Design, Fabrication, and Measurements of Extended L-Shaped Multiband Antenna for Wireless Applications

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

[1] ACTSENA Research Group
University of Engineering and Technology (UET), Taxila, 47050, Pakistan
Ashfaquetb11@gmail.com, farzana.arshad@uettaxila.edu.pk, iffat.naqvi@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 expounds a multi-band compact shaped antenna, which is based on CPW ground plane. FR-4 with a thickness of 1.6 mm is used as a substrate for the proposed antenna. The proposed antenna is capable of operating at 1.56 GHz for (Global Positioning System), 2.45 GHz (Wireless Local Area Network) and 4.49 GHz (Aeronautical Mobile Telemetry (AMT) fixed services). The efficiency at 1.56, 2.45, and 4.49 GHz is 79.7, 76.9 and 76.7%, respectively. The VSWR of the presented antenna is less than 1.5 at all the desired resonance modes, which confirms its good impedance matching. The performance of the proposed antenna is evaluated in terms of VSWR, return loss, radiation pattern and efficiency. CST®MWS® software is used for simulations. In order to validate the simulation results, a prototype of the designed antenna is fabricated and a good agreement is found between the simulated and measured results.

Index Terms ─ AMT Fixed Services, GPS, multiband antenna, Wi-Fi.

I. INTRODUCTION

With the rapid development of communication technology, researchers have paid huge attention towards multiband antennas. Portable devices demand multi-band antennas for their operation at different standards, like Wi-Fi, WiMAX, GSM, GPS [1] and many more. Due to the restriction of size selection, ease of fabrication and provision of connection to feed network, multi-band antennas offer edge over single band antennas. Multiband functionality can be achieved by introducing slots or cuts of different sizes in conventional microstrip antennas. Currently, some approaches for the design of multiband antennas, like the integration of a metamaterial inspired split ring resonator [2], and insertion of slots [3] within the radiating elements have been proposed. Defective ground planes [4] are also proposed to get multiple frequency bands. Similarly, different shapes of radiating elements [5-6] have been used to modify the microstrip antennas for achieving multi resonances. Despite all the latest advancements in microstrip antenna, they inherently exhibit narrow bandwidth. Monopole antenna is another attractive option for researcher due to their light weight, outstanding efficiencies, wide bandwidth, simple geometry and ease of fabrication. These antennas can be integrated with various portable devices for the efficient transmission and reception of data [7]. In order to incorporate these requirements, various types of multiband antennas have been designed recently [8]-[10].

In [11], a dual-band B-shaped antenna is (operating on 2.45 and 5.8 GHz) is proposed; however, it exhibits perturbed radiation patterns, E-shaped dual band antenna for WLAN application is designed in [12], but its efficiency is low (59%). Similarly, an H-shaped antenna for GPS and Wi-Fi applications is proposed in [13], but the antenna is bulky and its efficiency at the desired bands is 49-78%. Moreover, four sub-patches were employed to accomplish multi-band functionality in [14], but it increases the overall size (50×50 mm^2) of the proposed antenna which ultimately limits its integration with future wireless communication systems. In this context antenna structure needs careful optimization. Although, up to four operating bands were achieved in [15], this antenna is suitable for limited applications, due to complexity in shape. A monopole tri-band antenna is expounded in [16]. It is small in size, having three stage microstrip feed line possess distorted radiation pattern

Submitted On: October 12, 2017
Accepted On: April 1, 2018

and negative gain at 2 GHz band. In [17] triple-band microstrip antenna having complex geometry is presented for WLAN/WiMAX applications.

Similarly, CPW fed antennas are good candidates for achieving multi resonances. These antennas can be preferred due to the fact that they offer less coupling and easier integration with microwave circuits. A tri-band CPW (Coplanar waveguide) fed antenna is designed in [18]. The proposed antenna shows good performance, but it is difficult to fabricate due to its complex geometry. A CPW fed antenna having dimensions of 180x80 mm^2 is presented in [19].

This paper presents an efficient and compact multiband CPW fed antenna. The suggested antenna offers potential to replace multiple single band antennas in various applications. The proposed antenna is capable of operating at GPS (1.567 GHz), WLAN (2.45 GHz) and AMT Fixed services (4.49 GHz) with efficiency greater than 76%. The extended L-Shaped antenna is designed to operate on two lower frequency bands; moreover, this antenna is extended to acquire the higher resonance mode.

This paper is arranged as follows. Section II covers design methodology and underlying theory. Results are discussed in Section III. Section IV comprises the conclusion of this work.

