A Compact Quad-band CPW-fed Planar Resonator for Multiple Wireless Communication Applications

Aamir Khan [1], Syeda I. Naqvi [1], Farzana Arshad [1], Yasar Amin [1,2], and Hannu Tenhunen [2,3]

[1] ACTSENA Research Group
University of Engineering and Technology (UET), Taxila, 47050, Pakistan
aamirkhan_ciit@yahoo.com, iffat.naqvi@uettaxila.edu.pk, farzana.arshad@uettaxila.edu.pk

[2] iPack VINN Excellence Center
Royal Institute of Technology (KTH), Isafjordsgatn 39, Stockholm, SE-16440, Sweden
yasar.amin@uettaxila.edu.pk

[3] TUCS, Department of Information Technology
University of Turku, Turku-20520, Finland
hannu@kth.se

Abstract **─** This article presents a low-cost, compact antenna with coplanar waveguide (CPW) feed line for multiband wireless applications. The presented multiband radiator is envisioned for integration into microwave circuits and portable RF devices. The prototype is realized on 1.6 mm thick readily available FR4 substrate with a compact geometrical size of 24×32 mm^2. The acquired quad-bands are centered at: 2.45, 3.5, 5.2 and 5.8 GHz justifying the appropriateness of the proposed radiator for the WLAN and WiMAX applications, as well as Bluetooth and ISM wireless standards. From the aspect of integration into transportable handheld devices and system designing, the presented compact antenna illustrates more expandability and flexibility. The radiation characteristics measured in the E and H-planes for desired operating frequencies are monopole-like and omni-directional, respectively. A sufficient gain is also achieved. Simulated as well as experimental results exhibit agreeable behavior.

Index Terms **─** Coplanar Waveguide (CPW), multi-band antennas, WLAN, WiMAX.

I. INTRODUCTION

As the wireless communication standards have expanded affluently, it is desired for the antennas of current and future communication devices to be proficient for operative at multiple frequency bands to sanction various communication services for cellular as well as non-cellular applications. Wireless local area network (WLAN) has become the foremost standard for wireless communication these days. The frequency bands centered at: 2.45, 5.2 and 5.8 GHz are accredited for WLAN standards by the IEEE 802.11 [1]. Although WLAN is the primary internet access solution and provides a lot of amenities, the coverage becomes sparse and restricts its access to indoor use exclusively due to very few outdoor hot spots. As a matter of fact, Worldwide Interoperability for Microwave Access (WiMAX) operates similar to WLAN but at higher speed and covers more distance. The significance of WiMAX would be realized in the near future as a principal supplement to WLAN. The commonly used frequency bands defined by IEEE 802.16 for WiMAX are 2.5, 3.5 and 5.5 GHz [1, 2].

Moreover, the principal features of compactness, robustness, low profile, simplified fabrication, and adaptability in structures are desired for the antennas incorporated in transportable handheld terminals for wireless communication [3]. However, to achieve multiple bands with the employment of a single antenna offers substantial demands. Historically, exclusive strategies have been adapted to design multi resonators. Several earlier reported works had proposed slotted antennas with microstrip feed line to obtain multiband operations [4, 5-12]. An anchor-shaped slotted antenna has been proposed sustaining 2.45, 5.2 and 5.8 GHz WLAN along with 2.5, 3.5 and 5.5 GHz bands for WiMAX applications [4]. However, the size of the antenna is large. A quad-band slotted antenna for WLAN, WiMAX and GPS standards is obtained [5]. As the 1.5 GHz GPS band is obtained, the dimensions of about 56×44 mm^2 do not provide the required compactness. Sharma et al. [6] has presented a slotted dual-band antenna with single microstrip feed for the 2.4 GHz band supporting WLAN as well as 2.5 and 3.5 GHz bands covering WiMAX. The overall prototype size is 60×60 mm^2. A planar balance-shaped slot antenna with L-shaped micro-strip feed line

