Miniaturized Cross-Lines Rectangular Ring-Shaped Flexible Multiband Antenna

Aqsa Javed [1], Asma Ejaz [1], Sumrin Mehak [1], Yasar Amin [1,2], Jonathan Loo [3], and Hannu Tenhunen [2,4]

[1] ACTSENA Research Group, Department of Telecommunication Engineering
University of Engineering and Technology, Taxila, Punjab 47050, Pakistan

[2] iPack Vinn Excellence Center, Department of Electronic Systems, Royal Institute of Technology (KTH)
Isafjordsgatn 39, Stockholm SE-16440, Sweden

[3] Department of Computer Science, School of Engineering and Information Sciences
Middlesex University, London, United Kingdom

[4] Department of Information Technology, TUCS, University of Turku, Turku 20520, Finland

Abstract **─** A compact, flexible antenna for wireless applications, i.e., WLAN/WiMAX/Wi-Fi, UMTS2100, C-Band, and DSRC is presented. The quad-band antenna is designed and analyzed in terms of efficiency, gain, radiation pattern, return loss, and VSWR. The optimized design consists of a CPW fed rectangular ring patch with the semi-circular ground. The cross-lines and the semi-circular ground is investigated to ascertain the multi-band effect. A concept of inset feed mechanism is also interpolated to enhance impedance matching. The framed antenna is examined under the bent condition as well. The reported work is an apt candidate for the proposed applications because of its high efficiency of 95% with a peak gain of 3.22 dBi along with VSWR less than 2. With stable radiation pattern and bandwidth, there is a justified concurrence between simulated and measured results.

Index Terms **─** Compact, CPW, cross-lines, flexible, inset feed, multi-band, rectangular ring.

I. INTRODUCTION

Emerging wireless communication technologies are fostering the ways for the multiband antennas that are conveniently mergeable with the anticipated systems. The communication systems are operable at different frequencies, and it leads to the coverage of diversified applications. Consequently, multi-band antennas are essential units for these multifunctional packages. The name of microstrip patch antennas has been marked in the list of most demanding antenna type due to the additional perks of mini-sized, lightweight and low-cost. Therefore, antenna designers are eagerly working on multiband microstrip patch antennas. Many techniques can be applied to make an antenna multiband in nature such as, substrate-integrated suspended-line technique [1], slotted patch [2, 3], adding stubs [4], defected ground structures [5], proximity coupled technique [6], cutting edges [7] and many more.

Traditionally, the antennas were designed by using the rigid substrates like FR4 as reported in [8-10]. The development in the flexible electronics market sparked the idea of scaled-down flexible antennas. The diminutive size of the antenna permits its easy integration into advanced electronic packages. The conformal devices are unable to assimilate rigid substrates and demand moldable antennas. The persistent advancement stimulates the researchers to work for the latest communication systems by designing miniaturized antennas under the flexible substrates for utilization in diverse applications. The advantages of low cost, easy fabrication, and light-weight of flexible substrates rate their value high in the market. In the near past, a lot of work focus has been directed towards multiband antennas on the conformal substrates, for example, kapton [11], liquid crystal polymer (LCP) [12], Rogers RT/duroid [13], cotton layer [14], polyethylene terephthalate (PET) film [15] and paper [16]. These recent research findings give a boost to the implementation of the conformal antennas as bending causes minimal effect on the performance of the antenna.

A novel CPW fed rectangular ring patch antenna is investigated in this paper. The presented work is unique in the category of multiband antennas for its compactness and flexibility. The metallic cross-lines are added to the rectangular ring and optimized along with circular ground for achieving multi-band effect of the antenna. The inset feed mechanism is used to improve impedance

Submitted On: December 20, 2018
Accepted On: January 26, 2019

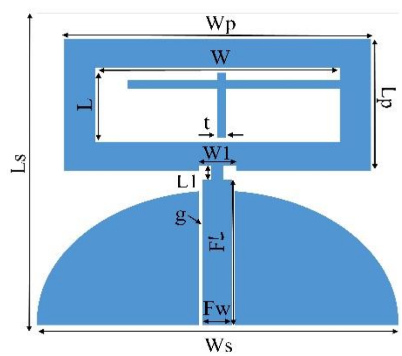
1054-4887 © ACES

matching. The presented work is suitable for UMTS (1900–2200 MHz), WiMAX (3.2–3.8, 5.1–5.8 GHz) bands WLAN/Wi-Fi (5.1-5.8 GHz), C-band (4-8 GHz) and dedicated short-range communication (DSRC 5.9 GHz) operations.

