Printed Prototype of a Wideband S-Shape Microstrip Patch Antenna for Ku/K Band Applications

M. Habib Ullah[1,2], M. T. Islam[2], and J. S. Mandeep[1,2]

[1]Department of Electrical, Electronic, and System Engineering
Faculty of Engineering and Built Environment,
University Kebangsaan Malaysia, Bangi, Selnagor, Malaysia 43600
habib_ctg@yahoo.com, mandeep@eng.ukm.my

[2]Institute of Space Science (ANGKASA),
University Kebangsaan Malaysia Bangi, Selnagor, Malaysia 43600.
titareq@yahoo.com

Abstract **─** Design and analysis of a printed prototype of an S-shape slotted patch antenna for 16.8 GHz Ku band application is proposed in this paper. The proposed miniaturized S-shape patch antenna has been designed and analyzed by using market available Ansoft high frequency electromagnetic simulator and fabricated on a printed circuit board. The measured -10 db return loss bandwidth ranges from 15.35 GHz to 19.65 GHz (25.59 %) with achieved gain of 6.2 dBi at the resonant frequency 16.8 GHz. A radiation efficiency of 88.2 % and 80° (320°-40°) 3 dB beam width has been testified. The symmetric and almost steady radiation pattern of the proposed antenna has been made suitable for the frequency range from 15.35 GHz to 19.65 GHz. Furthermore, the current distribution over the radiating patch is examined and a parametric study of the ground plane size has been conducted in this study.

Index Terms **─** Anechoic measurement chamber, finite element method, printed circuit board, microstrip patch antenna, and wideband.

I. INTRODUCTION

With the rapid growth of wireless technology antenna miniaturization has become a vital concern for the development of compact communication terminal [1-3]. Nowadays, all electronic communication devices are compulsory to be compact, smaller size, lightweight, and low cost with multiband operation capability [4-7]. Antennas are needed to be small enough to be integrated with compact communication module. Due to low profile, low cost, easy integration, and manufacturability; the demand of planar microstrip patch antenna has been increased to be integrated with more than one communication system into a compact module [8-12]. In order to design such small multifunctional wireless devices, antenna modules are required to be miniaturized accordingly [13-15]. To design miniaturized patch antennas for multiband operation, radiation efficiency, wide bandwidth, low manufacturing cost, steady radiation patterns, and consistent gain are required to be taken in to account. A number of studies on multiband antenna design have been reported, including DNG ZOR based antenna for multiband operation [16], switch fed reconfigurable antenna structure [17], flat-plate inverted-F antenna [18], step-shaped microstrip line fed printed monopole slot antenna [19], and folded 3D monopole multiband antenna [20].

A considerable amount of research effort has been given to design small antennas for Ku/K band applications. Due to scarcity of the bandwidth in lower bands and availability in higher band, Ku/K band has become very popular for radar applications. Recently, numerous small

Submitted On: May 30, 2012
Accepted On: Feb. 6, 2013

patch antennas are investigated for Ku/K band applications. A comprehensive analysis of MIMO SAR, virtual antenna has been done [21], wideband EBG antenna using double-layer frequency selective surfaces [22], an active phased array antenna for Ku-Band for mobile satellite [23], linearly polarized omnidirectional planar filtenna Ku-band [24], dual-polarized low-profile hemispherical luneburg lens antennas [25] etc.

An 8×10 mm^2 S-shape planar microstrip line fed slotted patch antenna has designed and configured for Ku/K band SAR remote sensing applications. The designed antenna has been fabricated on a printed circuit board (PCB). The low cost, long lasting, market available 1.5 mm thick FR4 material used as antenna substrate with dielectric constant (ε_r) of 4.6. The proposed antenna has been measured in far field environment and measured -10 dB return loss bandwidth 4.3 GHz from 15.35 GHz to 19.65 GHz with peak gain 8.77 dBi and 90.8 % of radiation efficiency. The symmetric and nearly steady and omnidirectional radiation pattern has also been measured. Furthermore, the effects of the length of ground plane have analyzed.