Submitted On: July 9, 2017
Accepted On: August 26, 2017

appropriate for WLAN/WiMAX triple-bands is proposed [7]. However, the geometry is somehow complicated, and gain is low as well. A multiband antenna covering only 2.45 and 5.2 GHz WLAN frequency bands along with 3.5 GHz WiMAX band has been reported [8]. The prototype is low gain with dimensions of 34×30 mm^2. Multiband antenna obtained in [9] covers the bands for WCDMA, WLAN, UWB, and C-band applications with geometrical dimensioning of 62×64 mm^2. An earlier proposed multi-frequency antenna supports the WiMAX as well as WLAN bands. The dimensions of the structure are 38×25 mm^2 [10]. In [11], a tri-band monopole antenna with microstrip feed line and overall size of 18×12 mm^2 is obtained. A circular shaped dual band patch antenna loaded with vertical slots and fed by meandered stripline is reported in [12]. The overall dimensions of the antenna are 51×41×2 mm^3.

In particular, considerable attention has been drawn towards the coplanar waveguide (CPW) due to their enviable benefits, predominately less dispersal, reduced radiation leakage, the negligible reliance of the characteristic impedance on the thickness of the substrate, and ease of fabrication due to the planar configuration. Integration with other microwave integrated circuits and RF devices as well as mounting is carried out efficiently with CPW feed [1, 13]. Multiband resonances are achieved by planar slotted antennas with CPW-feed on FR4 substrate [14, 15]. A CPW-fed bow-tie-shaped slotted antenna obtaining 2.45, 5.2 and 5.8 GHz WLAN band has been reported with overall dimensions of 60×45 mm^2 [14]. A quad-band prototype with CPW feed and four meander lines is projected and analyzed for L-band (1.15–1.25 and 1.5–1.9 GHz), 2.45 GHz and 3.5 GHz WLAN/WiMAX band [15].The four covered bands are narrow with comparatively large antenna geometry 57.37×67.5 mm^2. In [16], a compact 23×30 mm^2 CPW-fed antenna is reported that operates at three different bands of WLAN/WiMAX. Hence, it has been observed that there is always a tradeoff between the acquired frequency bands and the antenna size or complexity.

This article presents a coplanar waveguide quad-band antenna on FR4 substrate applicable for 2.45, 5.2 and 5.8 GHz WLAN along with 2.5 and 3.5 GHz WiMAX applications. The antenna also supports Bluetooth and ISM wireless applications. It is not merely capable of attaining the WLAN/WiMAX requisite bandwidths, but also affirms miniaturized and simple geometry. The progression of design and the experimental findings of the presented multi-resonant radiator are narrated and analyzed in detail.

II. ANTENNA DESIGN

The proposed planar and monopole prototype is depicted in Fig. 1. The proposed antenna structure is achieved by adding and etching out different slots from a standard rectangular patch through already established mathematical equations [17]. Consider:

$$W = \frac{\lambda}{2}\sqrt{\frac{2}{\varepsilon_r + 1}}, \tag{1}$$

$$L = 0.5\frac{\lambda}{\sqrt{\varepsilon_{reff}}} - 2\Delta L, \tag{2}$$

where W is the width and L is the length of the radiating patch in (1) and (2), respectively, whereas λ is the wavelength, ε_r is the relative dielectric constant and ΔL is the change in length due to fringing field effect and can be obtained using:

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)}, \tag{3}$$

where ε_{reff} is given as:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{W}\right)^{-0.5}. \tag{4}$$

These equations are for a standard rectangular patch; however, ultimate dimensions of the proposed antenna are achieved by using the technique of modify, test, and run. Furthermore, it has already been verified by various simulation analyses that the resonant frequencies can be obtained by making meandered path for the surface currents.