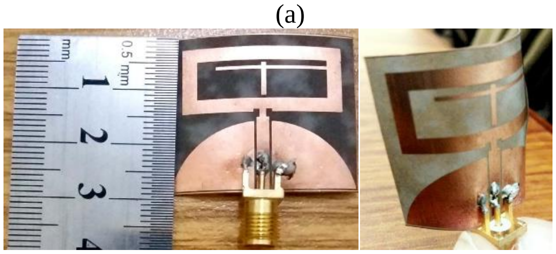
II. DESIGN PROCESS

A flexible CPW fed patch antenna is put forward in this paper. The antenna operates in multiple bands having the compact dimensions of $0.2176\lambda_0 \times 0.203\lambda_0$ and $0.59\lambda_0 \times 0.55\lambda_0$ with respect to lowest and highest resonant frequency, respectively. The simulations are performed in a commercially available simulation tool, i.e., CST Microwave Studio Suite®. The design is implemented on a flexible dielectric substrate Rogers® RT/duroid 5880 whose ε_r=2.2 and the tanδ=0.0009 with the thickness of 0.127 mm. The design process is executed by primarily designing a rectangular patch antenna. The design procedure went through four steps which will be discussed in the coming sections.

A rectangular ring patch antenna with embedded metallic cross-lines is shown in Fig. 1 (a). The semi-circular ground and the inserted cross-lines inside the rectangular ring are responsible for making the design operable in multiple frequency bands. The final antenna design resonates at four frequencies. The frequency bands achieved by the proposed antenna are 2.097-2.264 GHz for UMTS2100, 3.218-3.353 GHz for 3.5 GHz WiMAX, 4.28-4.81 GHz for C-band, and 5.7-6.2 GHz for 5/5.5/5.8 GHz WLAN/WiMAX/Wi-Fi, and DSRC.



(a)



(b)

Fig. 1. (a) Proposed antenna parameters with *Ls*=28mm, *Ws*=30mm, *Lp*=12mm, *Wp*=26mm, *L*=7mm, *W*=21mm, *L1*=1.5mm, *W1*=3mm, *Fw*=2mm, *Fl*=13mm, *t*=0.8mm, *g*=0.2mm, and (b) fabricated prototype.

A. Design approach

Initially, a CPW fed rectangular ring-shaped patch antenna is designed. Equation (1) and (2) provide a close estimation to predict the dimensions [17]:

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

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L, \qquad (2)$$

where W and L is the width and length of the patch, respectively, c is the speed of light, f_r stands for the resonant frequency, ε_r is the relative permittivity, ε_{reff} is the effective permittivity, and ΔL is the effective length. The dimensions of the design are finalized after running through a series of investigations and modifications. The performed simulation analyses authenticate that the addition of metal strips creates a way for the surface currents and paves a way to reach the four resonant frequencies.

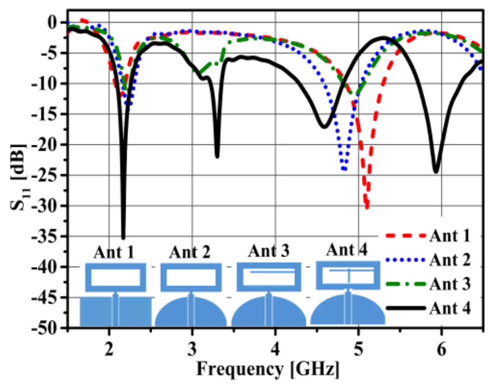


Fig. 2. The S-parameters of the four antennas.

