A Triple-Band Antenna Loaded with Reflector Surface for WLAN and 5G Applications

Tengfei Hu, Zhenni Pan, Megumi Saitou, Jiang Liu, and Shigeru Shimamoto
Department of Computer Science and Communication Engineering of Waseda University, Tokyo 169-8555, Japan
Email: hutengfei@fuji.waseda.jp, zhenni.pan@aoni.waseda.jp, megumi.saitou@ruri.waseda.jp, liujiang@aoni.waseda.jp, shima@waseda.jp

Abstract—In this paper, a novel triple-band antenna with reflector surface which has the property of both artificial magnetic conductor (AMC) surface and perfect electric conductor (PEC) for WLAN and Sub-6G 5G applications is proposed. The presented antenna is composed of two parts: the AMC surface and the microstrip-fed printed dipole. Baluns are used to excite the dipoles. This antenna design combines the advantages of AMC and PEC. In lower band and middle band, the inserted board works as AMC surface. This AMC surface can help the antenna to achieve unidirectional radiation pattern and low-profile characteristics. While at upper band the antenna works as PEC surface. PEC surface increases the gain of the antenna in upper band. As a result, the proposed antenna can offer an impedance band from 2.39 GHz to 2.63 GHz and from 3.61 GHz to 3.72 GHz and from 5.61 GHz to 5.84 GHz when the S11 is less than - 10dB. Stable radiation patterns with peak gain of 5.6 dBi, 6.5 dBi and 9.6 dBi are obtained in lower band, middle band and upper band, respectively. The proposed antenna can be used for multiband base stations for WLAN and 5G applications.

Index Terms—Artificial Magnetic Conductor (AMC), Perfect Electric Conductor (PEC), triple band, WLAN, Sub-6G 5G applications

I. INTRODUCTION

With the rapid development of wireless communication systems such as LTE, WLAN, 4G and 5G communication, the demand for multiple band or broad band antennas is growing. Printed microstrip antenna is a suitable candidate because of its attractive features such as light weight, low cost, low profile and easy conformability [1]. Recently, many types of microstrip antennas, which has different structures, such as V-sleeve shape [2], meander T-shaped strip [3], asymmetric E-shaped strip [4] and loading symmetrical L-strip [5], are proposed to realize multiband, miniaturization and wide impedance bandwidth. Among these studies, utilizing a thick substrate [4] and cutting the slots in the patch are known as the most common methods [6]. Meanwhile, in order to realize unidirectional radiation pattern with low profile, many studies have adopted a method of combining Artificial Magnetic Conductors (AMC) and antennas. It is well known that the image current obtained by a Perfect Magnetic Conductor (PMC) is in parallel and in-phase with original current [6]. AMC is a kind of metamaterial that emulates the behavior of Perfect Magnetic Conductor (PMC) [6] [8]. Due to the inherent of AMC in phase reflection characteristics, antenna with AMC structure potentially improves the performance such as gain, bandwidth and radiation properties, and so on [9]. Previous studies mainly use metal reflectors as Perfect Electric Conductor to achieve stable unidirectional radiation patterns. However, usually the distance between the antenna and the metal reflector is about 1/4 wavelength, because the direct and reflected electric field are in-phase at the dipole [10]. Some researches in [1] have been carried out to design low-profile antennas using AMC surface. Some researchers also use mushroom-type AMC to enhance the performance of the low profile microstrip antennas [11]. This is a very common method, but it is difficult to integrate in microwave and millimeter-wave circuits because of the necessity of via. For the antenna in [12], [13], low-profile dual-band dual-polarized antennas with an AMC surface is proposed. However, the design of [12] is complicated and the antenna in [13] is not very integrated and somewhat complex and difficult to be fabricated.