II. ANTENNA GEOMETRY AND THEORY

This section depicts the basic geometry and theoretical aspect/detail of the proposed antenna. For multiple resonances two antenna designs are investigated, Extended L-shaped Ant-1 and Extended L-shaped with a crescent, that is Ant-2. CPW-fed technique is used for incorporating different radiation features; the antennas have non-complex structure of the single metallic layer and are easy to integrate with other systems [6].

A. Antenna Geometry

The geometry of proposed antennas, Ant-1 and Ant-2 is shown in Figs. 1 (a) and (b) respectively. The proposed antennas are implemented on Flame Retardant 4 (FR-4) with thickness of 1.6 mm, relative permittivity 4.3 and loss tangent of 0.025, while copper having a thickness of 0.035 mm is used as a radiating element. Ant-1 is responsible for antenna's operation on two lower frequencies (1.565 GHz and 2.415 GHz), while the crescent shape takes care of antenna's working on higher frequency (i.e., 4.5 GHz). For excitation of antenna, a 50Ω transmission line with a width of 2.3 mm is used. Table 1 elaborates physical characteristics of the antenna.

B. Theory

According to transmission line theory model [20] the effective resonance length can be computed using the following mathematical equations.

The resonance length L and guided wavelength are related as follows:

$$L_{1.565} = \lambda_{1.565}/4, \quad (1)$$

$$L_{2.41} = \lambda_{2.41}/4, \quad (2)$$

$$L_{4.5} = \lambda_{4.5}/4. \quad (3)$$

Where the guided wavelength can be calculated as:

$$\lambda_{fr} = \frac{c}{fr\sqrt{\varepsilon e}}. \quad (4)$$

c in the above equation refers to speed of light, f_r is resonance frequency and ε_e is effective permittivity:

$$\varepsilon_e = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}(1+12h/w)^{-1/2}, \quad (5)$$

h, w and ε_r are the thickness of substrate, width of the radiating elements and relative permittivity respectively in equation (5).

The proposed antenna is optimized for best radiation efficiency η_{rad}. Radiation efficiency can be defined as the ratio of radiated power (P_{rad}) of the antenna to its input power (P_{in}):

$$\eta_{rad} = \frac{Prad}{Pin}. \quad (6)$$

The higher efficiency can be achieved by feeding the antenna properly, which results in minimum return loss (Γ). Factor Γ is the ratio of reflected electric field to the incident electric fields. Mathematically,

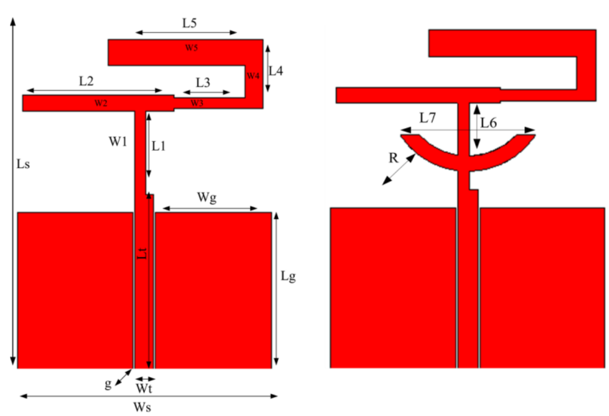
$$[\Gamma] = \frac{Zant-Zc}{Zant+Zc}, \quad (7)$$

where Z_{ant} is driving point impedance of antennas and Z_c is the characteristic impedance of the antenna. The proposed design has a characteristic impedance of nearly 50 Ω at all three resonances/resonating frequencies. For small return loss (Γ), the Voltage Standing Wave Ratio (VSWR) approaches unity.

The directivity and gain are related by efficiency. The gain is expressed in decibel (dB) and is given below:

$$G\ (dB) = 10\times\log(\eta_{rad}.D). \quad (8)$$

The equations presented above are applicable for the rectangular microstrip patch antenna; however, dimensions of proposed antenna are optimized after carrying out various simulations.



(a) (b)

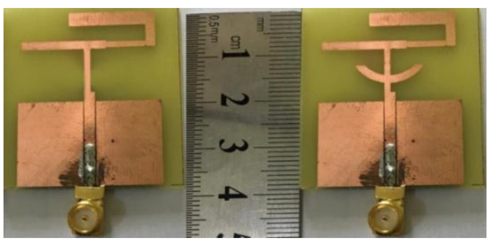
Fig. 1. Geometry of the proposed antennas. (a) Ant-1 and (b) Ant-2.