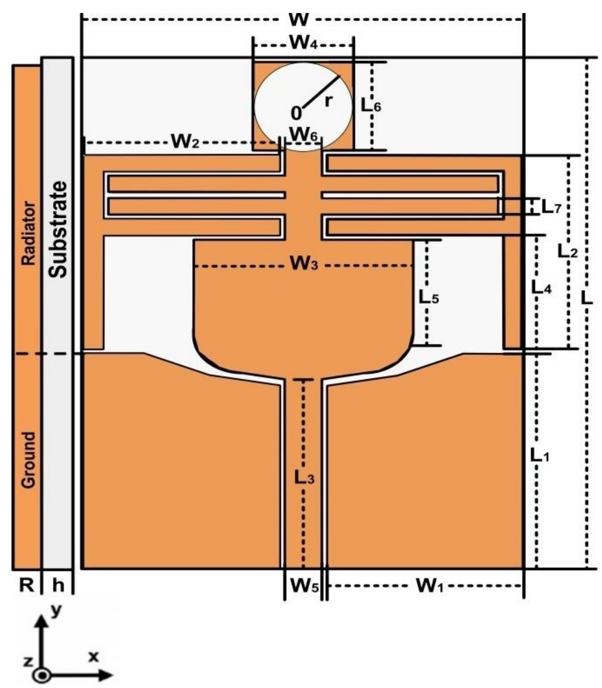

Fig. 1. Layout of the proposed antenna.

The designed radiator is capable of operating at four distinct bands. Great caution has been taken while developing and optimizing the radiator and CPW ground to acquire the preferred operating frequencies. The antenna with dimensions of 24×32 mm^{2}is realized on 1.6 mm thick FR4 substrate with ε_r = 4.4 and δ = 0.02. Table 1 further elaborates the dimensions of the presented design.

Table 1: Optimized parameters of the antenna

Parameter	Size (mm)	Parameter	Size (mm)
L	32	W	24
L_1	13.5	W_1	10.7
L_2	12.1	W_2	10.65
L_3	11.5	W_3	12
L_4	7.1	W_4	5.5
L_5	5.8	W_5	2
L_6	5.5	W_6	2
L_7	1	h	1.6
R	2.65	R	0.035

Figure 2 (a) clearly depicts the emergence of the prototype proposed in this work. To better understand the strategy followed to develop the prototype, the return loss (S_{11}) for the four design stages is plotted in Fig. 2 (b).

To begin with, Antenna1 is designed as shown in Fig. 2 (a). A basic rectangular patch with rounded corners near feed line and a small square patch on the top side linked with the bottom patch by a vertical rectangular strip at the center are the elements contributing the major radiations of the Antenna1. This antenna radiates at 3.6 GHz with $S_{11} < -10$ dB, as shown in Fig. 2 (b). Carrying the initial proposed design as the basis, Antenna2 is modeled by the addition of a circular slot inside the top square patch and a pair of F-shaped strips placed symmetrically at both sides of the Antenna1 as illustrated in Fig. 2 (a). It shifts and improves the first resonance at 3.6 GHz to 3.7 GHz, since the addition of circular slot significantly increases the equivalent electric length. At the same time another resonance at 2.8 GHz is generated as depicted clearly in Fig. 2 (b), because the F-shaped strips are introduced. In the third model, a horizontal strip is introduced in between the two symmetrical F-shaped strips with the aim of escalating the path for the current as shown in Fig. 2 (a). Antenna3 shifts the two resonances obtained by Antenna2 at 2.8 to 2.4 GHz and 3.7 to 4 GHz, as illustrated in Fig 2 (b). Third resonance centered at 5.7 GHz is also obtained. However, this resonance is inadequate in the sense that it does not produce $S_{11} < -10$ dB.

Finally, another horizontal strip of same dimension is introduced in between the F-shaped strips and below the horizontal strip that was added in the previous stage of design evolution as depicted in Fig. 2 (a). The proposed antenna obtained in the fourth step of evolution shifts the radiations of Antenna3 at 2.4 GHz to 2.45 GHz and 4 GHz to 3.4 GHz, whereas improving the impedance matching across the band. Furthermore, resonance at 5.7 GHz for Antenna3 is shifted to 5.8 GHz with $S_{11} < -10$ dB. Fourth radiation at the frequency of 5.2 GHz is also obtained. Thus, the proposed design provides four resonances at 2.45, 3.4, 5.2 and 5.8 GHz supporting WLAN and WiMAX bands, all with $S_{11} < -10$ dB, as shown in Fig. 2 (b). By applying the before mentioned strategy as well as going through some simulations and optimization techniques, the final radiating structure has been obtained with optimum results.

