A compact E-shaped antenna with C-shaped slots and a back-patch for multiband applications

Kim Ho Yeap^{1*}, Wei Long Yeo¹, Koon Chun Lai²,
Takefumi Hiraguri³, Kazuhiro Hirasawa⁴, Zi Xin Oh¹

We present the design of a tri-band E-shaped printed antenna with C-shaped slots. A Rectangular patch etched with an n-shaped slot is added at the back of the substrate to enhance the bandwidth and the return losses of the resonant bands - particularly, that of the second band. Our antenna is designed to operate at 1.51/2.46/6.11 GHz. As can be observed from the experimental results, it has 10 dB bandwidths of 157 MHz (1.416 to 1.573 GHz) 358 MHz (2.221 to 2.579 GHz) and 367 MHz (5.918 – 6.285 GHz) The first two bands cover the LTE, Bluetooth, IEEE 802.15.4 ZigBee and IEEE 802.11 WLAN applications. The third resonant band covers the unlicensed 6 GHz band which is widely implemented in wireless power transmission, as well as, RFID and satellite communications. In order to ease wireless congestion, the 6 GHz band is also currently being considered by the FCC to be opened up for the use of WiFi applications. Our antenna is fabricated on a single-sided FR4-epoxy, and it constitutes a compact size of 34 mm × 36 mm × 1.6 mm or $0.17\lambda \times 0.18\lambda \times 0.0081\lambda$, (based on the 1.51 GHz lowest resonant frequency) The antenna exhibits omnidirectional radiation patterns at the three resonant bands.

Keywords: planar antenna, multiband, return loss, radiation patterns, surface current density, E-shaped antenna, C-shaped slots, back-patch

1 Introduction

Owing to the rapid advancement in the wireless technology, portable wireless telecommunication devices which can support multiband applications have become ubiquitous nowadays. One of the most essential components in these devices is the antenna; without which, wireless signal transmission and reception in these devices would not have been made possible. In order to provide enough portability and to ensure affordability of the telecommunication devices, the antenna embedded in them must be compact in size, low profile, and relatively easy to be fabricated. Monopole planar antennas have been popularly implemented for wireless telecommunications, as they fulfill these requirements. Various designs of multiple bands planar antennas, applied particularly for the Wireless Local Area Network WLAN application, can be found in [1-6].

Unlike its single band counterpart, which is relatively simpler, the process involved in designing a multiband antenna turns out to be more laborious. In view of this, most of the multiband antennas found in the literature are developed solely to support dual-band applications [1 – 12]. Although the designs in [13-25, 17, 26-29] support more than two bands, the size of the antennas are either relatively large [13-23] or that their geometrical structures are complicated [17, 24, 25, 26-29], rendering

it difficult to be fabricated. Of course, the size of an antenna is wavelength or frequency dependent. Hence, the geometrical size of an antenna is usually traded for the operating frequency. This is to say that, an antenna designed particularly to be small may only operate at a reasonably high range of frequencies. In order to keep its size small, most of the antennas found in the literature are designed to operate above 1.5 GHz. It is to be noted, however, that most of the 4G Long-term-evolution LTE bands (such as band 11 to 14, 17 to 21, 26 to 29, and so on) fall below 1.5 GHz. In order to optimize the utilization of the LTE bands and to relieve the congestion of the bands operating above 1.5 GHz, an antenna which covers the resonant mode below 1.5 GHz is perceived to be necessary.

In this paper, a microstrip-fed monopole printed antenna, which can support three resonant bands is presented. The geometry of the antenna is modified from the conventional E-shaped planar antenna [30, 31]. Besides being low profile and having compact structure, we shall demonstrate that our antenna has good impedance matching and omni-directional radiation patterns at the three resonant bands, *viz* the 1.416 to 1.573 GHz, 2.221 to 2.579 GHz, and 5.918 to 6.285 GHz bands. The first resonant band covers the LTE band 11 (1427.9 to 1500.9 MHz) and band 21 (1447.9 to 1510.9 MHz) whereas, the second band finds wide applications in wireless communi-

¹ Department of Electronic Engineering, Universiti Tunku Abdul Rahman, Jalan Universiti, Bandar Barat, 31900 Kampar, Perak, Malaysia ² Academe Incubator, 203, Beijing 3rd, Qingcheng, Qingyuan, Guangdong, China, ³ Nippon Institute of Technology, Miyashiro-Machi, Saitama-Ken, Japan, ⁴ University of Tsukuba, Tsukuba, Ibaraki 305-8573, Japan, * Corresponding author: yeapkh@utar.edu.my

