Right hand circularly polarized 2.40 GHz truncated corner patch antenna for small satellite application

MD. SAMSUZZAMAN[a,c], NORBAHIAH MISRAN[a], M. TARIKUL ISLAM[a], M. R. I. FARUQUE[b], MOHAMMAD TARIQUL ISLAM[a]
[a]*Center of Advanced Electronic and Communication Engineering Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia*
[b]*Space Science Center (ANGKASA), Universiti Kebangsaan Malaysia, Malaysia*
[c]*Department of Computer and Communication Engineering, Patuakhali Science and Technology University, Bangladesh*

In this paper, a compact 2.40 GHz Right Hand Circularly Polarized (RHCP) printed antenna is designed, fabricated, and integrated with a small satellite body for satellite applications. The proposed antenna consists of a truncated corner patch and the square-shaped ground plane. The truncated coroner patch is responsible for achieving CP characteristics. A direct coaxial feed is used to excite the patch and ground of the proposed antenna. The antenna is fabricated and measured. Experimental and simulated results of the proposed design are agreed with each other. The antenna achieved more than 6.69 dBi realized gain at the operating band is simple in design. So, it'll be simpler to integrate it into the small satellite body. After integrating with the cube satellite body, the antenna shows stable performance in the desired operating band.

(Received March 17, 2019; accepted October 9, 2019)

Keywords: Patch antenna, Small Satellite applications, High gain, RHCP

1. Introduction

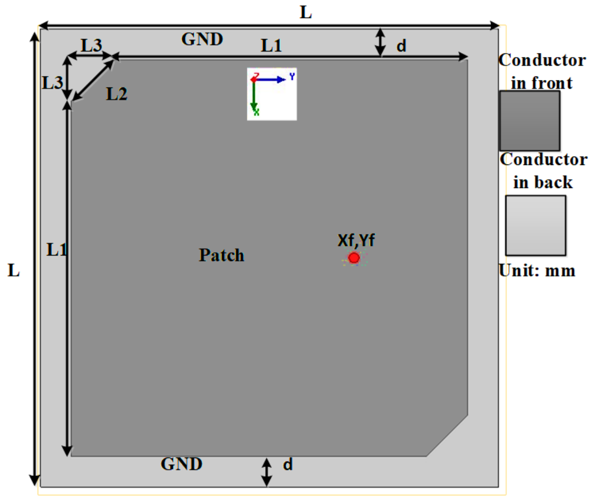
"Miniaturization" is the best technique to be used from a decade ago for making a small satellite without degrading its performance and capabilities. Presently, small satellites like mini, Pico, and micro-satellites are launching an increased number [1, 2].