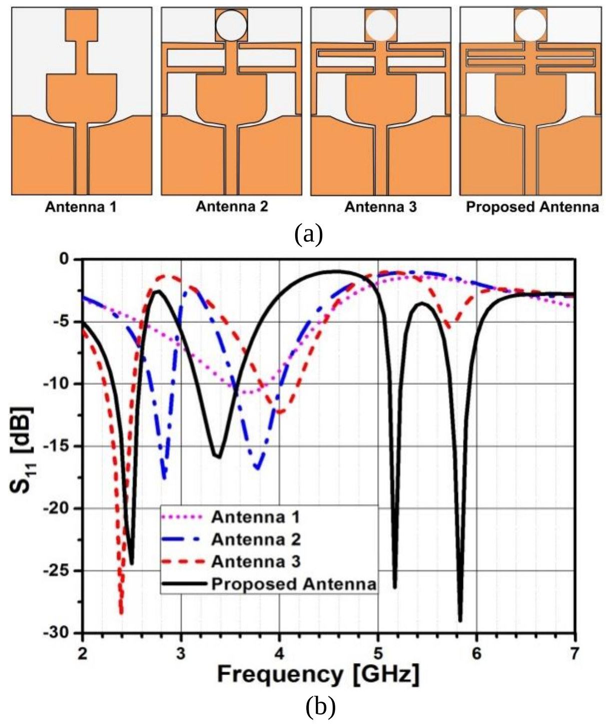

Fig. 2. (a) Design evolution of the proposed antenna, and (b) with subsequent S11.

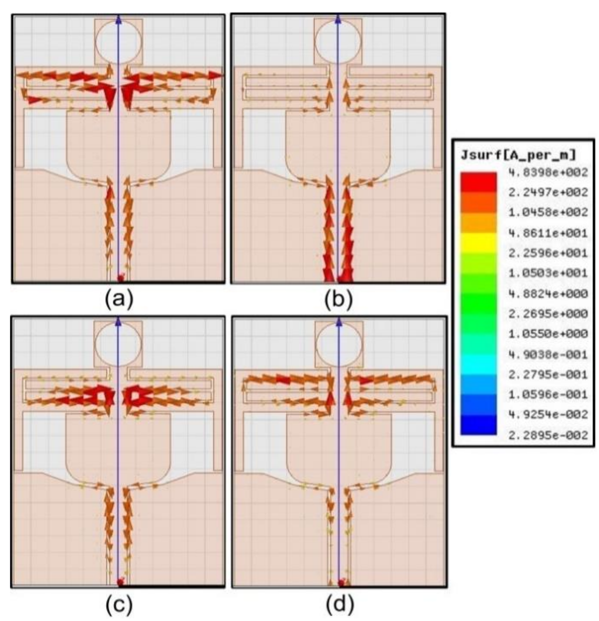

Fig. 3. Current distributions of the antenna for: (a) 2.45, (b) 3.5, (c) 5.2, and (d) 5.8 GHz.

For better investigation of the working principle of the multiband resonator, the analysis of current distribution is carried out at the four resonances 2.45, 3.5, 5.2 and 5.8 GHz, respectively as depicted in Figs. 3 (a)–(d). The current density is mainly observed at the F-shaped strips, the bottom of the rectangular patch and the first horizontal strip at 2.45 GHz, as illustrated in Fig. 3 (a). Whereas for 3.5 GHz, the concentration of the current is widely seen at the bottom of the rectangular patch, as evident in Fig. 3 (b). In the same manner, Fig. 3 (c) illustrates that at 5.2 GHz, major distribution of the current is on the horizontal strips. While for 5.8 GHz, the current density is mainly concentrated at F-shaped and the horizontal strips, as can be seen in Fig. 3 (d).

III. EXPERIMENTAL RESULTS AND DISCUSSION

According to the parameters of the prototype provided in Table 1, the multiband antenna for WLAN and WiMAX standards is fabricated and measured to validate the performance. The simulations were orchestrated using full wave electromagnetic design tool HFSS™, whereas measured results are obtained by the R&S®ZVL13 Vector Network Analyzer.

