Meta resonator based lower S-band antenna for cube-satellite communication system

HAITHAM ALSAIF[1], TOUHIDUL ALAM[2], TANVEER AHSAN[3,4], AKM ARIFUL HAQUE SIDDIQUE[5], MENGU CHO[6], NORBAHIAH BINTI MISRAN[3], MOHAMMAD TARIQUL ISLAM[3]

[1]*Electrical Engineering Department, College of Engineering, University of Ha'il, Ha'il 81481, Saudi Arabia*
[2]*Pusat Sains Angkasa (ANGKASA), Institut Perubahan Iklim, Universiti Kebangsaan Malaysia, Bangi 43600, Selangor, Malaysia*
[3]*Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Bangi 43600, Selangor, Malaysia*
[4]*Dept. of Computer Science and Engineering, International Islamic University Chittagong (IIUC), Chattogram-4318, Bangladesh*
[5]*Department of Physics, University of Chittagong, Chattogram 4331, Bangladesh*
[6]*Laboratory of Lean Satellite Enterprises and In-Orbit Experiments, Kyushu Institute of Technology, Fukuoka 804-8550, Japan*

In the space program, Cube Satellite has gained popularity in terms of nanosatellites, which can build by applying available the-shelf components and leads to cost-efficient. This concept generated another phase in space technology that inspired many sectors i.e.: business industries, government agencies, and the military to invest in this field. Circular polarisation plays a vital role for the smooth operation of the Cube-satellite communication system. The article proposed a meta resonator-based defected ground S-band circular polarised antenna for CubeSat applications. The antenna is designed and analysed by Computer Simulation Technology (CST) software. The computational and measured results showed that the proposed antenna obtained -10 dB bandwidth from 2.025-2.065 GHz with a peak realised gain of 5.2 dBi at the resonant frequency. The antenna also depicted 3dB axial ratio at the entire operating band. These properties make the proposed antenna a potential applicant for applications of lower L-band satellite communication.

(Received January 21, 2023; accepted June 6, 2023)

Keywords: Cube Satellite, Meta resonator, Lower S-band, Circular polarization

1. Introduction

The cube satellite has drawn concentration in the space market because of its low cost and shorter manufacturing time. It is easy to customise for a broad range of uses, including meteorology, earth observation, deep space, and the Internet of Things [1, 2]. CubeSats are a category of a small version of the satellites, which are the most popular CubeSats. Affordability and comparatively low-cost access to space are the main features of the CubeSats. The lower cost of CubeSat has made an impact on short-term space missions. The hostile environment of space is the ultimate stage ground to test satellites. Specially, the demand for 1kg to 10kg CubeSats has become huge over the last few years. Many sectors, such as business sectors, government agencies and the military, are also experimenting with CubeSats. The antenna plays a crucial role in the establishment and remote sensing of communication between Earth and the Satellite [1]. The antenna which has high gain, wide bandwidth and circular polarisation, is considered to increase the capabilities and potential of CubeSat communications. The patch antenna is attractive due to its low cost, low profile, and ease of fabrication [3-10]. Besides, meta resonators are attractive to increase the antenna performance [11-14]. Different frequency bands are used for satellite communication, such as L, S, C etc, whereas S-band is widely used for small satellite missions.

In [15], an L and S-band dual-feed circularly polarised (CP) CubeSats antenna is presented for Ground Communication (GPS). The resonant frequency of the antenna is 1.57 and 2.2 GHz, where the antenna is designed by a three-layer stacked. An S-band CP antenna is presented also in [16], where the antenna has been fed by a quadrature hybrid coupler and a peak gain of 5.2 dBi was achieved at 2.52 GHz frequency. Metamaterial integrated CubeSats CP antenna has been designed in [17], the peaks resonant frequency appeared at 2.25GHzz frequency and peaks gain achieved 4.87 dBi. A CubeSats mesh patch antenna designed for ground and inter-satellite communications in [18], where operation frequency is in S-band (2.45 GHz) and maximum gain achieved 4.8 dBi. A transparent substrate base CubeSats antenna has been designed in [19] for S bans Ground Communication (GPS). The resonant frequency of the antenna is 2.43 GHz with 5.3 dBi gain. A metallic helix antenna has been presented for S-band satellite communication, which operates at 2.025 to 2.29 GHz [20]. The overall size of the antenna is 94×94×48 mm^3. In [21], a shared aperture S-band antenna with the size of 82×82×4 mm^3 has been proposed for the nanosatellite communication system, which operates at 2.025 to 2.075 GHz.