II. PROPOSED ANTENNA DESIGN AND CONFIGURATION

The proposed S-shape antenna has been designed and analyzed by using finite element method (FEM) based market available high frequency electromagnetic simulator [26-27]. Figure 1 shows the schematic diagram of the proposed antenna design geometry. S-shape is obtained by cutting slots from the rectangle plate. The design of the microstrip radiating patch element of the proposed antenna comprises of the configuration of its dimensions. The basic idea of the patch dimension was taken from the established mathematical formulation [27]. Although, the available mathematical modeling is based on the conventional rectangular patch for the slotted S-shape radiating patch the dimension is determined using test and modify method,

$$W = \frac{c}{2f_0}\sqrt{\frac{\varepsilon_r+1}{2}} \tag{1}$$

$$L = \frac{c}{2f_0\sqrt{\varepsilon_r}} - 2\Delta l \, . \tag{2}$$

In the above equations (1) and (2), W is the width and L is the length of the patch, f_0 is the center resonant frequency, c is the speed of light in vacuum. The effective dielectric constant can be calculated by using the following equation [27],

$$\varepsilon_e = \frac{1}{2}(\varepsilon_r+1) + \frac{1}{2}(\varepsilon_r-1)\sqrt{\left(1+\frac{10h}{W}\right)} \tag{3}$$

where ε_r is the relative dielectric constant and h is the thickness of the substrate. Due to the fringing field around the periphery of the patch, the antenna electrically looks larger than its physical dimensions. The increment to the length, Δl due to the fringing field and can be expressed as [28],

$$\Delta l = 0.412h\frac{(\varepsilon_e+0.3)\left[\frac{w}{h}+0.8\right]}{(\varepsilon_e-0.258)\left[\frac{w}{h}+0.8\right]} \, . \tag{4}$$

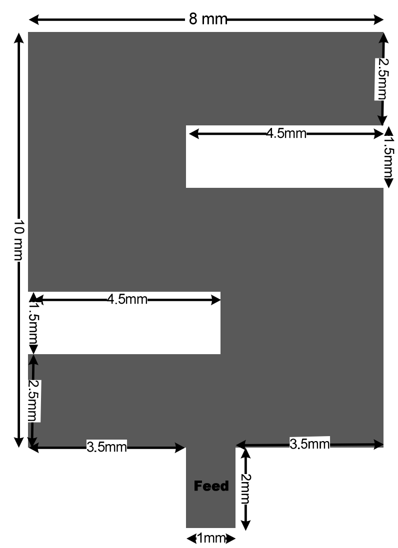
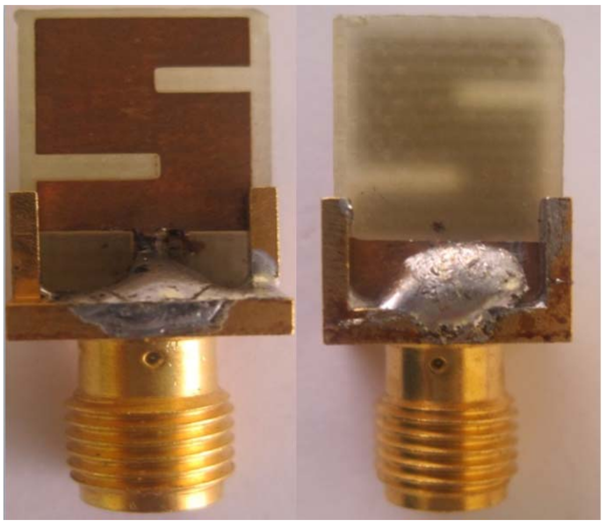


Fig. 1. Schematic diagram of the proposed antenna.

The patch width (W) has a minor effect on the resonance and it has been determined by using the mathematical modeling [29]. The length of the radiating patch (L), location of the feeding point and the slots has a dominant effect on the resonance. The length of the patch (L) is 0.44 λ and the width (W) is 0.56 λ, where λ is the corresponding wavelength at the resonance 16.8 GHz. By carefully tuning the dimension and location of the two 2.5×1.5 mm^2 slots the desired frequency band has been determined. The photograph of the proposed antenna prototype is shown in Fig. 2. A 2 mm long 1 mm wide microstrip line has been used for the feeding to meet the 50 ohm impedance characteristics. An SMA connector has been used at the end of the microstrip feed line for excitation.