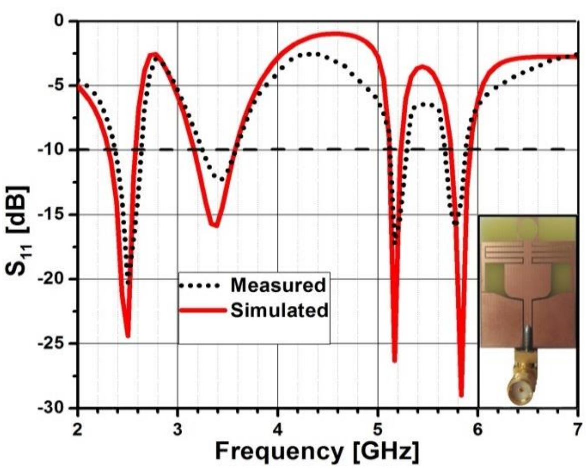

Fig. 4. Measured and simulated return loss of the antenna.

Figure 4 illustrates simulated and measured return loss. It is evident that the bands for wireless communication covered by the radiator are four. The bandwidths and commercial bands covered by the proposed antenna have been narrated in Table 2. The frequency bands measured and considered for S11 <−10 dB are 2.31-2.58 GHz covering the IEEE 802.11b&g WLAN systems (270 MHz bandwidth), 3.16-3.57 GHz suitable for the WiMAX applications (410 MHz bandwidth). Also 5.11-5.23 GHz band supporting the IEEE 802.11a WLAN (120 MHz bandwidth) and 5.72-5.92 GHz for the WLAN/WiMAX applications (200 MHz bandwidth) are obtained. Measured and simulated results are coherent; however, slight variations are due to the inevitable use of coaxial cable and SMA connector for measurement [18, 19].

Table 2: Frequency bands covered by antenna

Band No.	Bandwidth (GHz)	Covered Commercial Bands
1.	2.31-2.58	WLAN (2400-2480 MHz), LTE 2300 (2305-2400 MHz), ISM & Bluetooth (2400-2480 MHz), WiMAX (2500-2690 MHz), LTE 2500 (2500-2690 MHz)
2.	3.16-3.57	WiMAX (3400-3600 MHz)
3.	5.11-5.23	WLAN (5150-5350 MHz)
4.	5.72-5.92	WLAN (5725-5850 MHz), WiMAX (5250-5850 MHz)

The computed peak gain for the proposed antenna has been illustrated in Fig. 5. The peak gain value is 2.27 dB for the 2.45 GHz, 0.99 dB for 3.5 GHz, 1.08 dB for 5.2 GHz and 2.15 dB for the upper 5.8 GHz band. Thus, adequate amount of gain for the antenna has been obtained. However, the maximum achieved efficiency is 73% for the proposed antenna.

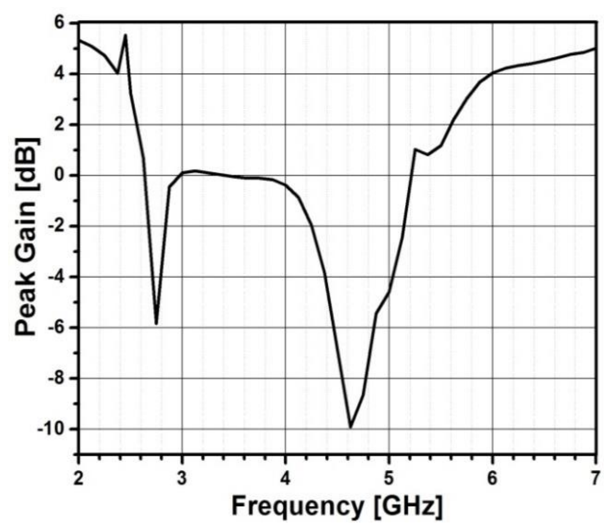

Fig. 5. Peak gain of proposed antenna.

The radiation plots measured in the E(y-z) plane as well as H(x-z) plane, for 2.45, 3.5, 5.2 and 5.8 GHz, have been provided in Figs. 6 (a)–(d). In E-plane the measured radiation plots are bi-directional while for the H-plane, an omni-directional response has been observed. Thus, monopole-like behavior has been obtained. Moreover, along with co-polarization the cross-polarization behavior is also observed in Figs. 6 (a)-(d). It can be seen that the cross-polarization level is less than -20 dB across the two lower frequency bands, i.e., at 2.45 GHz and 3.5 GHz, while the upper frequency bands at 5.2 GHz and 5.8 GHz acquire the cross-polarization level in between -20 dB and -10 dB. Hence, it is evident from the radiation characteristics that the antenna shows a steady response for the attained operating bandwidth.