Table 1: Dimension of Extended L-Shaped antenna

Parameter	Size (mm)	Parameter	Size (mm)
Ls	40	L5	16
Ws	38	L6	5.8
Lg	18	L7	15
Wg	13.85	W1	1.3
R	7.49	W2	1.8
G	0.15	W3	1.3
L1	9	W4	2.1
L2	18	W5	3
L3	8.5	Lt	20
L4	3.6	Wt	2.3

III. RESULTS

To analyze the performance of the proposed antennas, CST® Micro Wave Studio environment is used. Both antennas are then fabricated and measured as shown in Fig. 2. Both computed and simulated results show close resemblance in terms of return loss and radiation pattern. Fabrication errors attribute to the minor discrepancy emerged in frequency shifts.



(a) (b)

Fig. 2. Fabricated design: (a) Ant-1 and (b) Ant-2.

A. Reflection coefficient

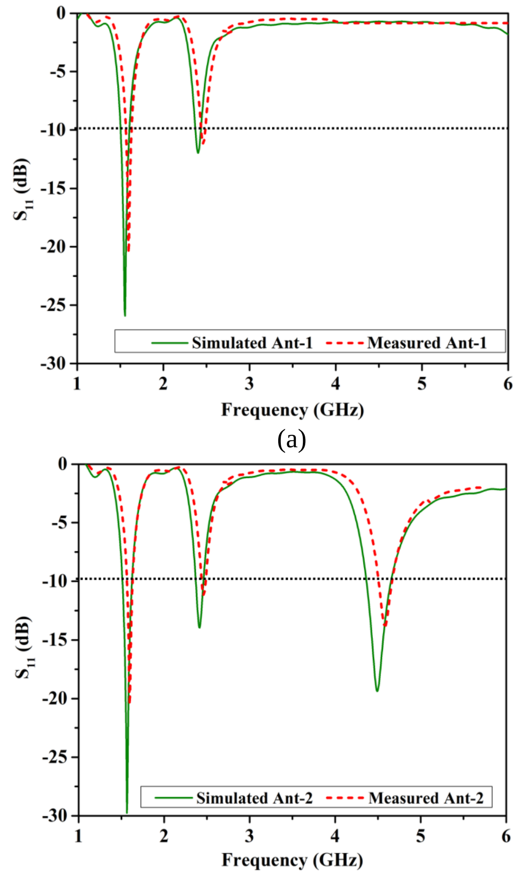
The proposed antenna is capable to work on 1.567 GHz (GPS), 2.41 GHz (WLAN) and 4.49 GHz (AMT fixed service). Figure 3 shows the reflection coefficient of Ant-1 and Ant-2. Both antennas are then fabricated and measured. The results reveal that close agreements between measured and simulated results has been achieved.

B. Voltage standing wave ratio (VSWR)

The simulated voltage standing wave ratio for the proposed designs is presented in Fig. 4. The VSWR of the Ant-1 is 1.06 and 1.5 at 1.56 GHz and 2.41 GHz respectively; while for Ant-2, VSWR is 1.24 at 4.5 GHz. This shows that designs are perfectly matched at desired frequencies.

C. Radiation patterns

The gain pattern and radiation pattern of the proposed antennas is presented in this section. Figure 5 illustrates the gain patterns. The far-field 3D patterns are presented in Fig. 6. The gain of the proposed antennas is 1.03, 1.33 and 1.84 dB at 1.565, 2.415 and 4.49 GHz, respectively. It is noticed that the designed antennas radiate omni-directional in H-plane for two lower frequency bands, while distinct behavior is observed for higher frequency. E-plane polar plots are depicted in figure of 8 having a null at θ = 90^0 for 1.56 and 2.45 GHz as shown in the figure below. For 4.49 GHz, the position of nulls is shifted to θ = 70^0 for E-plane pattern and is nearly omnidirectional except in null position. Both measured and simulated results are in good agreement.



(b)

Fig. 3. S parameter: (a) Ant-1 and (b) Ant-2.