Fig. 1. The geometry of the proposed antenna, the dark and light blue layers denote, respectively, the radiating patch at the surface and the patch beneath the substrate

Fig. 2. The evolution of the antenna design according to alphabetical order

Fig. 3. Return losses of the four antenna configurations in Fig. 2 (a) – dashed line, (b) – dashed-dotted line, (c) – dashed-dotted-dotted line, and (d) – solid line)

cations, including the LTE band 30 (2305 to 2360 MHz) Bluetooth (2.402 to 2.480 GHz) IEEE 802.15.4 Zigbee (2.412 to 2.472 GHz) and IEEE 802.11 WLAN (2.412 to 2.472 GHz) specifications. The third band falls within the regime of the 6 GHz band (*ie* the 5.925 to 6.425 GHz

band) Since the 6 GHz band is unlicensed, it is primarily implemented for wireless power transmission WPT [32–36]. By incorporating the function of WPT, the duration of the power source in a telecommunication device can therefore be prolonged. Besides WPT, the 6 GHz band is also widely applied in RFID [37] and satellite communications. We would also like to emphasize that, the increasing demand for wireless connectivity has urged the Federal Communications Commission FCC to open the 6 GHz band to ease wireless congestion [38], making it an important band for mobile services as well.

2 Antenna design

Figure 1 depicts the geometry of our microstrip-fed tri-band monopole antenna. Proposed antenna is fabricated on an FR4-epoxy substrate which has a thickness of 1.6 mm, dielectric constant of 4.4 and loss tangent of 0.022. Figures 2 and 3 describe the evolution of the design and the return losses which correspond to each stage of the design. The designs and validations are performed using Ansys high frequency structure simulator HFSS (2010) As can be observed from Fig. 2(a) the initial antenna structure originates from the conventional E-shaped planar antenna – the geometrical dimensions of which are computed based on the method in [30,31]. In order to improve the return losses of the resonant bands, we have subsequently etched two C-shaped slots from both sides of the E-shaped patch. The slots enhance the energy density by compressing the surrounding electrical energy [39]. It is to be noted that, the slots have been commonly used to improve the resonant effects of planar antennas [23] and split ring resonators [40]. Upon close inspection in Fig. 3 (*ie* the dashed line and dashed-dotted line curves) it can be clearly seen that the introduction of the slots has increased the magnitude of the lower and upper resonant frequencies by approximately 3.8 dB and 1.4 dB, respectively. In order to mediate three resonant bands in the antenna, a rectangular patch is subsequently added to the back of the substrate, gap-coupled with the microstrip ground plane, as depicted in Fig. 2(c). The conductor-backed patch acts as a parasitic structure [41] which improves impedance matching [20] around the 3 GHz frequency range. Although an additional resonant band is generated between the two original bands, as indicated by the dashed-dotted-dotted curve in Fig. 3, the 10-dB bandwidth is rather limited (*ie* less than 100 MHz) and its peak return loss barely surpasses 10 dB (*ie* the peak return loss is about 12.60 dB). To improve the performance of this band, an *n*-shaped slot is etched from the back patch, as shown in Fig. 2(d). By carefully modifying the geometrical dimensions of the radiating and back patches, the resonant frequencies f_r are then parametrically shifted to the targeted operating bands. The return loss of the final design is represented by the solid line curve in Fig. 3. The final dimensions of proposed antenna are summarized in Fig. 4 and Tab. 1.

Fig. 4. The final geometrical structure of the (a) – radiating patch and, (b) – microstrip and back patch of the antenna

Table 1. Dimensions of the proposed antenna

Parameter	Dimension (mm)	Parameter	Dimension (mm)
W_1	20	L_1	16
W_2	3	L_2	2
W_3	5.8	L_3	12
W_4	3	L_4	10
W_5	2.4	L_5	25
W_6	16	L_6	1
W_7	12	L_7	20
W_8	6	L_8	14
W_9	10	L_9	3
W_{10}	3	L_{10}	3
-	-	L_{11}	10