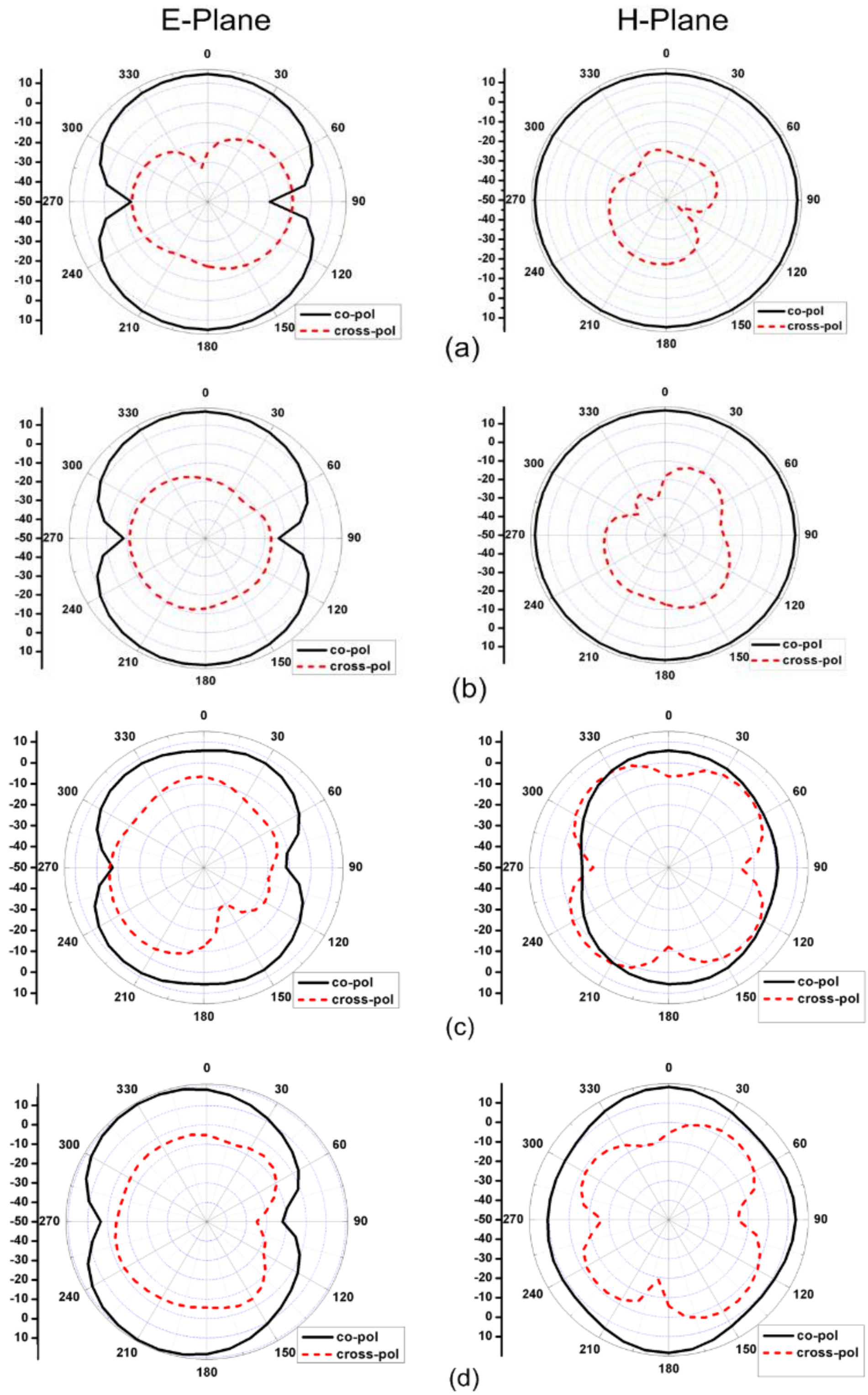

Fig. 6. Measured radiation patterns of antenna at: (a) 2.45 GHz, (b) 3.5 GHz, (c) 5.2 GHz, and (d) 5.8 GHz.