This work presents an antenna with circular polarisation for lower S-band satellite applications. The operating band of the antenna is from 2.025-2.065 GHz with 5.2 dBi realised gain at the resonant frequency.

2. Design methodology

The main consideration of the antenna design is stable circular polarisation, high gain, and simple antenna design. Fig. 1 (a) shows a 3×3 fractal meta-resonator array where Rogers RT 5880 substrate material with a thickness of 1.575 mm is used to design the meta-resonator array. Fig. 1(b) shows a circular polarised defected ground patch antenna. The ground plane of the antenna plays vital role to achieve circular polarization, which is consisted of crescent and circular patch loading inside R radius circular slot [22, 23]. Fabricated antenna prototype and the s-parameters measurement setup of the designed antenna and metamaterial is presented in Fig. 1 (c) and (d), respectively. The design parameters of the meta resonator and antenna are listed in Table 1. The fractal meta-resonator array has been simulated by CST studio software by keeping perfect electric and perfect magnetic boundary conditions in the x and y-axis respectively. The electromagnetic wave is applied towards negative z directions.

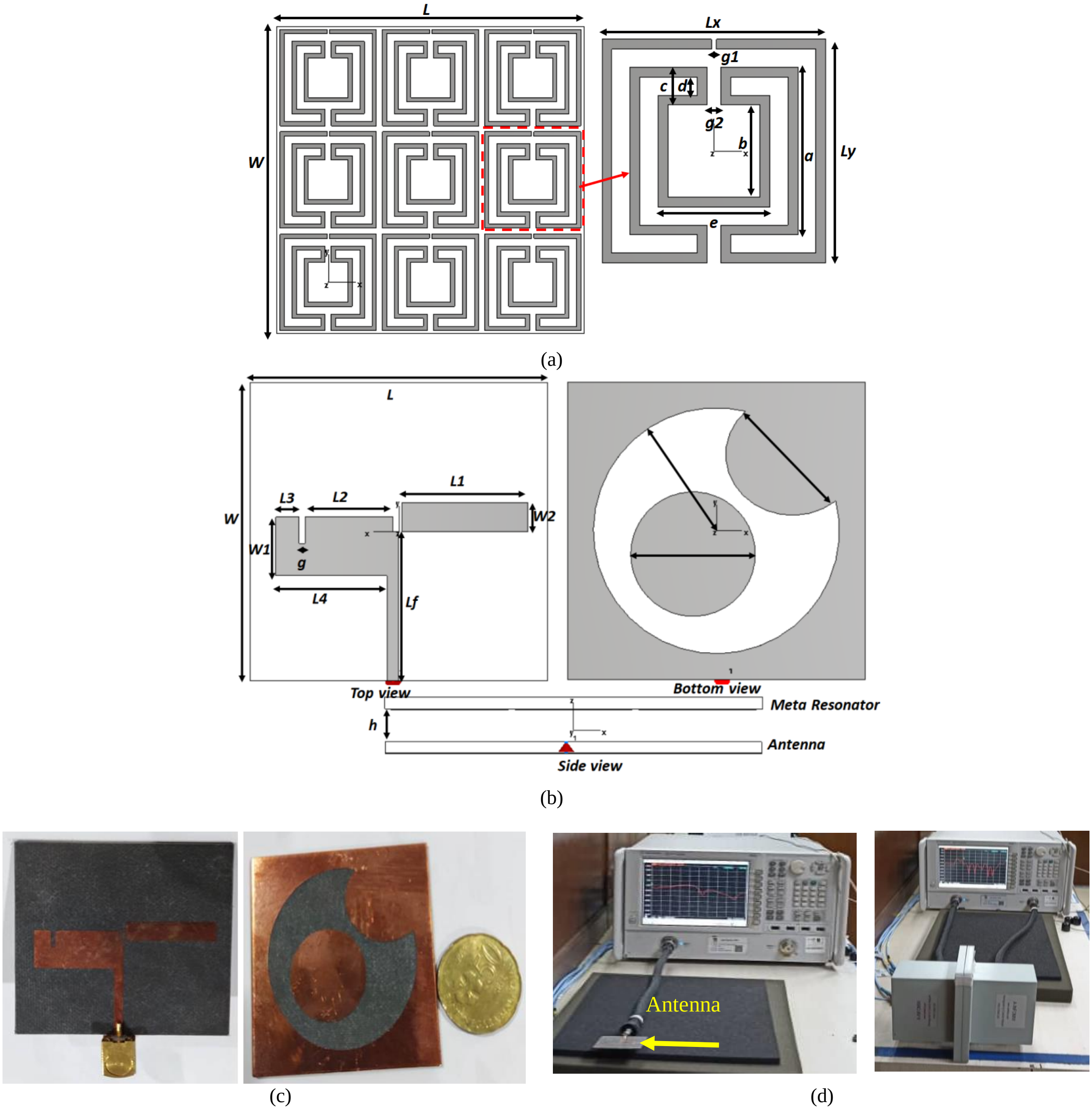


Fig. 1. Schematic layout of the proposed (a) meta resonator (b) antenna, (c) fabricated antenna, and (d) Measurement setup of s-parameters for antenna and metamaterial (color online)

Table 1. Design parameters

Parameter	Value (mm)	Parameter	Value (mm)
L	50.80	Lx	16.00