3 Results and discussion

Figure 5 depicts the design of our fabricated antenna and its actual dimensions. An experimental measurement was conducted in an anechoic chamber. The S_{11} parameters measured using a vector compared with the simulated results. Figure 6 illustrates the return losses of both results. Despite observing minor discrepancies at the first and third bands, both results are considered with each other. Since the design was simulated by assuming perfect free space environment, the discrepancies can be attributed to the lossy nature of air. The experimental return loss results show that our antenna has 10 dB bandwidths of 157 MHz (1.416 to 1.573 GHz) 358 MHz (2.221 to 2.579 GHz) and 367 MHz (5.918-6.285 GHz). The resonant frequencies f_r for these three bands are 1.51 GHz, 2.46 GHz, and 6.11 GHz. As mentioned in the Introduction section, the first band is essentially useful for the LTE bands operating below 1.5 GHz; the second band finds wide applications in the LTE bands above 1.5 GHz, as well as, Bluetooth, Zigbee, and WLAN specifications; whereas, the third unlicensed band is commonly implemented for wireless power transmission WPT, RFID and

satellite communications, and may soon be opened for mobile services, as well.

Fig. 5. Photographs of the (a) front and (b) back of the fabricated antenna.

Fig. 6. Measured (solid line) and simulated (dashed line) return losses of our antenna.

In order to obtain a better insight of the return loss, the surface current distributions of the antenna at $f_r = 1.51$ GHz, 2.46 GHz, and 6.11 GHz are simulated. As shown in Fig. 7, each part of the antenna structure is filled

Fig. 7. The surface current distributions of the antenna at (a) – 1.51 GHz, (b) – 2.46 GHz, and (c) – 6.11 GHz, the intensity of the current follows the spectrum of optical light, *ie* (d) – the lowest magnitude (0 A/m) is in blue and the highest (more than 75 A/m) is in red.

with surface current, with the peak current exceeding 32 A/m. It is apparent from the figure that the surface current density varies when the antenna operates at the three different resonant frequencies. The peak surface current density for the first and second f_r concentrates, respectively, at the upper and lower part of the antenna. The third f_r , on the other hand, has the largest area distributed with the peak current. Upon close inspection in Fig. 7(c) it can be observed that almost the entire center strip is filled with current above 32 A/m. This phenomenon suggests strongly that the third resonant mode at $f_r = 6.11$ GHz obtains the highest wave coupling as compared to the other two modes at $f_r = 1.51$ GHz and 2.46 GHz. It therefore exhibits the highest return loss in Fig. 6. Figure 8 shows the measured radiation patterns of the proposed antenna at 1.51 GHz, 2.46 GHz, and 6.11 GHz along the E- and H-planes. Clearly, the antenna produces good omnidirectional patterns along the *H* - and *E* -planes at the three resonant modes.

In this paper, a compact microstrip-fed tri-band planar antenna has been proposed and successfully fabricated. The antenna is modified from the conventional E-shaped patch antenna. A back patch is added above the ground plane to generate three resonant bands. Two C-shaped slots and an *n*-shaped slot are introduced, respectively, at the radiating stub and the back patch to improve the return loss of the resonant bands. The measured results show that the proposed antenna has 10 dB bandwidths of 157 MHz (1.416 to 1.573 GHz) 358 MHz

Fig. 8. Radiation patterns for the proposed antenna at (a)– 1.51, (b) – 2.46, and (c) – 6.11 GHz in the *H* - (dashed line) and *E* -planes (solid line)

(2.221 to 2.579 GHz) and 367 MHz (5.918 – 6.285 GHz). The measured resonant frequencies for these three bands are 1.51 GHz, 2.46 GHz, and 6.11 GHz. The antenna constitutes a compact size of $0.17\lambda \times 0.18\lambda \times 0.0081\lambda$ (based on the 1.51 GHz lowest resonant frequency). Our antenna can be easily fabricated and it constitutes a simple configuration. It also exhibits good return losses and radiation characteristics. The antenna covers the LTE, Zigbee, Bluetooth, WLAN, RFID, and satellite communications. The unlicensed 6 GHz band is also popularly implemented for wireless power transmission.