IV. CONCLUSION

The design of CPW-fed multi-band antenna with detailed simulated and measured results is proposed. By the inclusion of F-shaped and horizontal strips to the basic rectangular radiator, four resonances at 2.45, 3.5, 5.2 and 5.8 GHz are achieved supporting WLAN, WiMAX, LTE2300/2500, ISM and Bluetooth frequency bands. With the compact size of 24×32×1.6 mm^3, the prototype mitigates the incorporation into portable terminals. Moreover, steady monopole-like radiation patterns and adequate gains have been achieved for the desired bands. Therefore, the satisfactory outcome proves the significance of the antenna for diverse wireless applications.

ACKNOWLEDGMENT

This work was financially supported by Vinnova (The Swedish Governmental Agency for Innovation Systems) and UET Taxila, Pakistan through the Vinn Excellence Centers Program and ACTSENA Research Group Funding, respectively.

REFERENCES

[1] S. Chaimool and P. Akkaraekthalin, "CPW-Fed Antennas for WiFi and WiMAX," *Advanced Transmission Techniques in WiMAX*, ISBN: 978-953-307-965-3, InTech, 2012. Available from: http://www.intechopen.com/books/advanced-transmission-techniques-in-wimax/cpw-fed-antennas-for-wifi-and-wimax

[2] Y. Liu, Y. Wang, and Z. Du, "A broadband dual-antenna system operating at the WLAN/WiMax bands for laptop computers," *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 1060-1063, May 2015.

[3] R. S. Aziz, A. K. Arya, and S. Park, "Multiband full-metal-rimmed antenna design for smart phones," *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 1987-1990, Mar. 2016.

[4] W. Ren and C. Jiang, "A novel design of multiband printed anchor-shaped slot antenna," *Microwave and Optical Technology Letters*, vol. 58, no. 3, pp. 521-526, Mar. 2016.

[5] Y. F. Cao, S. W. Cheung, and T. I. Yuk, "A multiband slot antenna for GPS/WiMAX/WLAN systems," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 3, pp. 952-958, Mar. 2015.

[6] A. K. Sharma, A. Mittal, and B. V. R. Reddy, "Slot embedded dual-band patch antenna for WLAN and WiMAX applications," *Electronics Letters*, vol. 51, no. 8, pp. 608-609, Apr. 2015.

[7] W. Ren and C. Jiang, "Planar triple-band balance shaped slot antenna," *Microwave and Optical Technology Letters*, vol. 58, no. 5, pp. 1078-1082, May 2016.

[8] S. C. Basaran, U. Olgun, and K. Sertel, "Multiband monopole antenna with complementary split-ring resonators for WLAN and WiMAX applications," *Electronics Letters*, vol. 49, no. 10, pp. 636-638, May 2013.

[9] B. S. Yıldırım, E. Başaranand, and B. Türetken, "Compact and planar WCDMA/WLAN/UWB antenna with shorted loop and monopole elements," *ACES Journal*, vol. 31, no. 3, pp. 288-293, Mar. 2016.

[10] J. Pei, A. Wang, S. Gao, and W. Leng, "Miniaturized triple-band antenna with a defected ground plane for WLAN/WiMAX applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 298-301, Apr. 2011.

[11] N. Ojaroudi, M. Mehranpour, S. Ojaroudi, and Y. Ojaroudi, "Microstrip-fed monopole antenna with triple band performance for WLAN/WiMAX applications," *ACES Journal*, vol. 29, no. 3, Mar. 2014.

[12] M. R. Ahsan, M. T. Islam, and M. HabibUllah, "A new meandered-stripline fed dual band patch antenna," *ACES Journal*, vol. 30, no. 2, Feb. 2015.

[13] R. N. Simons, *Coplanar Waveguide Circuits, Components, and Systems*. ISBNs: 0-471-16121-7 (Hardback); 0-471-22475-8 (Electronic), John Wiley & Sons, Inc., 2001.

[14] L. C. Tsai, "A dual-band bow-tie-shaped CPW-fed slot antenna for WLAN applications," *Progress In Electromagnetics Research C*, vol. 47, pp. 167-171, Feb. 2014.