In this paper, a novel triple-band antenna loaded with the reflector surface for Sub-6GHz 5G communication and WLAN applications is proposed. The system can cover 2.4/5.8 GHz WLAN and Sub-6G 5G communication spectrums. Meanwhile, unlike other researches, this design takes the advantages of both AMC and PEC. At 2.4 GHz and 3.6 GHz, the FR-4 ground plane works as AMC surface, while at 5.8 GHz it is treated as PEC surface. It obtains the three measured operating bandwidths from 2.39 to 2.63 GHz, from 3.61 to 3.72 GHz and from 5.61 to 5.84 GHz, respectively. Achieving good impedance matching of triple band and unidirectional radiation patterns with enhanced gains are the remarkable characteristics of this design. Moreover, the utilization of AMC and PEC features not only simplifies the design, but also realize unidirectional radiation pattern in all three bands. The simulated results have been obtained by using the commercial simulation software HFSS and the measured results have been obtained by using the Keysight E5063A vector network analyzer.

This paper is organized as follows. Section II provides a comprehensive description of the geometry of AMC and the proposed triple band antenna. The simulated analysis of the AMC surface and the proposed antenna are described in Section III. A comparison of

Manuscript received April 18, 2020; revised Septmber 30, 2020.
doi:10.12720/jcm.15.10.729-734

measurement results and simulation analysis is also presented in this sectioA conclusion is given in Section IV.

II. GEOMETRY OF THE ANTENNA

The geometry of the proposed triple band antenna is shown in Fig. 1(a)-(b). As demonstrated in Fig. 1(a), the antenna consists of only two parts: the microstrip antenna and a reflector that can be used both as AMC and PEC surface. The triple band dipole microstrip antenna which is mounted on the reflector surface is constructed on a 0.5mm thick FR4 substrate with relative dielectric constant of 4.4 and 0.02 loss tangent, while the reflector surface with both AMC and PEC characteristics is printed on a 3mm thick FR4 substrate. There is a rectangular gap in the middle of the reflector for mounting the microstrip antenna. And the reflector contains 4×4 double ring structural unit cell. As shown in Fig. 1(b), two fan-shaped slots are printed on the top of the microstrip antenna as the radiation aperture. The two slots are connected by two strip lines which extending from the bottom rectangular patches.

The two fan-shaped slots are the microstrip antHQQD¶V radiation parts, thLV PHDQV WKDW E\ FKDQJLQJ operating bands of microstrip antenna can be independently adjusted. In the feeding line. An integrated balun is printed on the other side of the 0.5mm substrate. The bottom ends of the balun is connected to the feeding probe of SMA connectors. The parameters on the figures have been optimized and provided in 7DEOH Þ

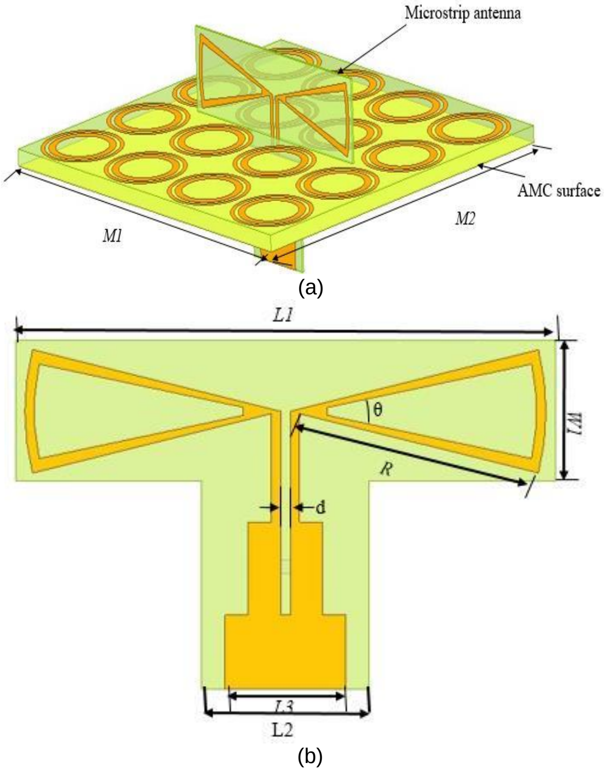


Fig. 1. (a) Three-dimensional view of the proposed antenna. (b) front side of microstrip antenna.