The popularity of small satellite is increasing day by day due to its low production cost, low launching cost although it provides higher reliability and used for small scale experiment in different universities. These type of satellites can be used in earth observation, educational purpose, and the system of communication [3-5]. Due to the physical size limitation of launching, it is difficult to employ a highly directive antenna with compact size. The typical dimension of the Cube-Sat is 10 cm ×10 cm × 10 cm, it's weight is significantly less than 1 kg, and it uses those parts which are commercially off-shelf [6]. In this research, 3-unit Cube-Sat (30 cm×10 cm ×10 cm) is used. For filling the P-pod launcher dimensional limitations, the property of the antenna will be low, the size will be minimized, directivity will be moderated, and performances of gain should be improved [2, 7]. For high-speed communication, S-band high gain antenna is essential for video or high-resolution image data transfer. Recently, compact circularly polarized microstrip antennas have got popularity due to the flexible orientation of transmitter and receiver in satellite communication, radio frequency identification(RFID) readers, mobile to mobile communication applications [8]. Several types of antennas have been investigated, and huge numbers of antenna designs have been published all over the years in the technical literature [9-12]. Gain enhancement strategies have already been proposed here nonetheless it requires a particular dielectric that includes a heavy layer [9]. The configuration of the stacked patch has been analyzed and acquired a gain around 9 dB which includes two patches, in 3 layer configuration the gain is 10 dB and parasitic patches of the 2×2 array possess a gain which is 10.5 dB [11]. For solving this issue, the researcher utilizes the helical antenna as like as an individual element which is principally a more substantial gain radiator [13]. When the shorting pin numbers are improved, the function of the patch is comparable to the annular patch [14]. In the CP antenna, the annular band is utilized for both requirements of compactness [12, 15] and the dual-frequency operation [16]. Single-layer, single-feed patch antennas have already been reported most recently, which includes embedded Y and T-shape slots to understand good dual-band CP features [17]. For earth observation, four rectangular patches are properly thrilled so you can get the highest gain and in addition for circular polarization [18]. Additionally, there are four rectangular patches, and in each patch side, there exists a square shape band slot in reconfigurable S-band patch antenna for cube satellites [19]. For Global Navigation Satellite System (GNSS), dual-band planar antennas (Zenith and Nadir) are used in different requirements [20]. Metamaterial loaded dual-band (S band) circular polarised antenna was proposed for nanosatellite payload communication [21]. The antenna achieves 710 MHz (3.06–3.77 GHz) of −10 dB impedance bandwidth with 160 MHz (3.02–3.18 GHz) and 210 MHz (3.05–3.26 GHz) of 3 dB axial ratio (AR) bandwidth for port 1 and port 2, respectively. S-band circular polarized (CP) antenna was also presented and investigate the performance compatibility for nanosatellite space mission [22]. But the antenna achieves only 5.58 dB gain with comparatively large dimension. Recently, dual-band (L and S band)stacked patch antenna was designed with dual-circular polarization for BeiDou navigation satellite system [23]. The designed antenna was complex in design and low gain.

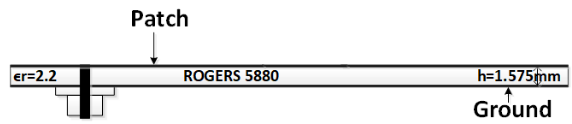
In this paper, a high gain RHCP antenna which has a compact dimension patch is designed, investigated, and verified. The proposed design consists of a two truncated corner cut the small square-shaped patch and the square-shaped ground plane. The truncated corned cut is used for optimize the desired AR operating band. The proposed antenna is excited by a single coaxial direct-fed which is connected to the patch and ground plane. The antenna is printed on low loss satellite application based compatible material, Rogers 5880. The proposed design also achieved comparatively higher RHCP gain in terms of its dimension. Simulated and measured results have agreed well. The antenna has also integrated with a small satellite body and checked the simulated performance, which is stable in the desired operating band. Due to the compact dimension and other antenna properties, the antenna can be a suitable candidate for 2.40 GHz band satellite applications.

2. Antenna layout design

The geometrical structure of the proposed antenna is shown in Fig. 1. The antenna consists of two truncated corner cut patch and the square-shaped ground plane. Low loss Rogers RT/ droid 5880 (TM) substrate material has used for the design with dielectric constant 2.2 and tangent loss 0.0009. Rogers's substrate is used for the design of the antenna due to the material space compatibility for satellite applications. The two truncated corner square-shaped patch is printed on the one side of the substrate, and the comparatively larger square-shaped ground plane is printed on the other side of the used substrate. A 50-ohm coaxial direct feed is used for connecting the patch and ground plane for excitation which location is identified as Xf, Yf in the design layout. The length of the patch and ground plane is defined by *L1* and L, respectively. Two identical truncated corner cut has introduced to achieve CP and axial ratio bandwidth in the desired operating band. The truncated corner cut dimension is defined as L2, L3, and L4. After optimizing the dimesons of cornet cut 2.45 GHz 3db axial ratio property has achieved. For understating the CP property of the proposed antenna design, a surface current magnitude and vector distribution have present in Fig. 2 at 2.40 GHz in four-phase value. From Fig. 2, we can observe that at 0-degree phase value, most of the dominant current direction is in the +X direction. After changing the phase value from 0 to 90 degree, most of the dominant current direction now in the +Y direction. When the phase has changed to 180 degrees, most of the dominant vector current direction has observed in the –X-direction. Finally, the phase has changed to 270 to complete the 360 phase, here most of the vector surface dominant current is observed in –Y direction. Overall, the dominant vector current rotates in an anticlockwise direction, which proves that the antenna shows Right Hand Circular Polarization property.