W	50.80	Ly	16.00
a	12.00	L1	21.5
b	6.00	L2	15.0
c	2.70	L3	4.00
d	1.30	L4	19.00
e	8.00	Lf	25.40
g	1.00	W1	10.00
g1	0.35	W2	5.00
g2	1.00	h	4.43

3. Results and discussion

The s-parameters of the designed meta resonator are illustrated in Fig. 2. The reflection coefficient (S_{11}) shows more than -20 dB resonance from 1.8-2.2 GHz frequency and the near-zero dB transmission coefficient (S_{21}) shows excellent resonance behaviour at the operating region of the meta resonator. The effective metamaterial property like effective permittivity and effective permeability are retrieved and presented in Fig. 3. The results show a high value of permittivity and permeability for the real part and a near-zero value for an imaginary part, which is responsible for the resonance behaviour of the fractal meta-resonator array.

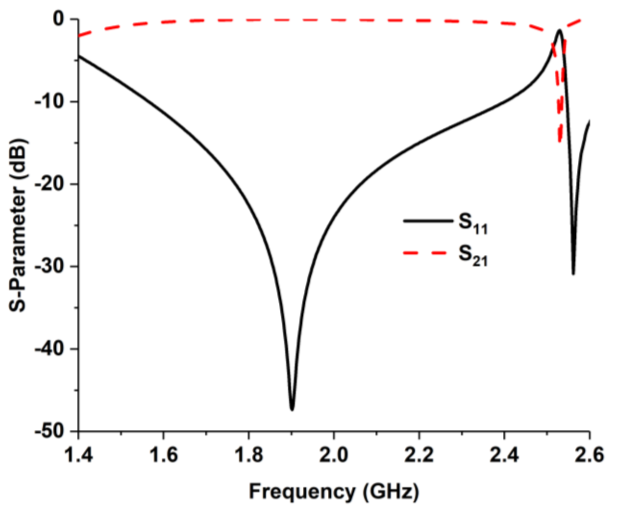


Fig. 2. Reflection coefficient of the proposed meta resonator (color online)

The designed 3×3 fractal meta-resonator array is placed on top of the antenna to enhance the gain of the antenna. Fig. 4(a) shows simulated and measured S-parameters, and the axial ratio of the proposed meta resonator-based defected ground antenna. The -10 dB reflection bandwidth of the proposed antenna has been achieved from 2.025-2.065 GHz and the corresponding axial ratio is less than 3dB at the operating band, which shows a stable circular polarisation of the designed meta resonator base defected ground antenna. The realized gain and the efficiency of the proposed antenna are presented in Fig. 4(b).