REFERENCES

- [1] A. Altaf and M. Seo, “A Tilted-D-shaped Monopole Antenna with Wide Dual-band Dual-sense Circular Polarization, *IEEE Antennas Wireless Propagation Letters*, vol. 17, no.12, pp. 2464-2468, 2018.
- [2] M. C. Tang, Z. Wu, T. Shi, and R. W. Ziolkowski, “Dual-band, Linearly Polarized, Electrically Small Huygens Dipole Antennas”, *IEEE Antennas Wireless Propagation Letters*, vol. 67, no.1, pp. 37-47, 2019.
- [3] L. Adam, M. N. M. Yasin, H. A. Rahim, P. J. Soh, and M. F. Abdulmalek, “A Compact Dual-band Rectenna for Ambient RF Energy Harvesting”, *Microwave Opt TechnolLett*, vol. 60, pp. 2740- 2748, 2018.
- [4] K. Djafari, M. Challal, A. Azrar, M. Dehmas, R. Aksas, and F. Mouhouche, “Compact Dual-band Fractal Hexagonal Ring Monopole Antenna for RFID GSM Applications”, *Microwave Opt TechnolLett*, vol. 60, pp. 2656-2659, 2018.

- [5] A. Desai, T. Upadhyaya, and M. Pelandoken, "Dual Band Slotted Transparent Resonator for Wireless Local Area Network Applications", *Microwave Opt. Technol. Lett.*, vol. 60, pp. 3034-3039, 2018.
- [6] S. Lee, S. Pyo, and J. H. Kim, "Dual-band Bidirectional Circularly Polarized Microstrip Antenna for CubeSat System", *Microwave Opt. Technol. Lett.*, vol. 60, pp. 2989-2992, 2018.
- [7] M. E. Newton, S. Mou, K. Ma, N. Yan, and F. Meng, "A Monopole Antenna based on SISL with Dual Bands for WLAN Operations", *Microwave Opt. Technol. Lett.*, vol. 60, pp. 2784-2787, 2018.
- [8] K. N. Paracha, S. K. A. Rahim, P. J. Soh, H. T. Chatha, M. H. Misran, and A. H. Lokman, "A Dual Band Stub-loaded AMC Design for the Gain Enhancement of a Planar Monopole Antenna", *Microwave Opt. Technol. Lett.*, vol. 60, pp. 2108-2112, 2018.
- [9] C. S. Voon, K. H. Yeap, K. C. Lai, C. K. Seah, and H. Nisar, "A Compact Double Psi-shaped Dual Band Patch Antenna for WLAN/LTE Applications", *Microwave Opt. Technol. Lett.*, vol. 60, pp. 1271-1275, 2018.
- [10] W. L. Yeo, K. C. Lai, K. H. Yeap, P. C. Teh, and H. Nisar, "A Compact-dual Band Hook-shaped Antenna for Wireless Applications", *Microwave Opt. Technol. Lett.*, vol. 59, pp. 1882-1887, 2017.
- [11] H. Lavakhamseh, C. Ghobadi, J. Nourinia, and M. Ojaroudi, "Multiresonance Printed Monopole Antenna for DCS/WLAN/WiMAX Applications", *Microwave Opt. Technol. Lett.*, vol. 54, pp. 297-300, 2012.
- [12] A. Mouradhesari, M. Naser-Moghadasi, and F. G. Gharakhili, "Design of Compact CPW-fed Monopole Antenna for WLAN/WiMAX Applications Using a Pair of F-shaped Slits on the Patch", *Microwave Opt. Technol. Lett.*, vol. 55, pp. 2337-2340, 2013.
- [13] S. N. Islam, M. Kumar, G. Sen, and S. Das, "Design of a Compact Quad-band Antenna with Independent Frequency Tuning", *Electronics Lett.*, vol. 54, pp. 920-922, 2018.
- [14] K. L. Wong, H. J. Chang, and W. Y. Li, "Integrated Triple-wideband Triple-inverted-F Antenna Covering 617960/17102690/33004200 MHz for 4G/5G Communications the Smartphone", *Microwave Opt. Technol. Lett.*, vol. 60, pp. 2091-2096, 2018.
- [15] S. A. Kumar, T. Shanmuganantham, and D. Dileepan, "Design Development of CPW Fed Monopole Antenna at 2.45 GHz 5.5 GHz for Wireless Applications", *Alexandria Engineering Journal*, vol. 56, pp. 231-234, 2017.
- [16] H. R. Cheong, K. H. Yeap, K. C. Lai, P. C. Teh, and H. Nisar, "A Compact CPW-fed Antenna with S-shaped Patches for Multi-band Applications", *Microwave Opt. Technol. Lett.*, vol. 59, pp. 541-546, 2017.
- [17] M. T. Wu and M. L. Chuang, "Multibroadband Slotted Bow-tie Monopole Antenna", *IEEE Antennas Wireless Propagation Letters*, vol. 14, pp. 887-890, 2015.
- [18] R. Z. Wu, P. Wang, Q. Zheng, and R. P. Li, "Compact CPW-fed Triple-band Antenna for Diversity Applications", *Electronics Lett.*, vol. 51, pp. 735-736, 2015.
- [19] H. Zhai, Z. Ma, Y. Han, and C. Liang, "A Compact Printed Antenna for Triple-band WLAN/WiMAX Applications", *IEEE Antennas Wireless Propagation Letters*, vol. 12, pp. 65-68, 2013.
- [20] A. K. Gautam, L. Kumar, B. K. Kanauija, and K. Rambabu, "Design of Compact F-shaped Slot Triple-band Antenna for WLAN/WiMAX Applications", *IEEE Transactions on Antennas Propagation*, vol. 64, pp. 1101-1105, 2016.