Figure 2 illustrates the effects of a series of design modifications. The results of the optimized rectangular ring show that the antenna resonates at a frequency of 5.09 GHz (Ant 1). The ground structure is modified to semi-circular shape for an increased number of bands and improved impedance matching. Thus, the antenna starts resonating at two distinct bands, i.e., 2.24 GHz and 4.84 GHz (Ant 2). A horizontal metallic line is introduced inside the rectangular ring (Ant 3) which results in three different resonating frequency bands, i.e., 2.22 GHz, 3.09 GHz, and 4.96 GHz. At this stage, the frequency bands do not match accurately. A straight vertical metallic line is introduced onto the already embedded horizontal-line (Ant 4), and it tends to add another band. Thus, we get four frequency bands at 2.17 GHz, 3.3 GHz, 4.59 GHz, and 5.93 GHz by antenna type 4, whereas only three frequency bands are achieved in [18]. The concept of inset feed is introduced with stepped feed design to improve the impedance matching. Ant 4 is characterized as the final proposed antenna. The -10dB impedance bandwidth of all the four accomplished bands is greater than 100 MHz. The achieved peak gain is 3.22 dBi. The highest efficiency among the resonating bands is 95%.

III. RESULTS AND DISCUSSION

The fabricated prototype of the antenna is tested, and juxtaposition of the simulated and the measured results is reported. There is decent cooperation between the simulated and measured results. The slight mismatch in the results is owing to the fabrication errors, SMA connector soldering and, measurement limitations during the prototype formation. The design is simulated and analyzed under the bent condition as well. The proposed antenna is curved to a radial value of 30 mm. There is a slight change observed in the outcomes of the flat and curved antenna, but the curved antenna nicely covers the targeted bands.

A. Return loss

The return loss of the proposed antenna-under-test is co-plotted in Fig. 3. The results are displayed using a different colour scheme for a better pictorial representation. The antenna resonates at four distinct frequency bands with return loss values of 34.97 dB, 21.928 dB, 17.06 dB, and 24.41 dB at the resonant frequencies of 2.17 GHz, 3.3 GHz, 4.59 GHz, and 5.93 GHz, respectively. The bandwidths achieved are 167 MHz (2.097-2.264 GHz), 135 MHz (3.218-3.353 GHz), 530 MHz (4.28-4.81 GHz), and 500 MHz (5.7-6.2 GHz) at each resonant frequency, with reference to -10 dB line [19]. The return loss of the flat and the curved antenna is analysed, and no great deprivation in the results is spotted. A slight frequency shift occurs towards the right side at the 2nd resonant frequency. Whereas, the other resonating bands remain at the same position with some impact on S_{11} value.

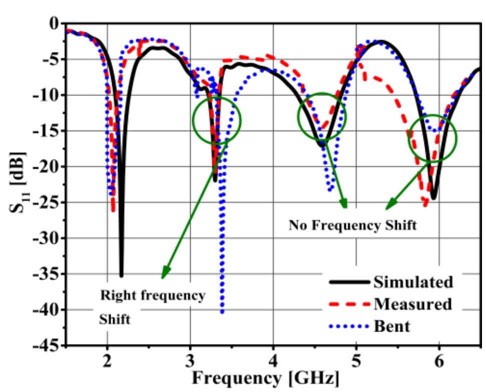


Fig. 3. Return loss of the proposed antenna.

B. Radiation patterns

The radiation characteristics of the presented antenna have also been studied. Figures 4 (a)-(h) depict the simulated and measured radiation patterns for the E (φ=0^0, y-z) and H (φ=90^0, x-z) plane at each central frequency. The E-plane characteristics depict the pattern like the number "Eight" which is a sound explanation for the antenna radiating bi-directional in E-plane. Whereas, the H-Plane radiation patterns illustrate that the antenna radiations are partially omni-directional and bi-directional at different resonant dips.