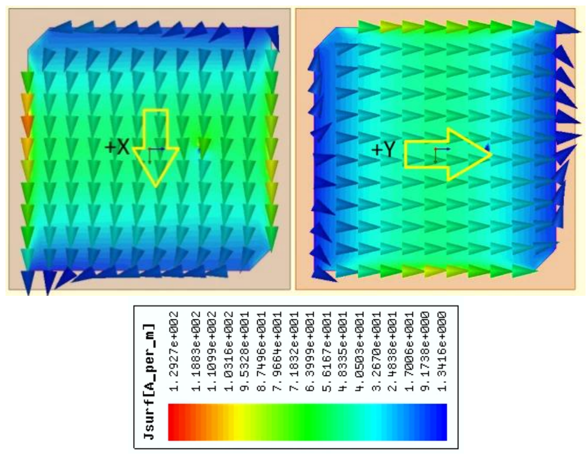


(a)

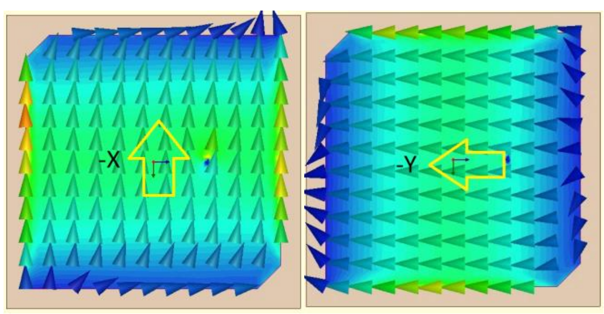


(b)

Fig. 1. Geometry of proposed antenna (a) top and bottom view b) side view



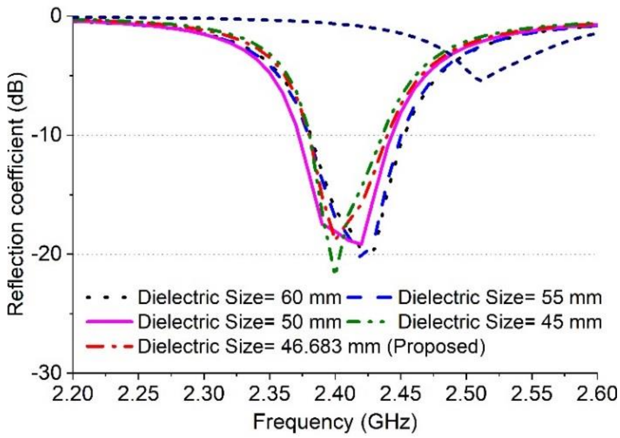
(a) 0^0 *(b) 90^0*



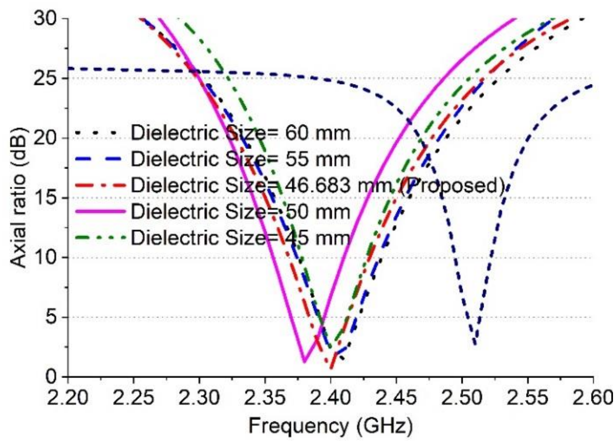
(c) 180^0 *(d) 270^0*

Fig. 2. Current characteristics at 2.40 GHz a) 0^0 b) 90^0 c) 180^0 d) 270^0

Fig. 3 shows the reflection coefficients and axial ratio result according to various types of dielectric size. The optimum result was achieved by the dielectric dimension at 46.64 mm.