(a) (b)

Fig. 2. Printed prototype (a) patch and (b) ground plane of the proposed antenna.

The proposed antenna is modeled as resistors with a standard 50 Ω, when designing the interface circuits at the operating frequencies. Figure 3 has illustrated the equivalent RLC circuit model of the proposed antenna. 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 the equivalent circuit modeling using only a single augmentation. A satisfactory agreement is also observed between SPICE and MoM simulations at the resonant frequencies. The RLC parameter is frequency dependent, the resonant frequencies have been determined by a conducting element L. The circuit parameters are R1 = 704.031 Ohm, R2 = 122.382 Ohm, R3 = 36.411 Ohm, C1 = 0.0516 PF, C2 = 0.0809 PF, C3 = 0.477 PF, and L = 0.0335 nH. The circuit shows high pass filter characteristics without inductor L. The resonant frequency has been determined by a conducting element L.

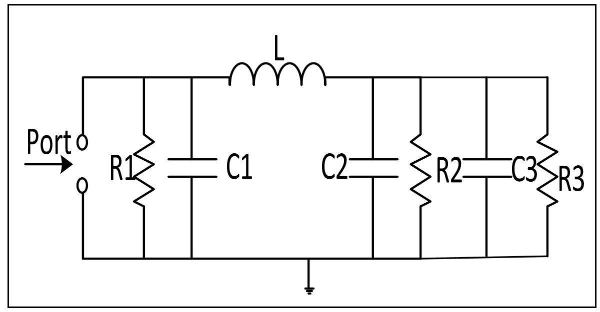


Fig. 3. Equivalent RLC circuit of the proposed antenna.

III. RESULTS AND ANALYSIS

The results of the proposed antenna prototype have been measured in a rectangular shape 5.5 m × 5 m × 3.5 m anechoic measurement chamber. A double ridge guide horn antenna is used as a reference antenna. The photograph of the anechoic measurement chamber is shown in Fig. 4. Pyramidal shape electrically-thick foam absorber with less than -60 dB reflectivity at normal incidence is used on the wall, ceiling, and floor. A turn table of 1.2 m diameter is used to rotate the measuring antenna with specification, 1 rpm rotation speed; 360^{o} rotation angle connected with a 10 meter cable between controllers. An Agilent vector network analyzer (VNA) range up to 20 GHz is used for measurement procedures.

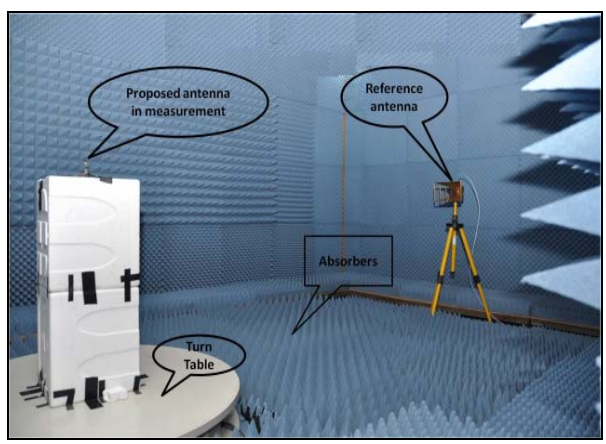


Fig. 4. Illustration of the anechoic measurement chamber.