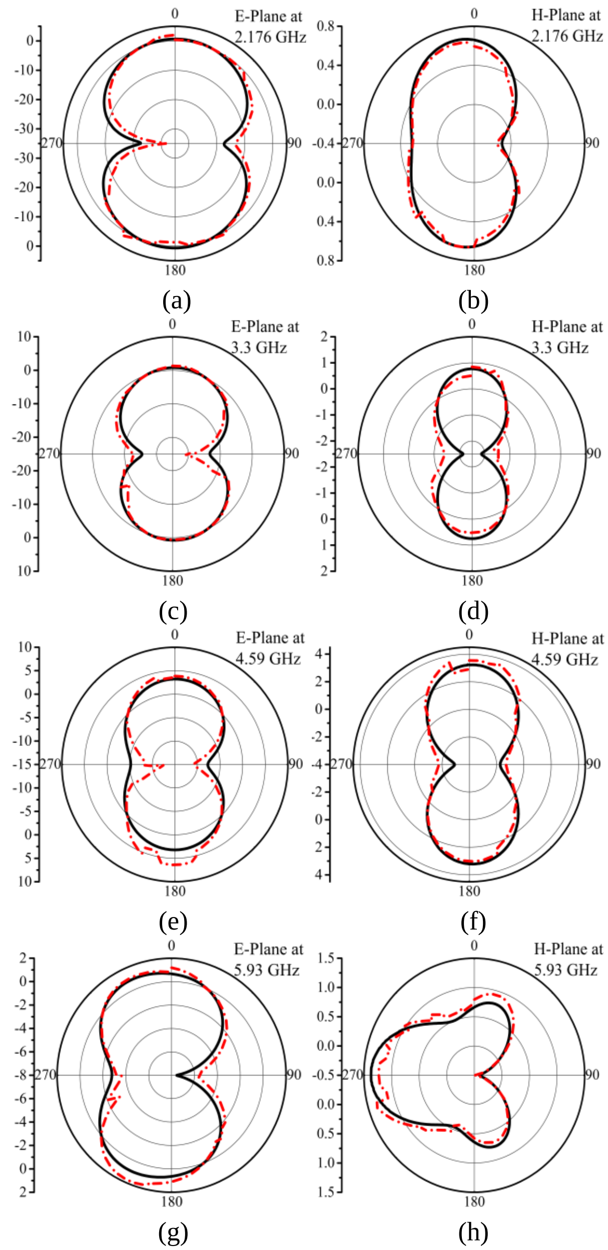
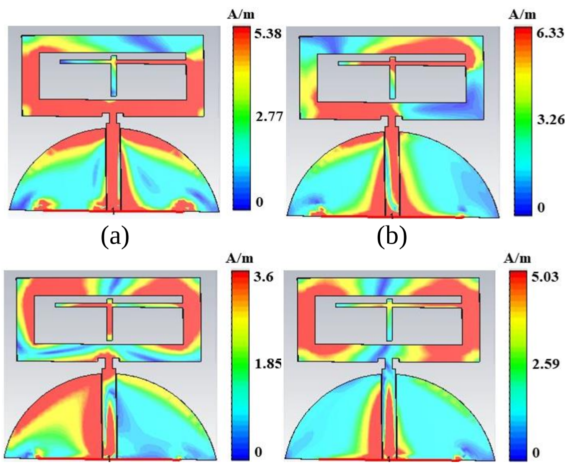


Fig. 4. Measured (dash line) and simulated (solid line) radiation pattern at each resonant frequency.

C. Current distributions

Figures 5 (a)-(d) offer the surface current distributions of the proposed antenna. They give satisfactory details about the effective area which tend to make suggested antenna resonate at the specific frequencies. Figure 5 (a) provides a visible indication of the antenna structure responsible for producing the lowest dip at 2.176 GHz. This figure depicts that the maximum density of current is at the edges of the ground and the main rectangular ring patch. Figure 5 (b) explains the appearance of another dip at 3.3 GHz. The figure gives a well-summarized description that the current density is along the horizontal line. Moreover, the current concentration is high at the upper and lower part of the rectangular ring. The current density around vertical line is highest at 4.93 GHz and is presented in Fig. 5 (c). This figure explains the reason for the third band as the position and size of the vertical line in the antenna causes the third frequency band to resonate. The current density at 5.93 GHz is depicted by Fig. 5 (d) which shows that the distribution of current is highest at the patch.