TABLE I: DESIGN PARAMETERS OF THE PROPOSED ANTENNA

Parameters	M1	M2	L1
Value(mm)	94.4	94.4	58
Parameters	W1	d	R
Value(mm)	18.2	1	27.5
Parameters	L2	L3	
Value(mm)	18	13	

III. SIMULATION AND RESULTS

The reflector surface consists of 3 layers: 16 periodic repeating units on the top, FR4 dielectric layer in the middle and copper ground on the bottom. As mentioned in previous sections, in the lower and middle band, the reflector operates as AMC surface which is widely used to improve antenna radiation performance and achieve low profile design. Fig. 2 shows the geometry of the AMC unit cell. The periodic patch consists of two rings with radius of R1, R2 and a distance of d1 between two circuits. Fig. 3 (a)-(c) demonstrates the simulated dual band reflection phases of the AMC unit.

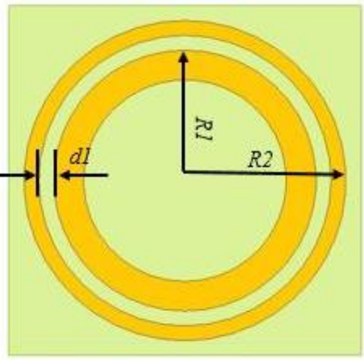
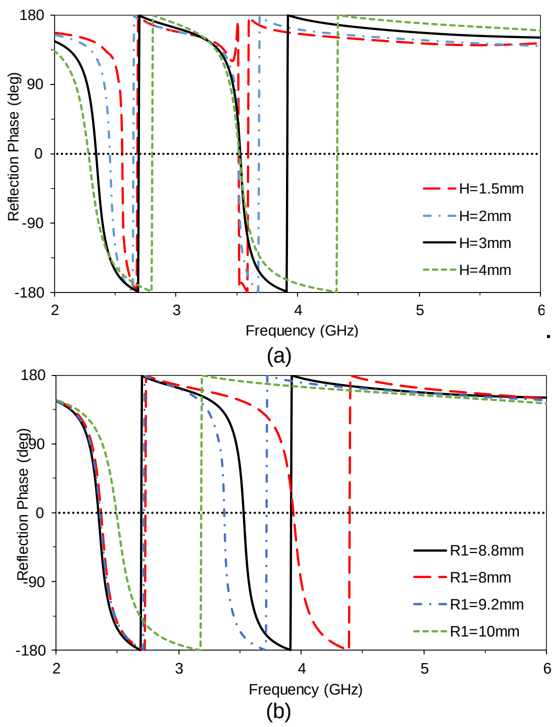
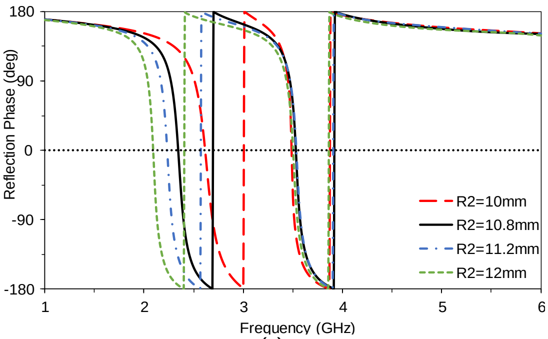


Fig. 2. Geometry of the AMC unit cell





(c)

Fig. 3. Simulated reflection phases of AMC unit. (a) Varying the size of H. Varying the size of R1 (c) Varying the size of R2