The return loss of the proposed antenna with three different lengths of the ground plane is shown in Fig. 5. It can be clearly seen that, the return loss value is much lower and a wider bandwidth is achieved from the proposed antenna with 4.5×2 mm^2 ground plane. The simulated and measured return loss of the proposed antenna is shown in Fig. 6. It can be observed from the graph that, 4.3 GHz (15.35 GHz – 19.65 GHz) -10 dB bandwidth has been measured from the proposed antenna prototype. The measured bandwidth covers 2.65 GHz of Ku band and 1.65 GHz of K band. Figure 7 shows the achieved radiation efficiency and gain of the proposed antenna. The average gain of the proposed antenna is 5.39 dBi and the average radiation efficiency is 88.25 %, which have been obtained over the entire operating frequency from 15.35 GHz to 19.65 GHz. A 6.20 dBi gain with 88.21 % radiation efficiency has been achieved at the of 16.8 GHz.

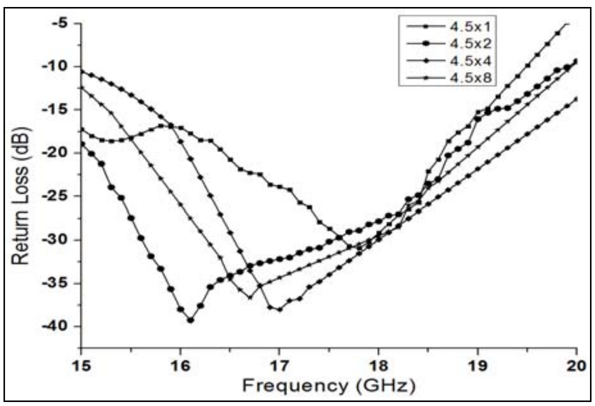


Fig. 5. Return loss of the antenna with four different ground plane sizes.

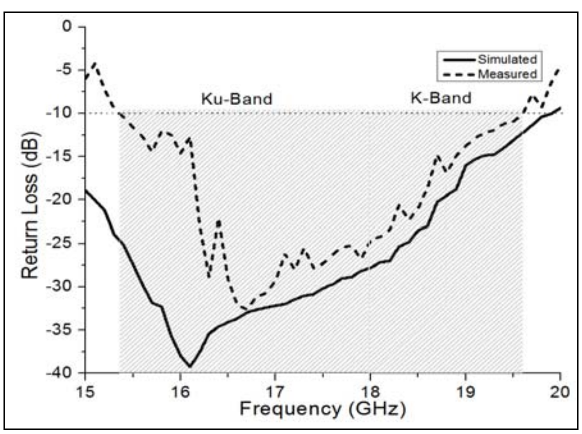


Fig. 6. Simulated and measured return loss of the proposed antenna.

The simulated and measured radiation pattern of the proposed antenna prototype are shown in Fig. 8. The measured 3 dB beam width 80° (320°-40°) can be clearly seen from the E-plane radiation pattern. It can also be observed from the radiation pattern, that the proposed antenna can operate as omnidirectional. In both radiation pattern of E- and H-planes, the cross-polar effect is much lower than the co-polar effect, which is desired. The measured co-polar value is not less than -10 dB from 290° to 90°, from 160° to 210° in E-plane and in H-plane from 260° to 80° and from 190° to 240°. The symmetric and almost steady radiation pattern makes the proposed antenna suitable for smooth operation in part of the K/Ku band application.

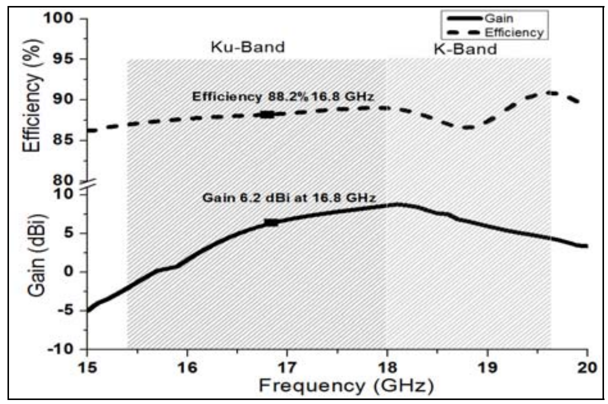


Fig. 7. Gain and efficiency of the proposed antenna.

Table 1: Comparison between the proposed antenna and some existing antennas.