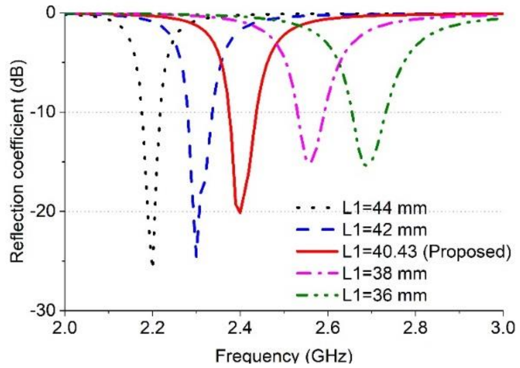
(a)



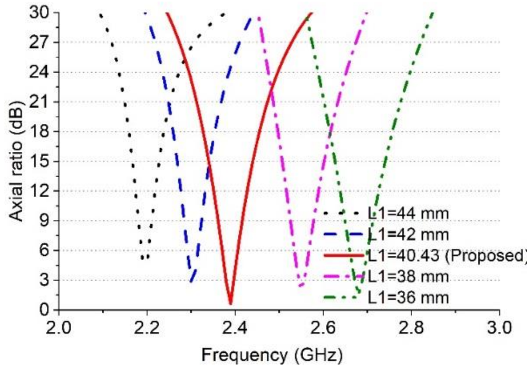
(b)

Fig. 3. Effect on (a) reflection coefficient (S_{11}) and (b) axial ratio various size of the dielectric substrate

Fig. 4 shows the effect of S_{11} and AR of different sizes of patch measurement parameter *L1*. By increasing the value of *L1*, the resonance frequency has shifted to the lower end and decreasing the value of *L1* from the optimized value; the resonance has shifted to a higher frequency in both S_{11} and AR. The optimized value of *L1* is 40.43 mm. Fig. 5 depicts the S_{11}, and axial ratio performance of different values of patch cut *L3*. The best S_{11} and AR performance have achieved by using the *L3* value of 3.7 mm.

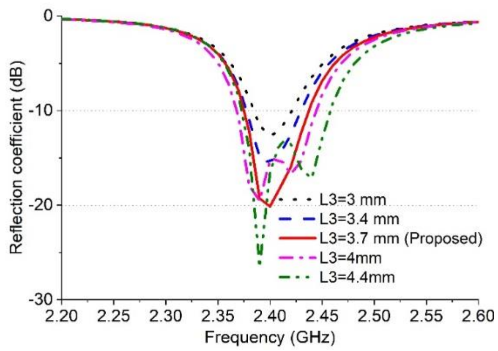


(a)

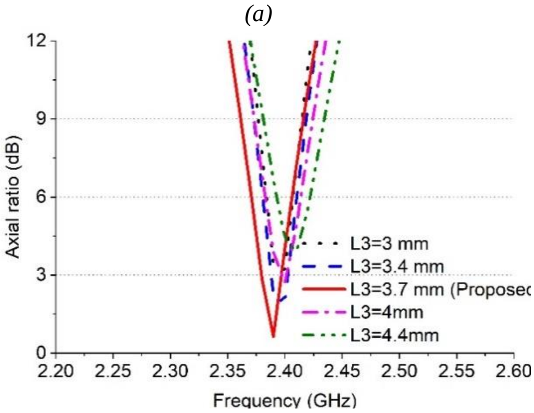


(b)

Fig. 4. Effect of (a) S_{11} and (b) axial ratio for various length of L1



(a)



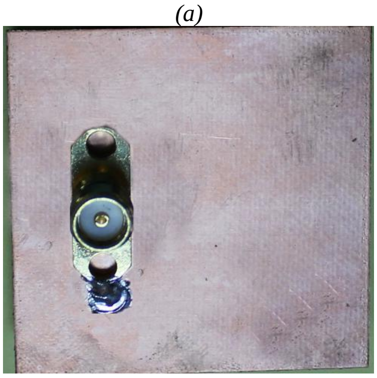
(b)

Fig. 5. Effect of (a) reflection coefficient (S_{11}) and (b) axial ratio for various length of L1