The operating bandwidth of the AMC unit can be obtained from the phase change from +90° to -90°. The resonance frequency of AMC surface corresponds to the 0° of the reflection coefficient phase. By loading a ring-shaped slot on the cell, two operating bandwidths can be generated. Moreover, the two distinct operating bands of AMC cell can be independently adjusted by changing the size and position of the main physical parameters. As we can see from Fig. 3 (a)-(c), both the resonance frequency and operating bands of AMC unit can be changed by various the parameters of R1, R2 and d. Fig. 3 (a) shows the reflection phases of varying the thickness H of the FR4 substrate from 1.5 mm to 4mm when all other dimensions remain the same. The increase in the thickness helps to improve the working bandwidth of the AMC cells and when the thickness is 3mm, the working frequency includes WLAN and Sub-6G 5G working bands. Fig. 3 (b) shows the reflection phases when inner circle radius R1 changes from 8.8 to 10mm. We can see that the increase of R1 results in the reduction of middle band resonant frequency from 3.9 to 3.4 GHz. However, when R1 is increased to 10mm, the AMC unit can only generate one operating band. Conversely, the increase of the radius of outer circle R2 results in the reduction of the lower band resonant frequency from 2.6 to 2.1 GHz, while middle band resonant frequency is almost unchanged. In short, both the lower band and middle band of the designed AMC unit can be independently adjusted by changing these physical parameters. The parameters of the patch have been optimized, R1 is 8.8mm, R2 is 10.8mm and H is 3mm. As shown in Fig.3, the two operating bands of the AMC unit is 2.2-2.4GHz and 3.4-3.6GHz respectively.

In order to reduce the difficulty of design, the AMC unit proposed in this paper is not designed to resonate in all three bands. As we can see from Fig. 3, there is no corresponding operating band and resonant frequency in the frequency range from 5 to 6 GHz. In another words, the AMC unit only have two operating bands but 5.8GHz operating frequency is not included. To improve antenna radiation properties at higher frequency band, the center of the dipole is placed at a distance of 1/4 wavelength from the reflecting surface. This design uses the metal on the backside of the FR4 board as a PEC reflective surface. Therefore, the proposed antenna utilizes the characteristics of AMC and PEC at the same time, so that the antenna has good radiation performance in all three frequency bands. Fig. 4. shows the reflection phase when the microstrip antenna is loaded on the reflector surface with a distance of 1/4 wavelength of 5.8GHz radio frequency. Compared with Fig. 3, we can see that, the operating band and resonance frequency are also generated in upper band from 4.8 to 6.8 GHz. It means that the reflector plays the role of PEC in upper frequency. The simulated peak gains at different frequency points are shown in Fig. 5. The gains at the operating bands can achieve nearly 5.6, 6.5 and 9.6 dBi at the lower, middle and upper working frequencies, respectively.