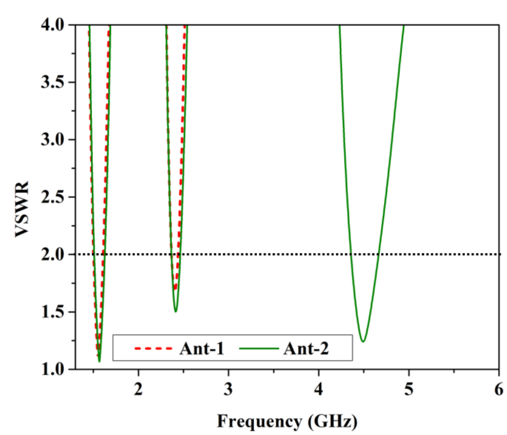


Fig. 4. Voltage Standing Wave Ratio.

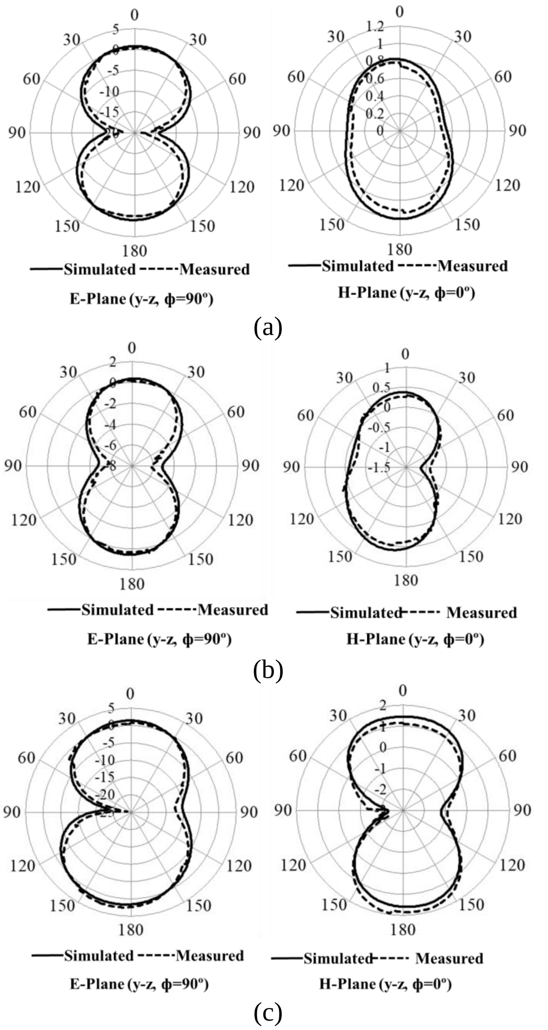


Fig. 5. Simulated and measured gain patterns: (a) 1.567 GHz, (b) 2.415 GHz, and (c) 4.5 GHz.

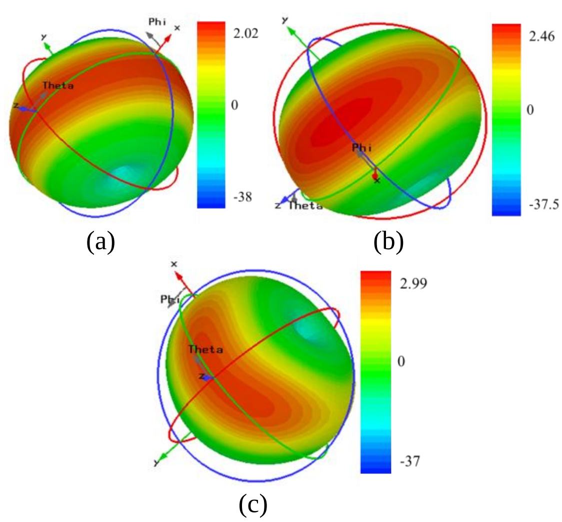


Fig. 6. 3D Radiation patterns: (a) 1.565 GHz, (b) 2.415 GHz, and (c) 4.49 GHz.

D. Surface current

Figure 7 depicts the simulated surface current distribution at different resonance frequencies. Figure 7 (a) suggests that the current distribution is maximum along the feedline and upper half part of the radiator which generates the lower frequency band (1.5 GHz). Figure 7 (b) shows the strong current intensity in the radiator as well as along the feed line which resonates at 2.45 GHz band. In part (c) maximum current density is observed in crescent shape and in the feedline. In this case, current follows the smaller path; hence, antenna resonates at large frequency of 4.49 GHz.