Author	Proposed	[30]	[31]	[32]
Frequency (GHz)	16.8	2.08	2.0	1.309
Size (mm^2)	20x14	79x38	58x58	40x40
Bandwidth (GHz)	4.3	0.440	1.03	0.009
Gain (dBi)	6.2	9.5	9.3	1.9

The current distribution along the radiating patch is shown in Fig. 9. The current flows stronger near the feeding point and around the cutting edge and weaker in the upper side farthest from the feed line. Comparison between the proposed antenna and some existing antennas is shown in Table 1. It can be clearly seen that, the proposed antenna is smaller in size with wider bandwidth and high gain. Conversely, some of reported antennas achieved higher gain compromising the overall size. These antennas would need bigger space to be integrated with small devices, which is not preferred.

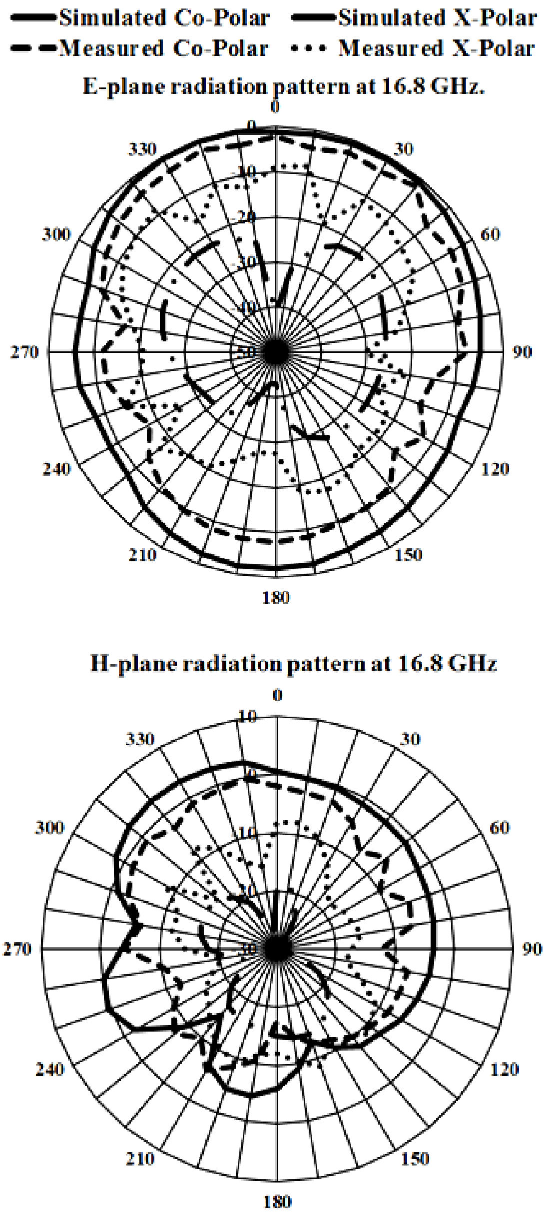


Fig. 8. E- and H-planes radiation pattern of the proposed antenna.

IV. CONCLUSION

A 0.44 λ × 0.56 λ microstrip line fed S-shape electrically small patch antenna has been designed, analyzed, and measured in this paper. The proposed slotted patch antenna has been fabricated on a 1.6 mm thick commonly available FR4 substrate. A parametric study of the proposed antenna has been conducted with four different lengths of ground plane and an optimized dimension is chosen. The measured -10 dB return loss bandwidth 4.3 GHz operating frequency from 15.35 GHz to 19.65 GHz with maximum gain 8.77 dBi of the proposed antenna prototype. The measured bandwidth covers 2.65 GHz of Ku band and 1.65 GHz of K band. The radiation efficiency of 88.21 % and gain 6.20 dBi has been achieved at the resonant frequency 16.8 GHz. The proposed antenna shows the omnidirectional pattern of a steady radiation characteristics.