The circular polarisation operation can be understood from surface current distributions at different time instants. It is shown from Fig. 5 that at ωt=0˚ the direction of the current flow is towards the +x axis and when ωt=90˚ the orientation of the current flow towards the negative y-axis. The direction of the current flow is the negative x-axis and positive y-axis when ωt=180˚ and 270˚, respectively, which made overall a left-hand circular polarisation of the proposed antenna. Therefore, circular patch and crescent shape structure has direct influence to achieve circular polarization and AR performances. The three-dimensional and two-dimensional radiation pattern of the designed antenna has been presented in Fig. 6. The single defected-ground antenna achieved only 0.628 dBi realised gain at the resonant frequency. However, by using the meta resonator on the top of the antenna, the gain enhances significantly, which is 5.2 dBi. Moreover, 3dB axial beamwidth of the proposed antenna is presented in Fig. 7.

A comparison with the existing antenna has been presented in Table 2, where the proposed antenna achieves attractive gain and operational frequency by a compact antenna size, which prioritises the proposed antenna for cube-satellite applications.

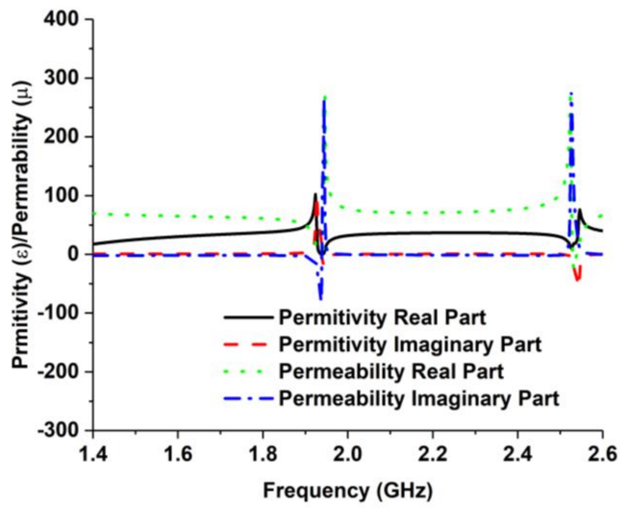
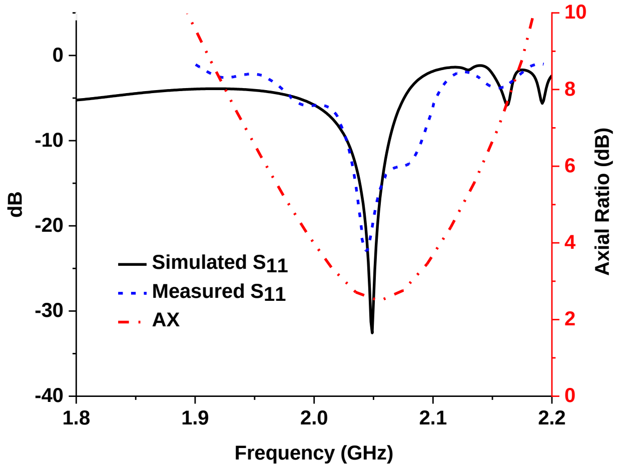
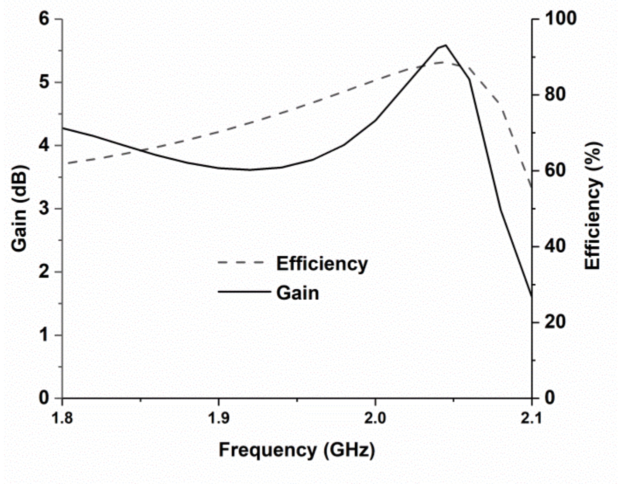