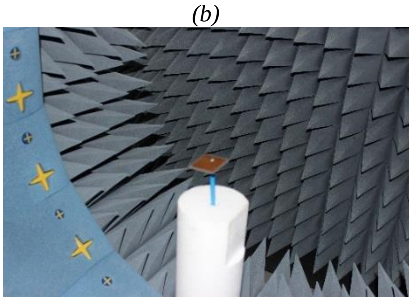
3. Experimental results and discussion

The simulation and modeling of the proposed antenna are done using commercially available CST Microwave studio and High-Frequency structure Simulator HFSS. A prototype of the final truncated corner CP antenna is fabricated and tested. The reflection coefficient (S_{11}) parameter is measured using N5247A PNA-X vector network analyzer, and the radiation and gain characteristics are measured using UKM, Satimo Star-Lab near-field measurement system. The photography of the fabricated prototype and Satimo Near field UKM chamber is shown in Fig. 6.

(a)



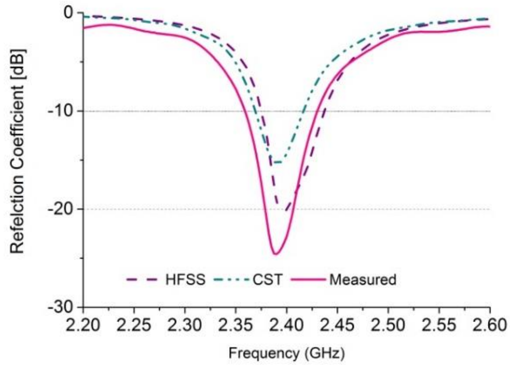
(b)



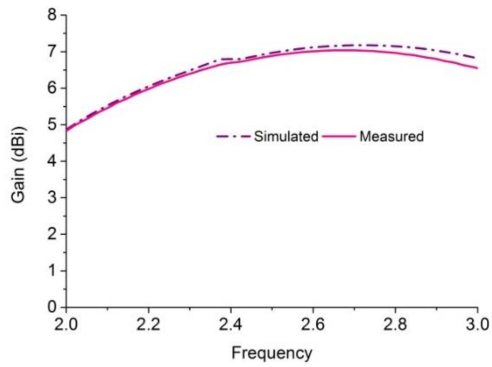
(c)

Fig. 6. Fabricated prototype of the proposed antenna a) The front side b) The backside c) Near Field Chamber

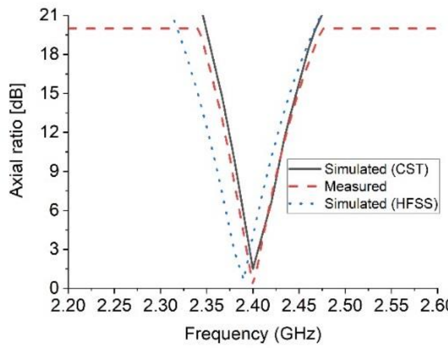
The comparison between simulated (CST and HFSS) and measured results of impedance bandwidth, axial ratio bandwidth, and gain is shown in Fig. 7. The simulated and measured impedance bandwidth (S_{11} <-10 dB) is shown in Fig. 7 (a). The simulated impedance bandwidth of 7 MHz from 2.37 GHz to 2.44 GHz (HFSS), 7MHz from 2.36 GHz to 2.41 GHz (CST) and 7 MHz from 2.36 GHz to 2.43 GHz. The simulated and measured 3-dB axial ratio bandwidth of 1.5 MHz (simulated) and 2 MHz (measured) is achieved, which is displayed in Fig. 7(b). The simulated and measured gain of the antenna is shown in Fig. 7(c). The measured bore-sight gain of 6.69 dBi is achieved at the center frequency. There is 0.5 dBi gain variation in the entire axial ratio bandwidth because of small fabrication errors and SMA connector losses [25]. The simulated and measured 2D and 3D radiation patterns at 2.40 GHz frequency in xz and yz planes are shown in Fig. 8. As shown in Fig. 8(a), (b), simulated and measured 2D radiation patterns are a good agreement in both RHCP and LHCP. The LHCP level is -20 dB below the RHCP level in both xz and yz planes. The designed antenna shows the RHCP dominated radiation pattern in the boresight direction.