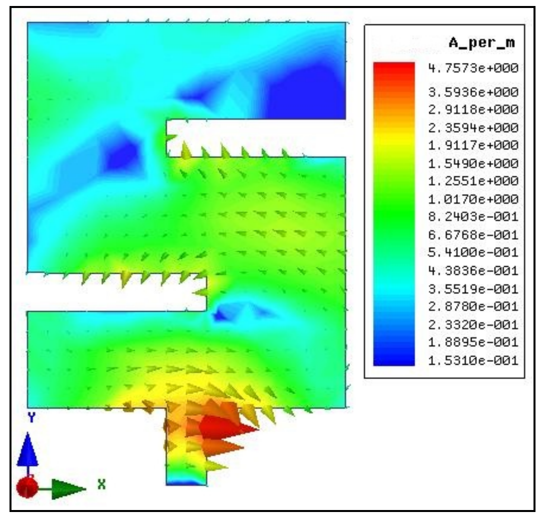


Fig. 9. Current distribution along the radiating patch of the proposed antenna.

REFERENCES

[1] M. Mighani, M. Akbari, and N. Felegari, "A novel SWB small rhombic microstrip antenna with parasitic rectangle into slot of the feed line," *Appl. Comp. Electro. Society (ACES) Journal*, vol. 27, no. 1, pp. 74-79, Jan. 2012.

[2] M. Mighani, M. Akbari, and N. Felegari, "A CPW dual band notched UWB antenna," *Appl. Comp. Electro. Society (ACES) Journal*, vol. 27, no. 4, pp. 352-359, April 2012.

[3] R. Azim, M. T. Islam, and N. Misran, "Design of a planar UWB antenna with new band enhancement technique," *Appl. Comp. Electro. Society (ACES) Journal*, vol. 26, no. 10, pp. 856-862, Oct. 2011.

[4] A. T. Mobashsher, M. T. Islam, and N. Misran, "Wideband compact antenna with partially radiating coplanar ground plane," *Appl. Comp. Electro. Society (ACES) Journal*, vol. 26, no. 1, pp. 73-81, Jan. 2011.

[5] D. Yang, Y. C. Jiao, P. Fei, B. Li, and Q. T. Zhang, "Design of a multiband quasi-yagi-type antenna with CPW-to-CPS transition," *IEEE Antennas Wirel. Propag. Lett.*, vol. 10, pp. 1120-1123, 2011.

[6] J. William and R. Nakkeeran, "A new UWB slot antenna with rejection of WiMax and WLAN bands," *Appl. Comp. Electro. Society (ACES) Journal*, vol. 25, no. 9, pp. 787-793, Sep. 2010.

[7] R. Azim, M. T. Islam, and N. Misran, "Compact tapered shape slot antenna for UWB applications," *IEEE Antennas Wirel. Propag. Lett.*, vol. 10, pp. 1190-1193, 2011.

[8] D. S. Javan and O. H. Ghouchani, "Cross slot antenna with U-shaped tuning stub for ultra wideband applications," *Appl. Comp. Electro. Society (ACES) Journal*, vol. 24, no. 4, pp. 427-432, August 2009.

[9] M. N. –Jahromi and N. K. -Barchloui, "Analysis of the behavior of Sierpinski carpet monopole antenna," *Appl. Comp. Electro. Society (ACES) Journal*, vol. 24, no. 1, pp. 32-36, Feb. 2009.

[10] C. Y. D. Sim, F. R. Cai, and Y. P. Hsieh, "Multiband slot-ring antenna with single- and dual-capacitive coupled patch for wireless local area network/worldwide interoperability for microwave access operation," *IET Microwaves, Antennas & Propag.*, vol. 5, no. 15, pp. 1830-1835, 2011.

[11] M. N. Shakib, M. T. Islam, and N. Misran, "High gain W-shaped microstrip patch antenna," *IEICE Electron. Express*, vol. 7, no. 20, pp. 1546-1551, 2010.

[12] A. A. L. Neyestanak, F. H. Kashani, and K. Barkeshli, "W-shaped enhanced-bandwidth patch antenna for wireless communication," *Wireless Personal Communications*, vol. 43, no.4, pp. 1257-1265, 2007.