(a) (b)

(c) (d)

Fig. 5. Current distributions at each resonant frequency: 2.176 GHz, 3.3 GHz, 4.59 GHz, and 5.93 GHz.

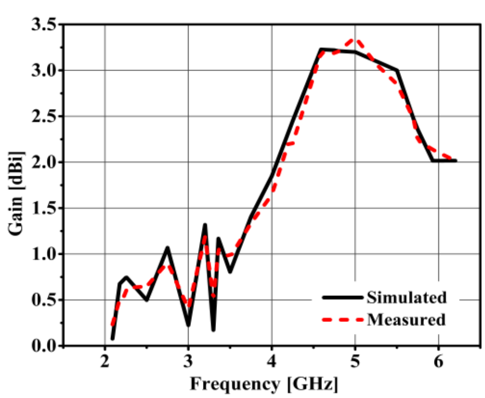


Fig. 6. Measured and simulated gain.

C. VSWR, gain and efficiency

The ascertained gain at operating frequency of each band is rational enough for a simple patch antenna. The attained peak gain is 3.22 dBi. Figure 6 depicts the gain at each resonating band.

The presented antenna is investigated for radiation efficiency. An admirable value of 95% efficiency is achieved highest among all the four bands. The VSWR values at each resonant frequency are below 2 which completely satisfies the required criteria [20].

Table 1 highlights the proposed antenna performance parameters such as gain, efficiency, bandwidth, return loss and VSWR for both states, i.e., bent and flat, which are fairly analogous and in good agreement.

Table 1: Comparison of antenna parameters before and after bending

Parameters	Before Bending				After Bending			
Freq. (GHz)	2.176	3.3	4.59	5.93	2.176	3.3	4.59	5.93
Return Loss (dB)	34.9	21.9	17.0	24.4	23.8	40.7	23.4	15.0
Bandwidth (MHz)	167	135	530	500	160	180	460	470
VSWR	1.06	1.18	1.32	1.12	1.27	1.09	1.29	1.43
Gain (dBi)	0.67	0.17	3.22	2.01	0.5	0.48	3.14	1.95
Efficiency (%)	72.9	54.8	87.8	95	71	70	80.9	97.1

The proposed work is kept under the comparative analysis with other related published work. The evaluated assessment is reported in Table 2. This table is an indication for the presented work to be a better choice for the desired applications.

Table 2: Comparison of proposed and previously reported antenna performance parameters

References	[2]	[10]	[13]	[16]	Proposed Antenna
Area (mm^2)	40 × 40	40 × 38	90 × 60	35 × 40	30×28
No. of operating bands	4	3	4	3	4
Gain (dBi)	1.43-3.06	1.03, 1.33, 1.84	5.47, 5.88, 1.97, 3.56	~0.3, ~0.35, ~2.9	0.67, 0.17, 3.22, 2.015
Bandwidth (MHz)	25, 25, 39, 41	109.5, 86.8, 283.9	260, 200, 160, 360	1320, 290, 990	165.7, 131.78, 529.8, 513.6
Efficiency (%)	42-74	79.7, 76.9, 76.7	------	45-58	72.9, 54.8, 87.8, 95
Flexibility	No	No	Yes	Yes	Yes

IV. CONCLUSION

A miniaturized flexible multi-frequency band antenna for quad-band operations is presented. The postulated design is appropriate for applications of WiMAX/WLAN/Wi-Fi, C-band, and DSRC. Cross-lines along with circular ground structure caused the antenna to interpret itself as multi-band in nature. An inset feed mechanism is applied to achieve the impedance matching followed by stepped feed structure. The prototype is kept under the bending analysis. There is a defensible correlation between simulated and measured results. The proposed antenna is analyzed and investigated concerning different performance parameters including return loss, gain, efficiency, and radiation pattern. The stable radiation characteristics are reported with an appropriate gain along with a very good antenna efficiency. The proposed work is an upright selection for the recommended wireless applications.