[15] K. Yu, Y. Li, and X. Luo, "A CPW-fed quad-band monopole antenna for L-band, WLAN and WiMAX communication applications," *Progress In Electromagnetics Research Symposium (PIERS)*, pp. 3996-4000, Aug. 2016.

[16] L. Li, Z. Z. Li, L. Ming-Fu, J. C. Jiang, and B. Tang, "A novel compact printed slot antenna with triple bands for WiMAX/WLAN applications using remodeling technology," *ACES Journal*, vol. 29, no. 6, June 2014.

[17] C. A. Balanis, *Antenna Theory Analysis and Design*. 3rd edition, John Wiley & Sons, Hoboken, NJ, USA, 2005.

[18] L. Liu, S. W. Cheung, Y. F. Weng, and T. I. Yuk, "Cable effects on measuring small planar UWB monopole antennas," *Ultra Wideband – Current Status and Future Trends*, 2012. Available from: http://dx.doi.org/10.5772/46080

[19] L. Liu, Y. F Weng, S. W Cheung, T. I. Yuk, and L. J. Foged, "Modeling of cable for measurements of small monopole antennas," *The 7th Loughborough Antennas and Propagation Conference (LAPC)*, Loughborough, United Kingdom, article no. 6114153, Nov. 14-15, 2011.

Aamir Khan received his B.Sc. degree in Electrical (Telecommunication) Engineering from COMSATS University, Islamabad, in the year 2015. Currently he is pursuing his degree of M.Sc. in Telecommunication Engineering from UET Taxila. He is also working on Microwave Propagation and Antennas with College of Electrical and Mechanical Engineering (CEME) Pakistan as an Internee. His research interests are Ultra-wide band, Multiband Antennas for current and future wireless standards.

Syeda Iffat Naqvi received her B.Sc. and M.Sc. degree in Computer Engineering and Telecommunication Engineering from UET Taxila, Pakistan in the year 2006 and 2011, respectively. Currently, she is pursuing her degree of Ph.D. in Telecommunication Engineering from (UET) Taxila. She is also a Member of ACTSENA Research Group. Her current research interests include RF and microwave antenna designing for cutting edge wireless technologies. Naqvi is a Member of IEEE and ACES.

Farzana Arshad received her B.Sc. and M.Sc. degree in Software Engineering and Telecommunication Engineering from UET Taxila, Pakistan in the year 2006 and 2010, respectively. Currently, she is working towards her Ph.D. degree in Telecommunication Engineering from UET Taxila. She is also a Member of ACTSENA Research Group. Her current research interests include Low profile Multiband and reconfigurable antenna design.

Yasar Amin is Chairman and Associate Professor of Telecommunication Engineering Department, University of Engineering and Technology Taxila, Pakistan. He is Founder of ACTSENA Research Group at UET Taxila, Pakistan. He has done his B.Sc. in Electrical Engineering in 2001 with specialization in Telecommunication and M.Sc. in Electrical Engineering in 2003 with specialization in System-on Chip Design from Royal Institute of Technology (KTH), Sweden. His Ph.D. is in Electronic and Computer Systems from Royal Institute of Technology (KTH), Sweden, with research focus on printable green RFID antennas for embedded sensors, while he has MBA in Innovation and Growth from Turku School of Economics, University of Turku, Finland.

Hannu Tenhunen is Chair Professor of Electronic Systems at Royal Institute of Technology (KTH), Stock-holm, Sweden. Tenhunen has held Professor positions as Full Professor, Invited Professor or Visiting Honorary Professor in Finland (TUT, UTU), Sweden (KTH), USA (Cornel U), France (INPG), China (Fudan and Beijing Jiatong Universities), and Hong Kong (Chinese University of Hong Kong), and has an Honorary Doctorate from Tallinn Technical University. He has been Director of multiple national large scale research programs or being an Initiator and Director of national or European graduate schools. He as actively contributed on VLSI and SoC design in Finland and Sweden via creating new educational programs and research directions, most lately at European level as being the EU-level Education Director of the new European flagship initiative European Institute of Technology and Innovations (EIT), and its Knowledge and Innovation Community EIT ICT Labs.