- [21] P. Pushkar and V. R. Gupta, "A Metamaterial based Tri-band Antenna for WiMAX/WLAN Application", *Microwave Opt. Technol. Lett.*, vol. 58, pp. 558-561, 2016.
- [22] J. Pei, A. G. Wang, S. Gao, and W. Leng, "Miniaturized Triple-band Antenna with a Defected Ground Plane for WLAN/WiMAX Applications", *IEEE Antennas Wireless Propagation Letters*, vol. 10, pp. 298-301, 2011.
- [23] H. Chen, X. Yang, Y. Z. Yin, S. T. Fan, and J. J. Wu, "Triband Planar Monopole Antenna with Compact Radiator for WLAN/WiMAX Applications", *IEEE Antennas Wireless Propagation Letters*, vol. 12, pp. 1440-1443, 2013.
- [24] J. Y. Deng, J. Yao, and L. X. Guo, "Compact Multiband Antenna for Mobile Terminal Applications", *Microwave Opt. Technol. Lett.*, vol. 60, pp. 1691-1696, 2018.
- [25] P. M. Paul, K. Kandasamy, and M. S. Sharawi, "A Tri-band Slot Antenna Loaded with Split Ring Resonators", *Microwave Opt. Technol. Lett.*, vol. 59, pp. 2638-2643, 2017.
- [26] G. Sami, M. Mohanna, and M. L. Rabeh, "Tri-band Microstrip Antenna Design for Wireless Communication Applications", *NRIAG Journal of Astronomy Geophysics*, vol. 2, pp. 39-44, 2013.
- [27] M. Li, Y. Wu, M. Qu, L. Jiao, and Y. Liu, "Triband Planar Shared-aperture Antenna Array with Similar-shaped Radiation Patterns", *Microwave Opt. Technol. Lett.*, vol. 60, pp. 2284-2288, 2018.
- [28] P. K. Li, C. J. You, H. F. Yu, Y. J. Cheng, Y. W. Yang, and J. H. Deng, "A High Frequency Ratio Quadri-band Frequency Independently Tunable Antenna with Spurious-mode Suppression", *Microwave Opt. Technol. Lett.*, vol. 60, pp. 1445-1452, 2018.
- [29] V. Singh, B. Mishra, A. K. Dwivedi, and R. Singh, "Inverted L-notch Loaded Hexa Band Circular Patch Antenna for X, Ku/K band Applications", *Microwave Opt. Technol. Lett.*, vol. 60, pp. 2081-2088, 2018.
- [30] K. H. Yeap, W. Ismail, S. L. Yap, and K. H. Yeap, "Parametric Study for E-shaped Microstrip Patch Antenna", *Malaysian Journal of Science*, vol. 35, pp. 284-318, 2016.
- [31] K. H. Yeap, W. Ismail, and K. H. Yeap, "Analytical Model for E-shaped Microstrip Patch Antenna", *ACES Journal*, vol. 32, pp. 332-338, 2017.
- [32] G. Yang, M. R. Islam, R. A. Dougal, and M. Ali, "A Reconfigurable Stacked Patch Antenna for Wireless Power Transfer Data Telemetry Sensors", *Progress Electromagnetics Research C*, vol. 29, pp. 67-81, 2012.
- [33] K. Niotaki, A. Collado, A. Giorgiadis, S. Kim, and M. M. Tentzeris, "Solar/Electromagnetic Energy Harvesting Wireless Power Transmission", *Proceedings of the IEEE*, vol. 102, pp. 1712-1722, 2014.
- [34] P. Lu, X. S. Yang, J. L. Li, and B. Z. Wang, "Polarization Reconfigurable Broadband Rectenna with Tunable Matching Network for Microwave Power Transmission", *IEEE Transactions on Antennas Propagation*, vol. 64, pp. 1136-1141, 2016.
- [35] M. Ali, G. Yang, and R. Dougal, "Miniature Circularly Polarized Rectenna with Reduced Out of Band Harmonics", *IEEE Antennas Wireless Propagation Letters*, vol. 5, pp. 107-110, 2006.
- [36] P. Lu, X. S. Yang, and B. Z. Wang, "A Two-channel Frequency Reconfigurable Rectenna for Microwave Power Transmission Data Communication", *IEEE Transactions on Antennas Propagation*, vol. 65, pp. 6976-6985, 2017.
- [37] Y. V. Gulyaev, S. G. Suchkov, S. S. Yankin, S. A. Nikitov, D. S. Suchkov, and V. P. Plessky, "SAW Radio-frequency Identification Tag for the 6-GHz Band", *Journal of Communications Technology Electronics*, vol. 60, pp. 429-432, 2015.
- [38] R. Merritt, "Merritt WiFi going 6 GHz, EE Times Asia, 2018, Accessed October 26, 2018, <http://www.eetasia.com/news/article/18072302-wifi-going-6ghz>.
- [39] J. B. Pendry, A. J. Holden, D. J. Robbins, and W. J. Stewart, "Magnetism from Conductors Enhanced Nonlinear Phenomena", *IEEE Transactions on Microwave Theory Techniques*, vol. 47, no. 11, pp. 2075-2084, 1999.
- [40] S. C. Basaran, U. Olgun, and K. Sertel, "Multiband Monopole Antenna with Complementary Split-ring Resonators for WLAN/WiMAX Applications", *Electron. Letters*, vol. 49, no. 10, pp. 636-638, 2013.