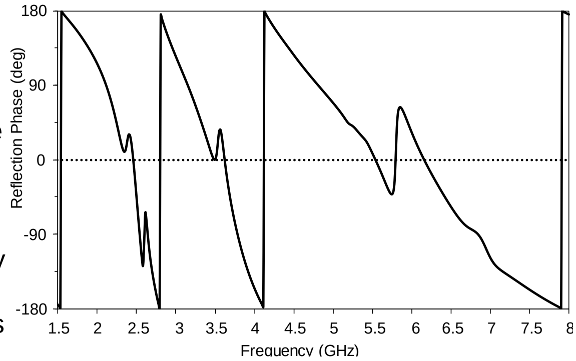


Fig. 4. Simulated reflection phases of proposed antenna

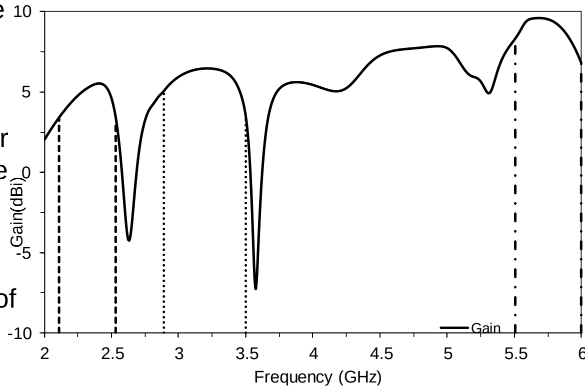


Fig. 5. Simulated gain

To validate the proposed antenna, a practically fabricated triple-band antenna is fabricated and illustrated in Fig. 6. The simulated and measured S parameters of return loss and VSWR are shown in Fig. 7 and Fig. 8. The two results are in good agreement with the simulation analysis. The slight distinction observed between them are mainly caused by fabrication tolerance, the soldering of the SMA connectors and the influence of other equipment. From the measured return loss results, it is clear that the proposed antenna works at three frequency bands: 2.39-2.63 GHz, 3.61-3.72 GHz and 5.61-5.84 GHz, with a -10dB return loss bandwidth of 240MHz at the center frequency 2.51 GHz, 110MHz at the center frequency of 3.66GHz and 230 MHz at the center frequency 5.72GHz. In accordance with the measured result, we can see clearly that the proposed antenna can be well applied to 2.4GHz WLAN, LTE, Sub-6G 5G application and 5.8GHz WIFI

Fig. 8(a)-(c) shows the simulated and measured VSWRs for the three ports. We are able to observe from VSWR results that the value which is less than 1.5 are ranging from 2.38 to 2.44GHz, 3.48 to 3.53 GHz and 5.74 to 5.86 GHz, respectively. While in the measured results, the antenna can reach a corresponding bandwidth from 2.37 to 2.43 GHz for the lower band, from 3.37 to 3.47 GHz for the middle band and from 5.64 to 5.76 GHz for the upper band. Good agreement between simulated and measured results is observed. We can also see that the measured value is slightly smaller than the simulation value. The little difference is mainly caused during antenna manufacturing and testing process.

Fig. 6. Photograph of the fabricated prototype.

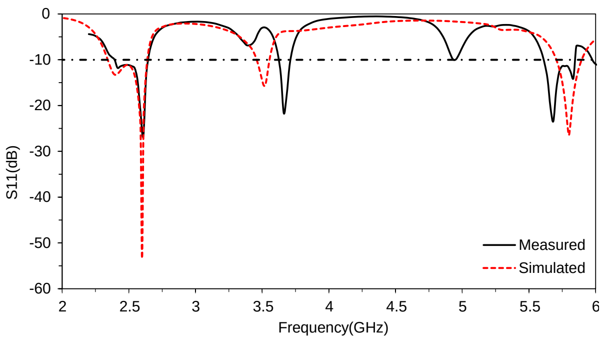
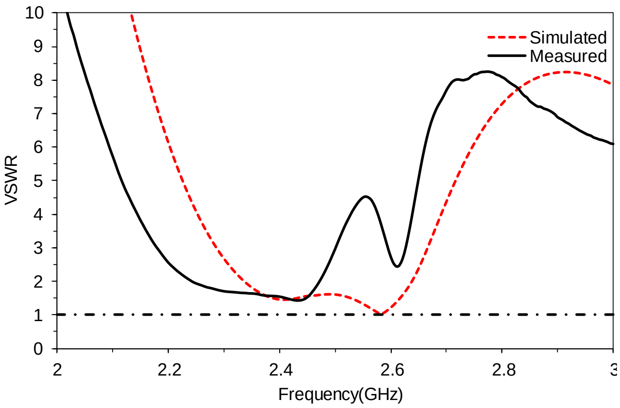
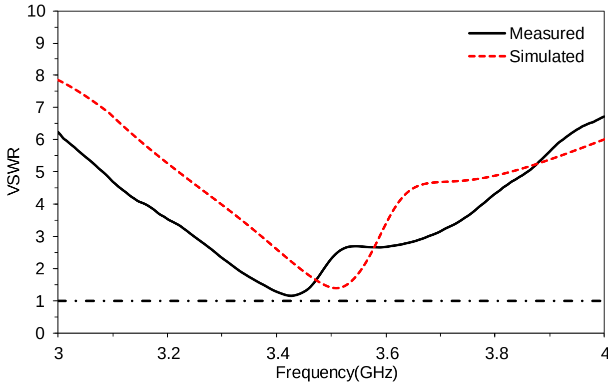