ACKNOWLEDGMENT

The authors would like to thank Higher Education Commission of Pakistan for Technology Development Fund (HEC-TDF) and Vinnova (The Swedish Government Agency for Innovation Systems) for financial assistance of this work.

REFERENCES

[1] Y. He, K. Ma, N. Yan, and H. Zhang, “Dual-band monopole antenna using substrate-integrated suspended line technology for WLAN application,” *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 2776-2779, 2017.

[2] A. Boukarkar, X. Q. Lin, Y. Jiang, and Y. Q. Yu, “Miniaturized single-feed multiband patch antennas,” *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 2, pp. 850-854, Feb. 2017.

[3] A. Araghi, “A compact planar ultra wideband antenna with triple-notched bands using capacitive coupled and parallel LC elements,” *Applied Computational Electromagnetics Society Journal*, vol. 31, no. 12, pp. 1416-1420, 2016.

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

[5] N. Gad and M. Vidmar, “Design of a microstrip-fed printed-slot antenna using defected ground structures for multiband applications,” *Applied Computational Electromagnetics Society Journal*, vol. 33, pp. 854-860, 2018.

[6] N. Majidi, M. R. Sobhani, B. Kılıç, M. Imeci, O. S. Güngör, and Ş. T. Imeci, “Design and comparison of 4 types of dual resonance proximity coupled microstrip patch antennas,” *Applied Computational Electromagnetics Society Journal*, vol. 33, no. 10, pp. 1135-1139, 2018.

[7] C. Hsu and S. Chung, “Compact multiband antenna for handsets with a conducting edge,” *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 11, pp. 5102-5107, Nov. 2015.

[8] M. Wu and M. Chuang, “Multibroadband clotted bow-tie monopole antenna,” *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 887-890, 2015.

[9] A. S. Supriya and J. Rajendran, “A low-cost tri-band microstrip patch antenna for GPS application,” *2017 Progress in Electromagnetics Research Symposium - Fall (PIERS - FALL)*, Singapore, pp. 60-65, 2017.

[10] A. Ahmad, F. Arshad, S. I. Naqvi, Y. Amin, and H. Tenhunen, “Design, fabrication, and measurements of extended L-shaped multiband antenna for wireless applications,” *Applied Computational Electromagnetics Society Journal*, vol. 33, no. 4, pp. 388-393, 2018.

[11] S. Ahmed, F. A. Tahir, A. Shamim, and H. M. Cheema, "A compact Kapton-based inkjet-printed multiband antenna for flexible wireless devices,” *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 1802-1805, 2015.

[12] E. Haque, S. Mahmuda, and F. Ahmed, “A capsule-like flexible multiband antenna for WBAN applications,” *TENCON 2017 - 2017 IEEE Region 10 Conference*, Penang, pp. 1614-1619, 2017.

[13] H. Liu, P. Wen, S. Zhu, B. Ren, X. Guan, and H. Yu, “Quad-band CPW-fed monopole antenna based on flexible pentangle-loop radiator,” in *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 1373-1376, 2015.

[14] S. M. H. Varkiani and M. Afsahi, “Grounded CPW multi-band wearable antenna for MBAN and WLAN applications,” *Microwave and Optical Technology Letters*, vol. 60, no. 3, pp. 561-568, 2018.

[15] A. T. Castro and S. K. Sharma, “Inkjet-printed wideband circularly polarized microstrip patch array antenna on a PET film flexible substrate material,” *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 1, pp. 176-179, Jan. 2018.

[16] H. F. Abutarboush, M. F. Farooqui, and A. Shamim, “Inkjet-printed wideband antenna on resin-coated paper substrate for curved wireless devices,” in *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 20-23, 2016.