[13] D. K. Ntaikos, N. K. Bourgis, and T. V. Yioultsis, "Metamaterial-based electrically small multiband planar monopole antennas," *IEEE Antennas Wirel. Propag. Lett.*, vol. 10, pp. 963-966, 2011.

[14] W. -C. Liu, W. -R. Chen, and C. -M. Wu, "Printed double S-shaped monopole antenna for wideband and multiband operation of wireless communications," *IEE Proceedings Microwaves, Antennas and Propag.*, vol. 151, no. 6, pp. 473-476, 2004.

[15] 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, June 2011.

[16] J. K. Ji, G. H. Kim, and W. M. Seong, "A compact multiband antenna based on DNG ZOR for wireless mobile system," *IEEE Antennas Wirel. Propag. Lett.*, vol. 8, pp. 920-923, 2009.

[17] A. C. K. Mak, C. R. Rowell, R. D Murch, and M. Chi-Lun, "Reconfigurable multiband antenna designs for wireless communication devices," *IEEE Trans. Antennas Propag.*, vol. 55, no.7, pp. 1919-1928, 2007.

[18] L. Pazin, N. Telzhensky, and Y. Leviatan, "Multiband flat-plate inverted-F antenna for Wi-Fi/WiMAX operation," *IEEE Antennas Wirel. Propag. Lett.,* vol. 7, pp. 197-200, 2008.

[19] K. –L. Wong and L. –C. Lee, "Multiband printed monopole slot antenna for WWAN operation in the laptop computer," *IEEE Trans. Antennas Propag.*, vol. 57, no. 2, pp. 324-330, 2009.

[20] H. Kanj and S. M. Ali, "Compact multiband folded 3-D monopole antenna," *IEEE Antennas Wirel. Propag. Lett.*, vol. 8, pp. 185-188, 2009.

[21] W. –Q. Wang, "Virtual antenna array analysis for MIMO synthetic aperture radars," *International Journal of Antennas and Propag.*, ID 587276, vol. 2012, pp. 1-10, 2012.

[22] L. Moustafa and B. Jecko, "Design of a wideband highly directive EBG antenna using double-layer frequency selective surfaces and multifeed technique for application in the Ku-band," *IEEE Antennas Wirel. Propag. Lett.*, vol. 9, pp. 342-346, 2010.

[23] S. Vaccaro, D. Llorens, J. Padilla, and R. Baggen, "Low cost Ku-band electronic steerable array antenna for mobile satellite communications," *in Proc.5th European Conference on Antennas and Propagation (EUCAP)*, Rome, Italy, pp. 2362-2366, 11-15 April 2011.

[24] C. Yu, W. Hong, Z. Kuai, and H. Wang, "Ku-band linearly polarized omnidirectional planar filtenna," *IEEE Antennas Wirel. Propag. Lett.*, vol. 11, pp. 310-313, 2012.

[25] A. R. Weily and N. Nikolic, "Dual-polarized planar feed for low-profile hemispherical luneburg lens antennas," *IEEE Trans. Antennas Propag.*, vol. 60, no. 1, pp. 402-407, 2012.

[26] M. Habib Ullah, M. T. Islam, J. S. Mandeep, and N. Misran, "A new bouble L shape multiband patch antenna on polymer resin material substrate," *Appl. Phys. A-Mater. Sci. Process.*, vol. 110, no. 1, pp. 199-205, 2012.

[27] M. H. Ullah, M. T. Islam, M. S. Jit, and N. Misran, "A three-stacked patch antenna using high-dielectric ceramic material substrate," *J. Intell. Mater. Syst. Struct.*, vol. 23, no. 16, pp. 1827-1832, 2012.

[28] M. Habib Ullah, M. T. Islam, J. S. Mandeep, and N. Misran, "A compact wideband antenna on dielectric material substrate for K band," *Electronics and Electrical Engineering*, vol. 123, no. 7, pp. 75-78, 2012.

[29] Q. Rao and W. Geyi, "Compact multiband antenna for handheld devices," *IEEE Trans. Antennas Propag.*, vol. 57, no.10, pp. 3337-3339, 2009.