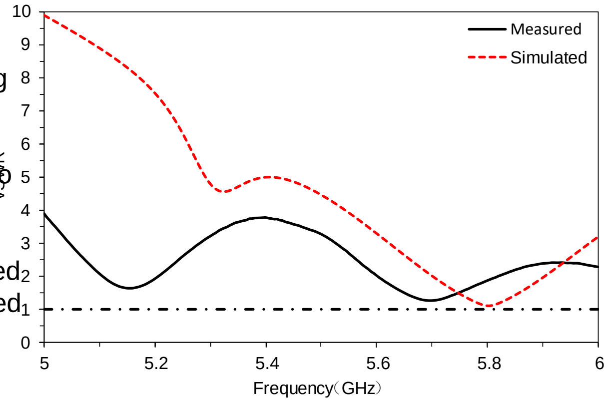
Fig. 7. Simulated and measured S-parameters of the proposed antenna.



(a)

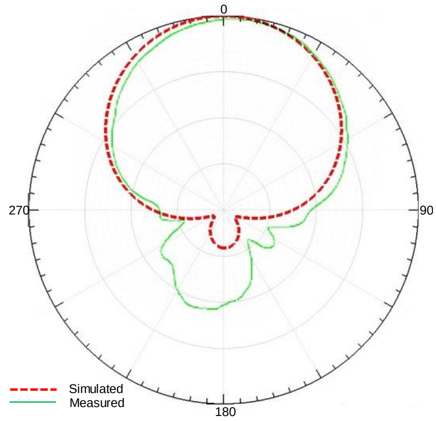


(b)

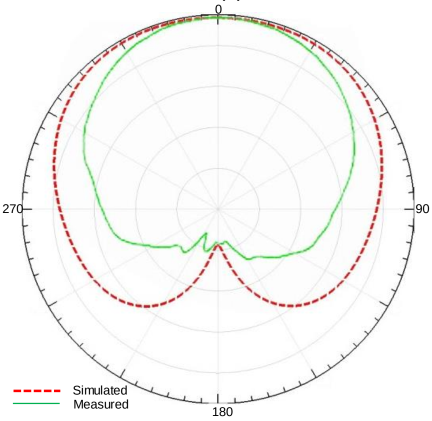


(c)

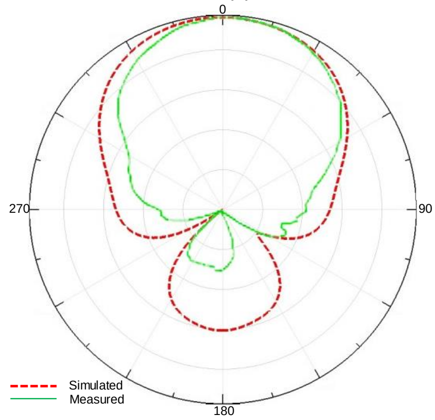
Fig. 8. Simulated and measured VSWRs versus frequency



(a)



(b)



(c)

Fig. 9. Measured and simulated radiation patterns for proposed antenna at (a) 2.4, (b) 3.5, and (c) 5.8 GHz

The measured and simulated radiation patterns of the proposed antenna at the several typical operation frequencies are also investigated. Fig. 9(a) plots the measured and simulated radiation patterns at 2.4 GHz; the results at 3.5 GHz are shown in Fig. 9(b); the radiation patterns at 5.8 GHz are illustrated in Fig. 9(c). From these three diagrams it can be observed that the main beams are always in the broadside direction. Compared with the simulation results, it is very clear that the measured results match well at the frequency of 3.5GHz. At 2.4 GHz, the radiation of the main lobe match well, while unwanted lobe appears on the backside. But this still meets the design requirements. At high frequency of 5.8GHz, the measured results are even better than the simulated results because the front-to-back ratio is higher. It means that for the proposed antenna the reflection performance than expected. Above all, the radiation pattern can satisfy the design requirement of wireless communication from these measured results.