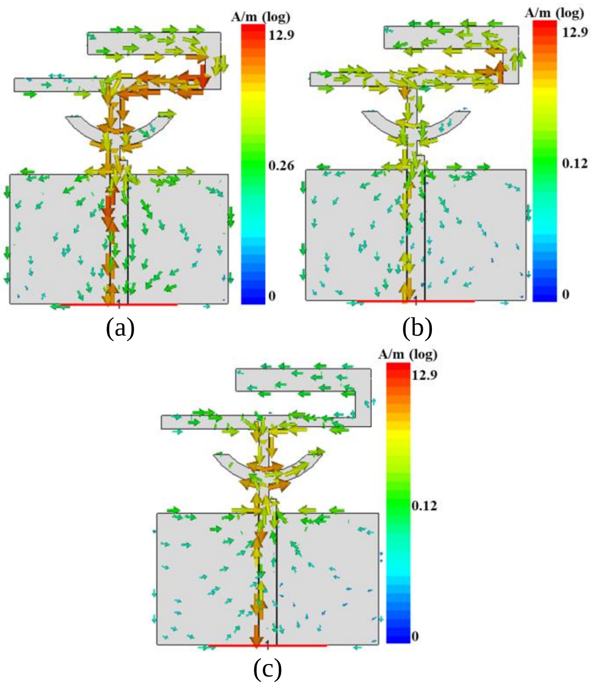


Fig. 7. Surface current distribution: (a) 1.56 GHz, (b) 2.41 GHz, and (c) 4.49 GHz.

Table 2: Comparison table

Characteristic	[12]	[8]	[9]	[10]	[6]	[7]	This Work
Area (mm^2)	1200	5625	3905	8496	3600	4500	1520
Height (mm)	0.4	4.8	1.6	1.6	0.4	1	1.6
Substrate	FR-4	FR-4	FR-4	FR-4	FR-4	FR-4	FR-4
No of resonance	2	2	3	2	3	3	3
Bandwidth (MHz)	130, 355	----	100, 110, 300	120, 750	22, 300, 9600	84, 200’ 100	109, 86, 284
Efficiency (%)	57, 58	85, 77		----	56, 70, 52	97, 95, 95	78, 77, 77

The proposed design is compared with some work published recently. Comparison in terms of various parameters is presented in Table 2. In [12] miniaturize design is presented, but only two resonances with minimum efficiency (even less than <58% are achieved). While [6], [9], and [10] are successful in attaining high bandwidth, but at the cost of size and number of resonances. Tri-band antennas proposed in [6], [7], & [9] cannot be easily integrated with most of the applications due to their bulky size. Moreover, [6] present-tri-band antenna with high bandwidth but low efficiency. It can be concluded that the proposed design is miniaturized and show better performance in terms of bandwidth, efficiency and radiation patterns. Table 3, summarizes overall performance of the proposed antenna at three different frequencies.

Table 3: Summarized results

Parameters	Frequency 1	Frequency 2	Frequency 3
Frequency (GHz)	1.565	2.415	4.49
Return loss (dB)	-29.76	-13.95	-19.375
Directivity (dB)	2.02	2.46	2.99
Gain (dBi)	1.03	1.33	1.84
Bandwidth (MHz)	109.5	86.8	283.9
Efficiency (%)	79.7	76.9	76.7
VSWR	1.067	1.501	1.24

IV. CONCLUSION

In this paper, coplanar waveguide (CPW) multiband antennas are designed and analyzed. The proposed antennas operate at three different frequencies, i.e., GPS (1.565 GHz), WLAN (2.45 GHz) and AMT fixed services (4.49 GHz). Radiating element consists of two parts, an extended L-shaped, while the other is an extended L-shaped with a crescent. Extended L-Shaped design is responsible for operation at two lower frequencies (1.565 GHz and 2.415 GHz), while the Ant-2 is responsible for the higher frequency (4.5 GHz). The proposed antennas are compact, lightweight and efficient (<76%) and can be used for different wireless applications. Prototype of the proposed designs is fabricated and measured. Both computed and simulated results are compared in term of return loss and gain pattern. The measured results show good agreement.

ACKNOWLEDGMENT

This work was financially supported by Vinnova (The Swedish Governmental Agency for Innovation Systems) and University of Engineering and Technology Taxila, Pakistan through the Vinn Excellence Centers program and ACTSENA research group funding, respectively.

REFERENCES

[1] A. Ramadan, M. Al-Husseini, K. Y. Kabalan, and A. EI-Hajj, "Fractal-shaped reconfigurable antennas," *INTECH Open Access Publisher*, vol. 1, pp. 237-250, 2011.

[2] V. Rajeshkumar and S. Raghavan, "A compact metamaterial inspired triple band antenna for reconfigurable WLAN/WiMAX applications," *AEU-Int. J. Electron. Commun.*, vol. 69, pp. 274-80, 2015.