[30] M. T. Islam, M. N. Sakib, and N. Misran, "Design analysis of high gain wideband L-probe FED microstrip patch antenna," *Progress In Electromagnetics Research (PIER)*, vol. 95, pp. 397-407, 2009.

[31] 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 Wirel. Propag. Lett.*, vol. 11, pp. 427-430, 2012.

[32] S. L. C. Xiao, Y. X. Guo, Y. -Y. Bai, M. -C. Tang, and B. -Z. Wang, "Compact circularly-polarised microstrip antenna with symmetric-slit," *Electron. Lett.*, vol. 48, no. 4, pp. 195-196, 2012.

Mohammad Habib Ullah was born in Chittagong, Bangladesh in 1980. He has awarded his B.Sc Honors in Computer and Communication Engineering from International Islamic University Chittagong (IIUC), Bangladesh and M.Sc. degree in Communication Engineering from International Islamic University Malaysia (IIUM) in 2003 and 2011, respectively. He has worked several national and international companies in Bangladesh, Kingdom of Saudi Arabia and Malaysia as engineer and academician. He worked as research assistant in several research project funded by government and non-government organization. Currently, he is pursuing his Ph.D. degree at Universiti Kebangsaan Malaysia and worked as research assistant at Institute of Space Science (ANGKASA) in a research project funded by Malaysian government. He has authored and co-authored 26 International refereed journal articles and 5 conference papers. His research interest focuses on telecommunication, wireless communication, MIMO, CDMA, antenna & propagation, networking etc. He is editor and reviewer of several reputed indexed peer reviewed journals.

Mohammad Tariqul Islam was born in Dhaka, Bangladesh in 1975. He received his B.Sc. and M. Sc. Degrees in Applied Physics and Electronics from the University of Dhaka, Dhaka, Bangladesh in 1998 and 2000, respectively and a Ph.D. degree in Telecommunication Engineering from the Universiti Kebangsaan Malaysia (UKM) in 2006. In August 2000, he became an Adjunct Research Fellow at Bose Research Center, University of Dhaka, Dhaka. From September 2000 until June 2002, he worked as a lecturer at International Islamic University Chittagong (IIUC), Dhaka. In August 2006, he became an Assistant Professor at IIUC. He has been very promising as a researcher, with the achievement of several International Gold Medal awards, a Best Invention in Telecommunication award and a Special Award from Vietnam for his research and innovation. He has filled 6 patent applications. He has authored or co authored 102 international journal papers and 90 international and local conference papers and 3 books. Thus far, his publications have been cited 560 times, and the H-index is 15 (Source: Scopus). He has been awarded "Best Researcher Award" in 2010 and 2011 at UKM. He served as a faculty member at the Multimedia University (MMU), Malaysia from May 2007 until May 2008. He is currently a Professor at the Institute of Space Science (ANGKASA), UKM, Malaysia. He is also an associate fellow of the Institute of Visual Informatics. His research interests concern enabling technology for RF, antenna technology, electromagnetic absorption and radio astronomy instruments. He is now handling many research projects from the Ministry of Science, Technology and Innovation (MOSTI), Ministry of Higher Education Malaysia (MOHE) and some International grants from Japan.

Mandeep Jit Singh received his B.Eng. (with honors) and Ph.D. degrees in Electrical and Electronic Engineering from the University of Notrhumbria, UK, and Universiti Sains Malaysia, in 1998 and 2006, respectively. From 2006 up to June 2009, he was attached at Universiti Sains Malaysia as a Lecturer. Currently, he is attached to the Universiti Kebangsaan Malaysia as a Senior Lecturer. His areas of specialization are radiowave propagation in satellite communication system, radar, antenna design, RF, and microwave. His current research collaboration is with the Association of Radio Industries and Business (ARIB) Japan to analyze the rain fade at Ku-band in tropical climate using satellite involving countries such as Thailand, Philippines, Indonesia, and Fiji. Singh has published 30 papers in journals, most in his special field radiowave propagation. He has reviewed more than 40 articles from IEEE Journals to PIERS Journals.