IV. Conclusion

A new triple band antenna loaded with reflector surface which has the property of both artificial magnetic conductor (AMC) surface and perfect electric conductor (PEC) for WLAN and Sub-6G 5G applications is presented. The proposed antenna can meet the requirement of three bands for WLAN and 5G commercial applications. The operating band can cover lower band from 2.39 to 2.63 GHz, middle band from 3.61 to 3.72 GHz and from 5.61 to 5.84 GHz, respectively. Moreover, the proposed antenna has the advantages of low cost, easy to make and good unidirectional radiation. The simulated and experimental results show that the proposed triple band antenna is a better candidate for WLAN and 5G commercial communication system such as IoT and Intelligent Drive.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Mr Hu conducted the research; Miss Saitou analyzed the data; Mr. Hu and Ms. Zhenni wrote the paper; Prof. Liu provided guidance and Prof. Shimamoto is in charge of this project. All authors had approved the final version.

References

[1] W. Hu, R. N. Lian, Z. Y. Tang et al., "Wideband, low-profile, dual-polarized slot antenna with an AMC surface for wireless communications," International Journal of Antennas and Propagation, 2016.

[2] G. Augustin, P. C. Bybi, V. P. Sarin, P. Mohanan, C. K. Aanandan, and K. Vasudevan, "A compact dual-band planar antenna for DCS-1900/PCS/PHS, WCDMA/IMT-2000, and WLAN applications," IEEE Antennas and Wireless Propagation Letters, vol. 7, pp. 108-111, 2008.

[3] T. N. Chang and J. Jiang, "Meandered t-shaped monopole antenna," IEEE Transactions on Antennas and Propagation, vol. 57, no. 12, pp. 3976-3978, Dec. 2009.

[4] + 0DOHNSRRU DQG 6 Curtised asymmetric LQ shaped microstrip patch antenna with folded 6 D W F K I H H G ´ IET Microw., Antennas Propag., vol. 7, no. 2, pp. 85-91, Jan. 2013.

[5] W. Hu, Y. Z. Yin, P. Fei, and X. < D Q J " & R P S D F W triband square-slot antenna with symmetrical l-strips for WLAN/WiMAX applications," IEEE Antennas Wirel. Propag. Lett., vol. 10, pp. 462-465, 2011.

[6] H. Malekpoor and S. Jam, "Improved radiation performance of low profile printed slot antenna using wideband planar AMC surface," IEEE Transactions on Antennas and Propagation, vol. 64, no. 11, pp. 4626-4638, Nov. 2016.

[7] R. Dewan, S. K. A. Rahim, S. F. Ausordin, and H. U. Iddi, "Design of triple band artificial magnetic conductor G X F W R U ," Proc. IEEE Asia-Pacific Conf. Appl. Electromag., 2012, pp. 253-256.

[8] ' - * U H J R L U H & 5 : K L W H D Q G - 6 & artificial magnetic conductors loaded with Non-Foster negative L Q G X F W R U V ," in Proc. IEEE Int. Work. Antenna Technol., vol. 10, 2012, pp. 237-240.

[9] . = K D Q J ; = K R X = : H L Dipole + = K D L dual-E D Q G D Q W H Q Q D O R D G H G Z L W K W K H ... in Proc. IEEE 6th Asia-Pacific Conf. Antennas Propagation, 2018, pp. 1-3.