(a)



(b)



(c)

Fig. 7. Simulated and Measured result (a) reflection coefficient (S11), (b) Gain, and (c) Axial ratio

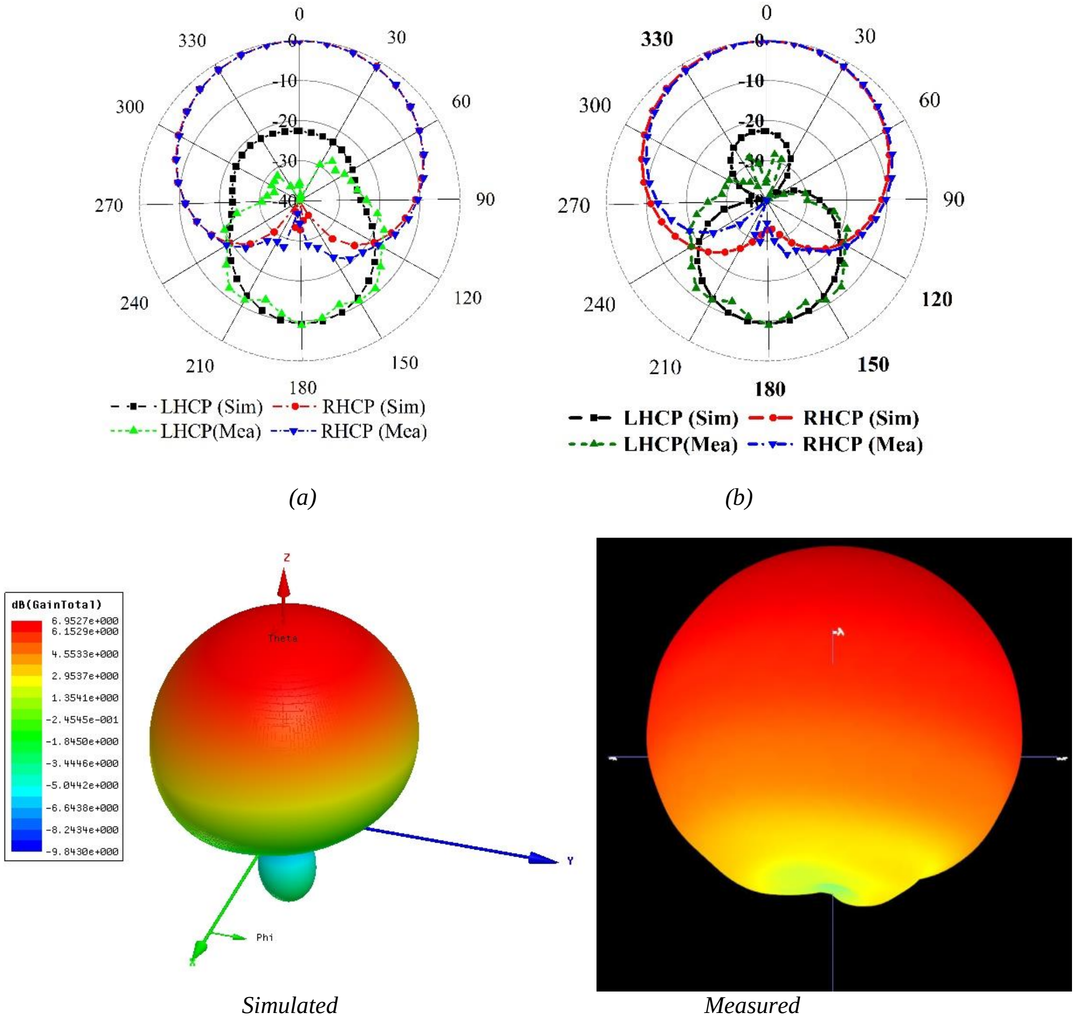


Fig. 8. Numerical and measured RHCP and LHCP Radiation pattern at 2.40 GHz (a) xz plane (b) yz Plane and (c) 3D radiation pattern

4. Antenna integration with satellite body

Fig. 9 shows the proposed antenna with the small satellite body (1U CubeSat). In Fig. 10, the comparison of the reflection coefficient is shown with the help of HFSS and CST simulation software. In this comparison, all the curves have a large portion, which is less than -10 dB, which means all the outcomes are stable here. When the antenna is with a satellite body, it shows a good performance. Its performance isn't degraded.