Fig. 3. Retrieved properties of the proposed meta resonator (color online)



(a)



(b)

Fig. 4. (a) Reflection coefficient and axial ratio and (b) radiation properties of the proposed antenna (color online)

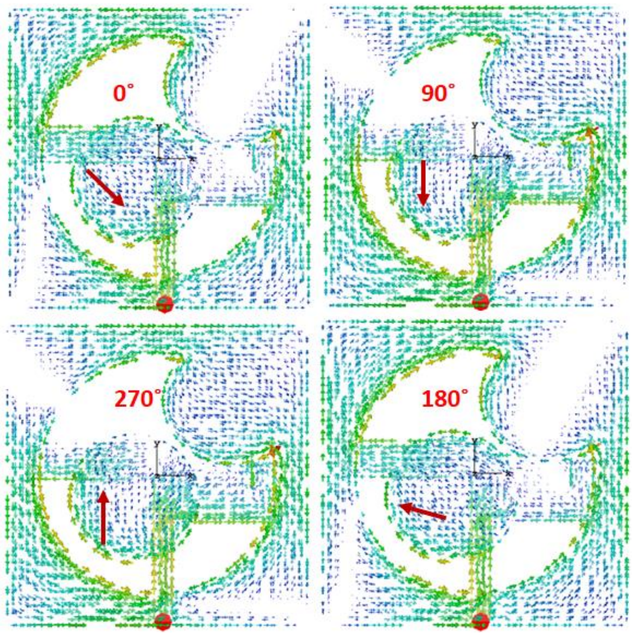
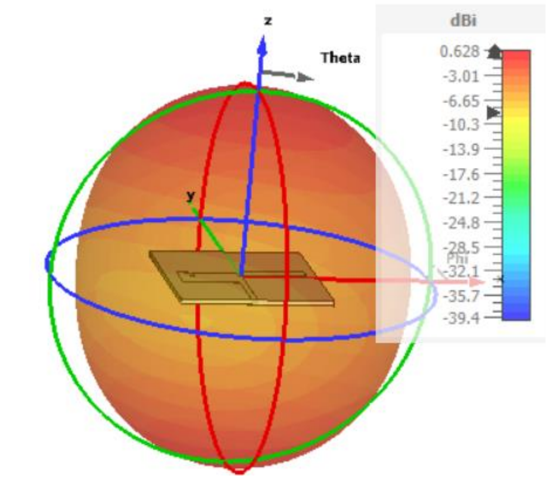
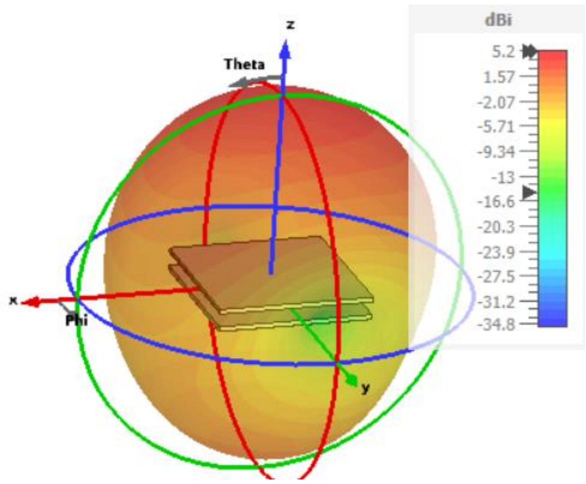