[10] 6 5 % H V W "Improving the performance properties of a G L S R O H H O H P H Q W F O R V H O \ V S D F H G W ... IEEE Antennas Wirel. Propag. Lett., vol. 3, no. 1, pp. 359-363, 2004.

[11] F. Elek, R. Abhari, and G. V. Eleftheriades, "A X Q L directional ring-slot antenna achieved by using an electromagnetic band-J D S V X U I D F H ," IEEE Trans. Antennas Propag, vol. 53, no. 1, pp. 181-190, Jan. 2005

[12] Y. He, Z. Pan, X. Cheng, Y. He, J. Qiao, and M. M. 7 H Q W] H U L V "A novel dual-band, dual-polarized, miniaturized and low-profile base station antenna," IEEE Trans. Antennas Propag., vol. 63, no. 12, pp. 5399-5408, 2015.

[13] + = K D L . = K D Q J 6 < D Q J "Low-profile D Q G ') H Q J dual-band dual-polarized antenna with an AMC surface for WLAN applications," IEEE Antennas Wirel. Propag. Lett., vol. 16, pp. 2692-2695, 2017.

Tengfei Hu was born in Hubei Province, China, in 1992. He received the B.S. degree in electronic science and engineering from Jilin University, Changchun, China, in 2014. He is currently pursuing the M.S. degree with the department of Computer Science and Communications Engineering, School of Fundamental Science and Engineering, Waseda University, Japan. His research interests include antenna and energy harvesting system design.

Zhenni Pan 6 ¶ 0 ¶ U H F H Y H G W K H B.S. degree in computer science engineering from China Agricultural University, Beijing, China, in 2007. She received the M.S. and Ph.D. degree in information and telecommunications from the Graduate School of Global Information and Telecommunication Studies (GITS), Waseda University, Japan, in 2011 and 2018, respectively. She was a research associate from 2013 to 2018 at Waseda University. Currently, she is an assistant professor at Global Center for Science and Engineering, Faculty of Science and Engineering, Waseda University. Her research interests include green wireless communications, mobile communications, MIMO systems, wireless sensor networks, UAV and optical communication.

Megumi Saito 6 Œ eceiveUd M.S degree from Graduate School of Global Information and Telecommunication Studies, Waseda University, Japan in 2014. She is a PhD candidate at Department of Computer Science and Communications Engineering, School of Fundamental Science and Engineering. She is also a research associate Waseda University, Japan. Her research interest includes D2D, Cooperative Access scheme in Cellular Networks.

Jiang Liu 6 ¶ 0 ¶ 6 0 ¶ U H F H L Y the B.E. degree in electronics engineering from Chong Qing University of Technology, China, in 2001, and the M.S. and Ph.D. degree in information and telecommunications from the Graduate School of Global Information and Telecommunication Studies (GITS), Waseda University, Japan, in 2006 and 2012 respectively. She was a research associate from 2009 to 2012, and an assistant professor from 2013 to 2017 at Waseda University. Currently, she is an associate professor at Faculty of Science and Engineering, Waseda University. Her main fields of research interests include optical wireless communication, cellular system design, sensor network, and smart grid systems.

Shigeru Shimamoto (M'94) received the B.E. and M.E. degrees from the University of Electro-Communications, Tokyo, Japan, in 1985 and 1987, respectively. He received the Ph.D. degree from Tohoku University, Sendai, Japan, in 1992. He joined NEC Corporation from 1987 to 1991. From 1991 to 1992, he was a research associate in the University of Electro-Communications, Tokyo, Japan. He was a research associate in Gunma University, Gunma, Japan, from 1992 to 1993. From 1994 to 2000, he was an associate professor in the Graduate School of Global Information and Telecommunication Studies (GITS), Waseda University, Tokyo, Japan. Since 2001, he has been a professor in the Graduate School of GITS, Waseda University. He was a visiting professor of E.E. at Stanford University in 2008. His main fields of research interests include satellite communications, mobile communications, optical wireless communications, ad-hoc networks, sensor networks, and body area networks.