GHz) and 8 dBi peak gain with efficiency more than 90% have been achieved. The input impedance and symmetric radiation pattern are presented and examined. Comparison between the proposed antenna and some existing antennas based on the applications and substrate material similarity is tabulated for analysis. The comparison result shows that proposed antenna has achieved wider bandwidth, better gain, and efficiency with comparatively smaller overall dimension than some of the reported antennas.

Conflict of Interests

The authors declare that they have no conflict of interests regarding the publication of this paper.

References

[1] Y. Liu, L.-M. Si, M. Wei et al., "Some recent developments of microstrip antenna," *International Journal of Antennas and Propagation*, vol. 2012, Article ID 428284, 10 pages, 2012.

[2] M. T. Islam, R. Azim, and N. Misran, "Linear polarized patch antenna for satellite communication," *Information Technology Journal*, vol. 9, no. 2, pp. 386–390, 2010.

[3] M. R. I. Faruque, M. T. Islam, and N. Misran, "Analysis of electromagnetic absorption in mobile phones using metamaterials," *Electromagnetics*, vol. 31, no. 3, pp. 215–232, 2011.

[4] R. Azim, M. T. Islam, and N. Misran, "Dual polarized microstrip patch antenna for Ku-band application," *Informacije MIDEM*, vol. 41, no. 2, pp. 114–117, 2011.

[5] A. Ferchichi, N. Sboui, A. Gharsallah, and H. Baudrand, "New antennas based on triangular patch as a solution for RFID application," *Applied Computational Electromagnetics Society Journal*, vol. 25, no. 3, pp. 199–205, 2010.

[6] H.-W. Liu, C.-H. Ku, and C.-F. Yang, "Novel CPW-fed planar monopole antenna for WiMAX/WLAN applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 9, pp. 240–243, 2010.

[7] K. Mandal and P. P. Sarkar, "A compact high gain microstrip antenna for wireless applications," *AEU—International Journal of Electronics and Communications*, vol. 67, no. 12, pp. 1010–1014, 2013.

[8] A. M. Abbosh and M. E. Bialkowski, "Design of ultrawideband planar monopole antennas of circular and elliptical shape," *IEEE*

Transactions on Antennas and Propagation, vol. 56, no. 1, pp. 17–23, 2008.

[9] M. S. Alam, M. T. Islam, and N. Misran, "A novel compact split ring slotted electromagnetic bandgap structure for microstrip patch antenna performance enhancement," *Progress in Electromagnetics Research*, vol. 130, pp. 389–409, 2012.

[10] G.-M. Yang, X. Xing, A. Daigle et al., "Planar annular ring antennas with multilayer self-biased nico-ferrite films loading," *IEEE Transactions on Antennas and Propagation*, vol. 58, no. 3, pp. 648–655, 2010.

[11] B. Li, J.-S. Hong, and B.-Z. Wang, "A novel circular disc monopole antenna for dual-band WLAN applications," *Applied Computational Electromagnetics Society Journal*, vol. 27, no. 5, pp. 441–448, 2012.

[12] H. F. AbuTarboush and H. S. Al-Raweshidy, "A connected E-shape and U-shape dual-band patch antenna for different wireless applications," in *Proceedings of the 2nd International EURASIP Workshop on RFID Technology*, 2008.

[13] R. Bakshi and S. K. Sharma, "A wideband U-slot loaded modified E-shape microstrip patch antenna and frequency agile behavior by employing different height ground plane and ribbon type switches," *Applied Computational Electromagnetics Society Journal*, vol. 26, no. 7, pp. 539–550, 2011.

[14] S. K. Padhi, N. C. Karmakar Sr., C. L. Law, and S. Aditya Sr., "A dual polarized aperture coupled circular patch antenna using a C-shaped coupling slot," *IEEE Transactions on Antennas and Propagation*, vol. 51, no. 12, pp. 3295–3298, 2003.

[15] M. Habib Ullah, M. T. Islam, J. S. Mandeep, and N. Misran, "A new double L shape multiband patch antenna on polymer resin material substrate," *Applied Physics A: Materials Science & Processing*, vol. 110, no. 1, pp. 199–205, 2012.

[16] J. Yang and A. Kishk, "A novel low-profile compact directional ultra-wideband antenna: the self-grounded Bow-Tie antenna," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 3, pp. 1214–1220, 2012.

[17] M. T. Islam, M. N. Shakib, and N. Misran, "Design analysis of high gain wideband L-probe fed microstrip patch antenna," *Progress in Electromagnetics Research*, vol. 95, pp. 397–407, 2009.

[18] B. Li, Y.-Z. Yin, W. Hu, Y. Ding, and Y. Zhao, "Wideband dual-polarized patch antenna with low cross polarization and high isolation," *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 427–430, 2012.

[19] M. Moosazadeh, A. M. Abbosh, and Z. Esmati, "Design of compact planar ultrawideband antenna with dual-notched bands using slotted square patch and pi-shaped conductor-backed plane," *IET Microwaves, Antennas & Propagation*, vol. 6, no. 3, pp. 290–294, 2012.

[20] C. Yu, W. Hong, Z. Kuai, and H. Wang, "Ku-band linearly polarized omnidirectional planar filtenna," *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 310–313, 2012.

[21] C. A. Balanis, *Antenna Theory: Analysis and Design*, John Wiley & Sons, New York, NY, USA, 3rd edition, 2005.