In Fig. 11, a comparison of gain is shown. Gain's outcome is stable when the satellite body includes the antenna. Here, peak gain is 7dBi. By measuring the S_{11} and gain, it is observed that the performance of the antenna is stable. It satisfies all the requirements. The performance comparison of the proposed design is shown in Table 1.

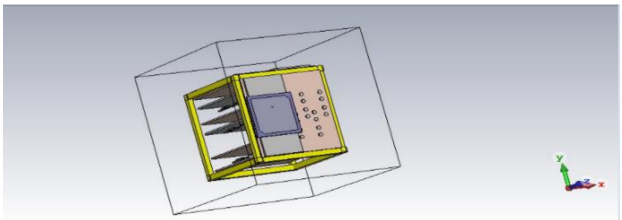


Fig. 9. The proposed antenna is placed on the satellite

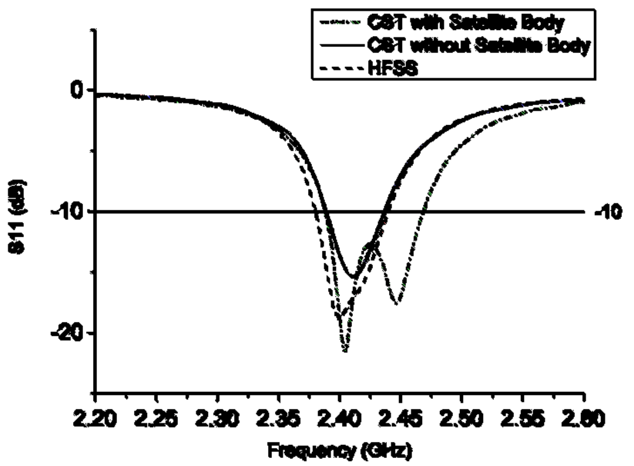


Fig. 10. Comparison of reflection coefficient (S_{11})

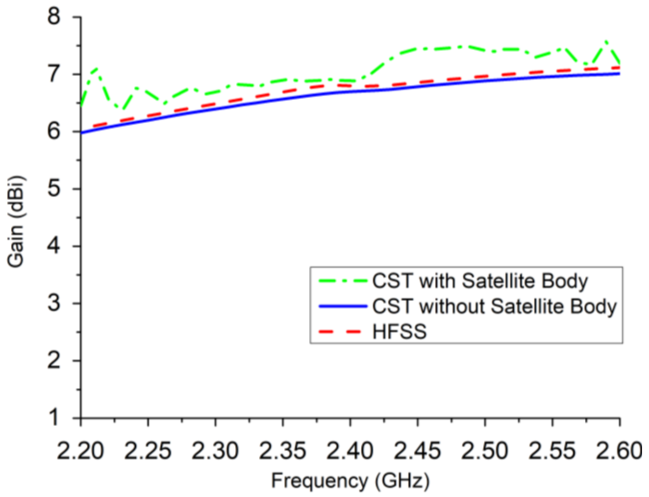


Fig. 11. Comparison of peak gain after integration antenna with small satellite body

Table 1. Comparative analysis of the proposed antenna

Ref.	Frequency Range (GHz)	Dimension (mm^2)	Peak Gain (dB)
[8]	1.698-1.709	Not mentioned	5
[10]	-	50.80 ×70.60	5.3
[24]	0.900-0.925	135 × 122	3
Proposed	2.36-2.43	46.683 × 46.683	6.69

6. Conclusion

In this article, a right hand circularly polarized (RHCP) slotted patch antenna has investigated and designed for 2.40 GHz band small satellite applications. The proposed antenna consists of two truncated corner cut patch and square shape ground plane which is connected through a coaxial probe. Right-hand circular polarization has achieved by using the truncated corner cut. The proposed designed is simulated using HFSS and CST and fabricated. Simulated and measured results have a good agreement. The antenna has achieved 7 MHz bandwidth from 2.37GHz to 2.43 GHz with 6.69 dB peak in at 2.40 GHz frequency with this compact dimension . The proposed antennas have also integrated into a small satellite body and achieved stable performance in the designed frequency. Due to the low profile, RHCP, and highly directional antenna property, the proposed design can be a suitable candidate for small satellite S-band applications.