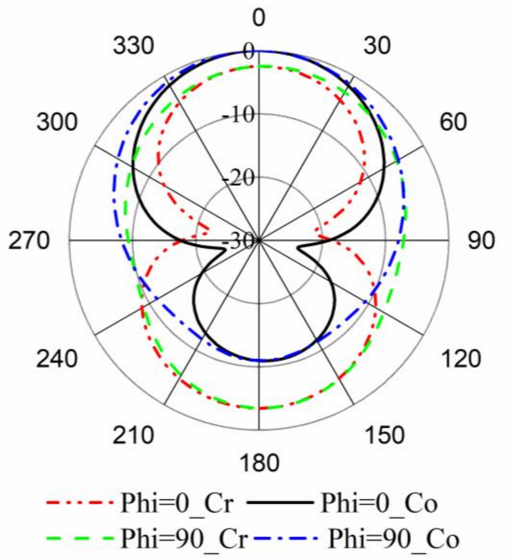
Fig. 5. The surface current distribution of the proposed antenna (color online)



(a)



(b)



(c)

Fig. 6. Realized gain of the proposed antenna at the resonating frequency (a) 3D pattern without metamaterial, (b) 3D pattern with metamaterial and (c) 2D pattern with metamaterial (color online)

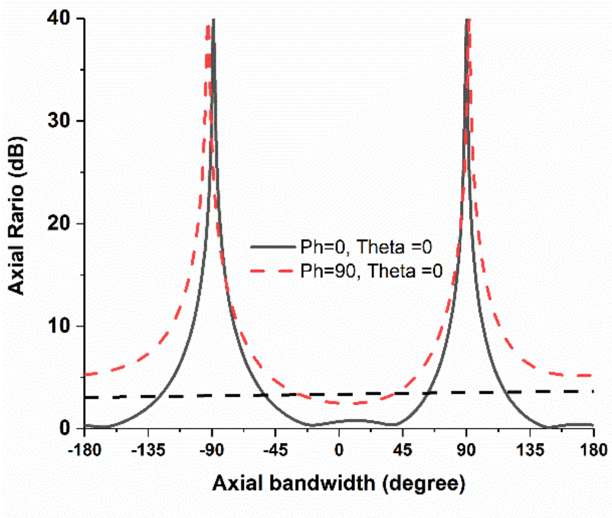


Fig. 7. 3dB axial beamwidth of the proposed antenna (color online)

Table 2. Comparison with the existing antenna

Ref.	Antenna configurations	Size L×W (mm^2)	Operating frequency (GHz)	Gain (dBi)
[20]	Spherical helix antenna	94×94	2.025-2.29	7.39
[18]	Mashed patch	74×74	2.45-2.6	4.8
[17]	Parch antenna	100×100	2.2-2.45	4.87
[16]	closed-loop radiator	180×80	2.4-2.5	5.2
[21]	Shared aperture antenna	82×82	2.025- 2.075	6
Proposed	Slotted ground	50×50	2.025-2.065	5.2

4. Conclusion

This paper proposes a circularly polarised meta resonator base defected ground antenna for lower S-band cube satellite communication. The -10 dB operating band of the proposed antenna is from 2.025-2.065 GHz, and the axial ratio achieved less than 3dB at the operating band. The peak gain of 5.2 dBi has been attained by the metal resonator. The passband property of the metal resonator increases the gain of the antenna. The effective metamaterial property of the designed meta resonator and surface current distribution of the proposed antenna has been discussed in detail to understand the circular polarisation and gain enhancement. The compact size, high gain and circular polarisation make the proposed antenna an attractive candidate for the cube-satellite applications.

Acknowledgment

This work is supported by the research grant code: ZF-2022-006 and Universiti Kebangsaan Malaysia (UKM) research grant code: GUP-2022-074.