- [41] J. Pourahmadazar, C. Ghobadi, J. Nourinia, and H. Shirzad, "Multiband Ring Fractal Monopole Antenna for Mobile Devices", *IEEE Antennas Wireless Propagation Letters*, vol. 9, pp. 863-866, 2010.

Received 17 June 2019

Kim Ho Yeap received his BEng (Hons) from Petronas University of Technology in 2004, MSc from National University of Malaysia in 2005 and PhD from Universiti Tunku Abdul Rahman in 2011. He is a senior member of the IEEE, a chartered engineer registered with the UK engineering council and a professional engineer registered with the board of engineers Malaysia. He has published more than 100 scientific articles which include journal and conference papers, book chapters and books. He is currently an Associate Professor in Universiti Tunku Abdul Rahman. He is also the editor-in-chief of *i-managers Journal on Digital Signal Processing*.

Wei Long Yeo received his BEng (Hons) Electronic Engineering and Master of Engineering Science from Universiti Tunku Abdul Rahman in 2017 and 2019, respectively. He is currently working as a product development engineer in JSB Tech, Singapore.

Koon Chun Lai received both his BEng (Hons) and the Masters degree from Universiti Malaysia Sarawak and PhD

from Universiti Tunku Abdul Rahman. He is currently a staff in Academe Incubator, China.

Takefumi Hiraguri received the ME and PhD degrees from the University of Tsukuba, Ibaraki, Japan, in 1999 and 2008, respectively. In 1999, he joined the NTT Access Network Service Systems Laboratories, Nippon Telegraph and Telephone (NTT) Corporation. He is now a Professor in Nippon Institute of Technology. He has been engaged in research and development of high speed and high communication quality wireless LANs systems. He is a member of IEICE.

Kazuhiro Hirasawa received his PhD degree in Electrical Engineering from Syracuse University, Syracuse, NY, in 1971. From 1967 to 1975, he was with the department of Electrical and Computer Engineering, Syracuse University. From 1975 to 1977, he was a consultant on research and development of various antennas. Since 1978, he has been with the University of Tsukuba, Ibaraki, Japan. Currently, he is an Emeritus Professor in University of Tsukuba and an International Collaborative Partner of Universiti Tunku Abdul Rahman, Malaysia. He is also an IEEE Life Fellow and IEICE Fellow.

Zi Xin Oh received her BEng (Hons) from Universiti Teknikal Malaysia Melaka. She is currently pursuing her Masters degree in Universiti Tunku Abdul Rahman.