[17] C. A. Balanis, *Antenna Theory, Analysis and Design*. 2nd ed., New York: J. Wiley & Sons, 1997.

[18] P. S. Bakariya, S. Dwari, M. Sarkar, and M. K. Mandal, “Proximity-coupled microstrip antenna for bluetooth, WiMAX, and WLAN applications,” *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 755-758, 2015.

[19] Mehr-e-Munir and U. Farooq, “Multiband microstrip patch antenna using DGS for L-band, S-band, C-band & mobile applications,” *2016 13th Inter-*

national Conference on Modern Problems of Radio Engineering, Telecommunications and Computer Science (TCSET), Lviv, pp. 198-201, 2016.

[20] V. Singh, B. Mishra, P. N. Tripathi, and R. Singh, "A compact quad-band microstrip antenna for S and C-band applications," *Microwave and Optical Technology Letters*, vol. 58, no. 6, pp. 1365-1369, 2016.

Aqsa Javed received her bachelor's degree in B.Sc. Telecommunication Engineering in 2017 from University of Engineering and Technology, Taxila, Pakistan. In 2017, she has joined ACTSENA research group as a Research Scholar plus started to pursue her master's degree focused on antennas from UET, Taxila, Pakistan.

Asma Ejaz received her B.Sc. and M.Sc. degree in Telecommunication Engineering from University of Engineering and Technology Taxila, Pakistan in 2013 and 2015, respectively. At present, she is an Instructor and a Ph.D. Research Scholar in the same institute. She is working under ACTSENA Research Group focused on passive chipless RFID tags and advancements in antenna design. She is also a student member of IEEE and Applied Computational Electromagnetics Society (ACES).

Sumrin Mehak Kabir received her B.E. degree from National University of Modern Languages, Islamabad, Pakistan, in 2013. She completed her M.S. in Electrical Engineering from National University of Sciences and Technology, Pakistan. Her research interest includes communication systems, signal processing, information coding, and antennas and wave propagation. Until now she has 8 publications in different journals and international conferences. Currently, she is doing her Ph.D. at the University of Engineering and Technology Taxila.

Yasar Amin is Chairman and Associate Professor of Telecommunication Engineering Department University of Engineering and Technology, Taxila, Pakistan. He is the Gounder of ACTSENA Research Group at UET Taxila, Pakistan. He did his B.Sc. in Electrical Engineering in 2001 and M.Sc. in Electrical Engineering in 2003 from Royal Institute of Technology (KTH), Sweden with specialization in System-on-chip design. His Ph.D. is in Electronic and Computer Systems from Royal Institute of Technology (KTH), Sweden, with his research focus printable green RFID antennas for embedded sensors. He is presently serving as leading Guest Editor at two International Journals and active Reviewer of more than a dozen well reputed international journals. He has contributed to over 40 journal papers, over 30 reviewed international conference papers.

Jonathan Loo a.k.a. Kok-Keong-Loo received his M.Sc. degree in Electronics from the University of Hertfordshire, UK in 1998 and his Ph.D. degree in Electronics and Communications from the same university in 2003. He leads a research team of 8 Ph.D. students in the area of communication and networking. His research interest includes network architecture, communication protocols, network security, embedded systems, video coding and transmission, wireless communications, digital signal processing, and optical networks. He has successfully graduated 13 Ph.D.'s as Principle Supervisor and contributed over 150 publications in the aforementionedspecialist areas.

Hannu Tenhunen is Chair Professor of Electronic Systems at Royal Institute of Technology (KTH), Stockholm, Sweden. Tenhunen has held Professor position as Full Professor, Invited Professor or Visiting Honorary Professor in Finland (TUT, UTU), Sweden (KTH), USA (Cornel U), France (INPG), China (Fudan and Beijing Jiaotong Universities) and Hong Kong (Chinese University of Hong Kong) and has an Honorary Doctorate from Tallinn Technical University. He has been Director of national large-scale research programs. He has actively contributed to VLSI and SoC in Finland and Sweden via creating new educational programs and research directions.