References

[1] Q. Zhang, B. Zhou, M. Islam, M. Cho, M. Samsuzzaman, S. Kibria, P. A. Catherwood, W. G. Scanlon, A. Hussain, B. Einarsson, IEEE Antennas and Propagation Magazine **57**(2), 1 (2015).
[2] H. H. Abdullah, A. Elboushi, A. E. Gohar, E. A. Abdallah, IEEE Access **9**, 45123 (2021).
[3] M. Samsuzzaman, M. T. Islam, Microwave and Optical Technology Letters **57**(2), 445 (2015).
[4] M. Alam, N. Misran, B. Yatim, M. T. Islam, International Journal of Antennas and Propagation

2013, 1 (2013).
[5] M. N. Shakib, M. T. Islam, N. Misran, IET Microwaves, Antennas & Propagation **4**(10), 1456 (2010).
[6] J. Tiang, M. Islam, N. Misran, J. Mandeep, Journal of Electromagnetic Waves and Applications **25**(13), 1851 (2011).
[7] R. Azim, M. T. Islam, N. Misran, Informacije MIDEM-Journal of Microelectronics Electronic Components and Materials **41**(2), 114 (2011).
[8] R. Azim, M. T. Islam, N. Misran, International Review of Electrical Engineering **5**(4), 1848 (2010).
[9] S. Abulgasem, F. Tubbal, R. Raad, P. I. Theoharis, S. Lu, S. Iranmanesh, IEEE Access **9**, 45289 (2021).
[10] N. Saeed, A. Elzanaty, H. Almorad, H. Dahrouj, T. Y. Al-Naffouri, M.-S. Alouini, IEEE Communications Surveys & Tutorials **22**(3), 1839 (2020).
[11] M. A. W. Nordin, M. T. Islam, N. Misran, Progress In Electromagnetics Research **136**, 157 (2013).
[12] M. T. Islam, N. Misran, IEICE Electronics Express **7**(4), 240 (2010).
[13] T. Alam, A. F. Almutairi, M. Samsuzzaman, M. Cho, M. T. Islam, Scientific Reports **11**(1), 1 (2021).
[14] S. X. Ta, V. C. Nguyen, K. K. Nguyen, C. Dao - Ngoc, International Journal of RF and Microwave Computer - Aided Engineering **31**(4), e22560 (2021).
[15] Y. Yao, S. Liao, J. Wang, K. Xue, E. A. Balfour, Y. Luo, IEEE Antennas and Propagation Magazine **58**(3), 16 (2016).
[16] H. Lobato-Morales, S. Villarreal-Reyes, E. Guerrero-Arbona, E. Martinez-Aragon, R. Chávez-Pérez, J. Medina-Monroy, C. Figueroa-Torres, International Conference on Electronics, Communications and Computers (CONIELECOMP), Cholula, Mexico, 157 (2019).
[17] A. Ygnacio-Espinoza, D. Peñaloza-Aponte, J. Alvarez-Montoya, A. Mesco-Quispe, M. Clemente-Arenas, International Conference on Electromagnetics in Advanced Applications, Cartagena, Colombia, 605 (2018).
[18] S. K. Podilchak, D. Comite, B. K. Montgomery, Y. Li, V. G.-G. Buendia, Y. M. Antar, IEEE Access **7**, 96560 (2019).
[19] N. Neveu, M. Garcia, J. Casana, R. Dettloff, D. R. Jackson, J. Chen, IEEE International Conference on Wireless for Space and Extreme Environments, Baltimore, MD, USA, 1-4 (2013).
[20] V. Laquerbe, R. Fragnier, IEEE Antennas and Wireless Propagation Letters **21**(4), 715 (2022).
[21] D. E. Serup, R. J. Williams, S. Zhang, G. F. Pedersen, 4th European Conference on Antennas and Propagation (EuCAP), Copenhagen, Denmark, 1-4 (2020).
[22] S. Trinh-Van, Y. Yang, K. Y. Lee, Y. S. Kim, K. C. Hwang, Applied Sciences **9**(6), 1117 (2019).
[23] T. T. Le, V. H. The, H. C. Park, Microwave and Optical Technology Letters **58**(7), 1634 (2016).

*Corresponding author: touhidul@ukm.edu.my, tariqul@ukm.edu.my