Acknowledgments

This work was supported by the Universiti Kebangsaan Malaysia, Grant No. MI-2018-016 and FRGS/1/2011/TK/UKM/02/1.

References

[1] Y. Rahmat-Samii, V. Manohar, J. M. Kovitz, IEEE Antennas and Propagation Magazine **59**, 22 (2017).
[2] M. Samsuzzaman, M. T. Islam, S. Kibria, M. Cho, IEEE Access **6**, 54282 (2018).
[3] W. Marchant, E. R. Taylor, Journal of Reducing Space Mission Cost **1**, 277 (1998).
[4] M. T. Islam, M. Cho, M. Samsuzzaman, S. Kibria, *I*EEE Antennas and Propagation Magazine, **57**, 30 (2015).
[5] M. Samsuzzaman, M. Islam, J. Mandeep, Optoelectron. Adv. Mat. **7**, 760 (2013).
[6] H. Heidt, J. Puig-Suari, A. Moore, S. Nakasuka, R. Twiggs, 2000.
[7] J. Puig-Suari, C. Turner, R. Twiggs, 2001.
[8] F. Ferrero, C. Luxey, G. Jacquemod, R. Staraj, IEEE Antennas Wirel. Propag. Lett. **4**, 13 (2005).
[9] H. Yang, N. G. Alexopoulos, IEEE Trans. Antennas Propag. **35**, 860 (1987).
[10] R. Q. Lee, K.-F. Lee, *I*EEE Trans. Antennas Propag. **38**, 1298 (1990).
[11] S. Egashira, E. Nishiyama, IEEE Trans. Antennas Propag. **44**, 1533 (1996).
[12] M. Samsuzzaman, M. T. Islam, S. Kibria, M. Cho, Microwave Opt. Technol. Lett. **57**, 1503 (2015).
[13] S. F. Mahmoud, A. R. Al-Ajmi, Progress In Electromagnetics Research **86**, 71 (2008).
[14] D. Jackson, J. Williams, A. K. Bhattacharyya, R. L. Smith, S. J. Buchheit, S. Long, IEEE Trans. Antennas Propag. **41**, 1026 (1993).
[15] X. Bao, M. Ammann, Electron. Lett. **42**, 192 (2006).
[16] J.-S. Row, Electron. Lett. **40**, 153 (2004).
[17] K.-P. Yang, K.-L. Wong, IEEE Trans. Antennas Propag. **49**, 377 (2001).
[18] A. Nascetti, E. Pittella, P. Teofilatto, S. Pisa, IEEE antennas and wireless propagation letters **14**, 434 (2015).
[19] E. Pittella, S. Pisa, M. Pontani, A. Nascetti, P. D'Atanasio, A. Zambotti, et al., IEEE Aerospace and Electronic Systems Magazine **31**, 6 (2016).
[20] M. Maqsood, B. Bhandari, S. Gao, R. D. V. Van Steenwijk, M. Unwin, Dual-band circularly polarized antennas for GNSS remote

sensing onboard small satellites, in Communication Systems Networks and Digital Signal Processing (CSNDSP), 2010 7th International Symposium on, 2010, pp. 86.
[21] T. Alam, M. T. Islam, M. Cho, Electron. Lett. **54**, 1104 (2018).
[22] T. Alam, M. T. Islam, M. Amanath Ullah, M. Cho, Microwave Opt. Technol. Lett. **60**, 2817 (2018).
[23] H. Yang, Y. Fan, X. Liu, IEEE Antennas Wirel. Propag. Lett., 2019.
[24] G. Liu, L. Xu, and Z. Wu, Int. J. Antennas Propag. **2013** (2013).
[25] M. T. Islam, R. Azim, and N. Misran, Information Technology Journal, **9**, 386 (2010).

*Corresponsing author: samsuzzaman@ukm.edu.my
tariqul@ukm.edu.my