[3] W. C. Liu, C. M. Wu, and N. C. Chu, "A compact low-profile dual-band antenna for WLAN and WAVE applications," *AEU-Int. J. Electron. Commun*., vol. 66, pp. 467-71, 2012.

[4] A. K. Gautam, A. Bisht, and B. K. Kanaujia, "A wideband antenna with defected ground plane for WLAN/WiMAX applications," *AEU-Int. J. Electron. Commun*., vol. 70, pp. 70, 2016.

[5] L. Bing, J. S. Hong, and B. Z. Wang, "A novel circular disc monopole antenna for dual-band WLAN applications," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 27, pp. 41-448, 2012.

[6] T.-H. Chang and J.-F. Kiang, "Compact multi-band H-shaped slot antenna," *IEEE Transactions on Antennas and Propagation*, vol. 61, pp. 4345-4349, 2013.

[7] H. Wang, and M. Zheng, "An internal triple-band WLAN antenna," *IEEE Antennas and Wireless Propagation Letters*, vol 10, pp. 569-572, 2013.

[8] M. F. Karim and A. Alphones, "A low-profile dual-band circularly polarized GPS antenna," *In Microwave Conference (APMC) Asia-Pacific*, pp. 1-4, 2016.

[9] C.-X. Mao, S. Gao, Y. Wang, and B. Sanz-Izquierdo, "A novel multiband directional antenna for wireless communications," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 1217-1220, 2017.

[10] X. He, S. Hong, H. Xiong, Q. Zhang, and E. M. Tentzeris, "Design of a novel high-gain dual-band antenna for WLAN applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 8, pp. 798-801, 2009.

[11] H. U. Iddi, M. R. Kamarudin, T. A. Rahman, and R. Dewan, "Design of dual-band B-shaped monopole antenna for MIMO application," *In Antennas and Propagation Society International Symposium (APSURSI), IEEE*, pp. 1-2, 2012.

[12] S. D. Sairam and S. A. Arunmozhi, "A novel dual-band E and T-shaped planar inverted antenna for WLAN applications," *In Communications and Signal Processing (ICCSP)*, pp. 1922-1926, 2014.

[13] T.-H. Chang and J.-F. Kiang, "Compact multi-band H-shaped slot antenna," *IEEE Transactions on Antennas and Propagation*, 61, no. 8, pp. 4345-4349, 2013.

[14] H. F. AbuTarboush, R. Nilavalan, S. W. Cheung, and K. M. Nasr, "Compact printed multiband antenna with independent setting suitable for fixed and reconfigurable wireless communication systems," *IEEE Trans. Antennas Propag*., vol. 60, pp. 3867-3874, 2012.

[15] A. Khan, S. I. Naqvi, F. Arshad, Y. Amin, and H. Tenhunen, "A compact quad-band CPW-fed planar resonator for multiple wireless communication applications," *Applied Computational Electromagnetics Society Journal*, vol. 32, pp. 11, 2017.

[16] 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, pp. 636-638, 2013.

[17] A. K. Gautam, L. Kumar, B. K. Kanaujia, and K. Rambabu, "Design of compact F-shaped slot triple-band antenna for WLAN/WiMAX applications," *IEEE Transactions on Antennas and Propagation*, vol. 64, pp. 1101-1105, 2016.

[18] R. Z. Wu, P. Wang, Q. Zheng, and R. P. Li, "Compact CPW-fed triple-band antenna for diversity applications," *Electronics Letters*, vol. 51, pp. 735-736, 2015.

[19] S. W. Chen, D. Y. Wang, and W. H. Tu, "Dual-band/tri-band/broadband CPW-fed stepped-impedance slot dipole antennas," *IEEE Transactions on Antennas and Propagation*, vol. 62, pp. 485-49, 2014.

[20] C. A. Balanis, *Antenna Theory, Analysis and Design*. 2nd ed., New York: J. Wiley & Sons, pp. 14, 68 and 817-820, 1997.

Ashfaq Ahmad received his B.Sc. degree in Telecommunication Engineering from UET Peshawar in 2016. He is doing his M.Sc. in Telecommunication Engineering from UET Taxila. Currently, he is doing research on reconfigurable antennas. His research interests include planar antenna, millimeter wave antennas, multi band antennas, implanted antennas, Specific Absorption Rate analysis and EBGs.

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.

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.

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 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), Stockholm, 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.