Circularly Polarized S-Band Satellite Antenna With Parasitic Elements and Its Arrays

Eun-cheol Choi, Jae W. Lee, *Member, IEEE*, Taek-Kyung Lee, *Member, IEEE*, and Woo-Kyung Lee, *Member, IEEE*

***Abstract*—A structural modification of S-band turnstile antenna with cylindrical parasitic elements around a main radiator is introduced and investigated with respect to its gain, axial-ratio (AR) beamwidth, and radiation pattern. The overall structure is composed of a main radiator of two crossed bowtie-shaped dipole antennas and a feeding network using a Wilkinson power divider with phase differences between two parts. A final optimization of the parameter values for the enhancement of AR beamwidth is carried out from the parametric studies. The proposed antenna has not only a broad 5-dB AR bandwidth of 12.3% ranging from 2025 to 2290 MHz, but also a stable peak gain of 7.6 dBic with circular polarization (CP) characteristic.**

***Index Terms*—Circular polarization (CP), parasitic element, telemetry, tracking, and command (TT&C), turnstile antenna.**

I. Introduction

IN ALL satellite communications, telemetry, tracking, and command (TT&C) is an essential and fundamental system in monitoring and controlling the status of the operating satellite system [1]. In order to process the information data attained from the receiver, TT&C antennas should satisfy the given specification and cover the transmitting and receiving frequency bands of 2200 $\sim$ 2290 and 2025 $\sim$ 2125 MHz, respectively. In addition, since the connection between the transmitting and receiving signal should be maintained even if change is due to a change of fine position, a relatively low gain and wide beamwidth are required in the S-band satellite antenna.

According to the research for TT&C satellite antennas satisfying the given specifications of transmitting and receiving environments, various structure candidates have been studied and investigated. For instance, microstrip patch [2], quadrifilar helix [3], conical spiral [4], and turnstile antenna [5]–[8] have been suggested and employed to transmit and receive the information data. As is well known, the microstrip antenna has its own advantages of being lightweight, being easy to fabricate, and having robust characteristics against vibration and impact of the launching vehicle, particularly with a relatively narrow bandwidth being unable to cover both transmitting and receiving frequencies. Also, the quadrifilar helix antenna has the drawback of achieving a wide input impedance bandwidth over transmitting/receiving frequencies, while with a relatively wide beamwidth and an excellent axial ratio (AR). Even the conical spiral antenna, which is difficult to manufacture and obtain an excellent input impedance bandwidth, has many advantages such as wide beamwidth and low VSWR over a relatively wide bandwidth. Compared to the other types of TT&C antennas, a turnstile antenna with simplified modification schemes has several attractive features in terms of easy fabrication, low complexities, and robust structures. Especially, it has been studied that the turnstile antenna has a wide beamwidth and wide input impedance bandwidth.

In this letter, we propose a turnstile S-band satellite antenna with parasitic elements using cylindrical arrays and a power divider as a feeding network. By adjusting the height and optimizing the locations and the number of cylindrical parasitic elements surrounding the main horizontal bowtie-shaped dipoles, the target band, which is 2025 $\sim$ 2290 MHz covering all the transmitting/receiving frequencies, is achieved with the required electrical performances of 3-dB beamwidth above the average 85° and axial ratios under 5 dB at $\theta = \pm 60°$.

In Sections II and III, the modified turnstile antenna with parasitic elements and its arrays is introduced with the electrical performances using the parametric studies, parameter optimization, and verification through the measurements. The effects of the locations and the height of the parasitic elements on the radiation pattern and axial ratio will be discussed. As a conclusion, a brief summary is provided in Section IV.

II. Modified Turnstile Antenna with Parasitic Elements and Its Arrays

A. Antenna Configuration

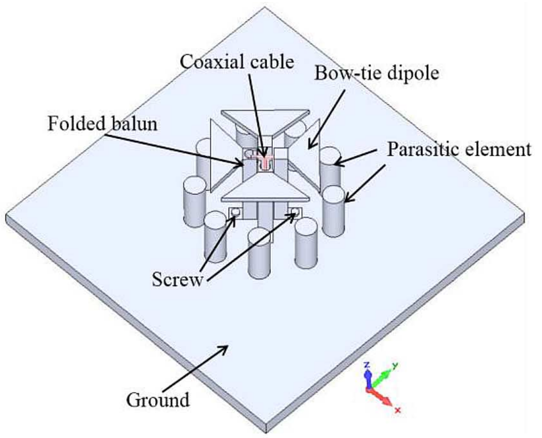
Fig. 1 shows the geometry of the proposed modified turnstile antenna with multiple parasitic elements surrounding the main radiators. The main radiator of bowtie-shaped dipole antennas plays an important role in controlling the resonance frequency and the main beam direction of the radiation pattern. As a feeding network, a Wilkinson power divider with two stubs generating a phase difference of 90° between two parts is located beneath the ground plane. The employed substrate for the fabricated power divider shown in Fig. 1(b) is an RT/Duroid 5880 having a relative dielectric constant of 2.3 and a thickness of 0.787 mm. Two sections of the power divider have been adopted for obtaining a wide bandwidth, and a semi-flexible coaxial cable is used for the signal transmission from the power

Manuscript received June 06, 2014; accepted July 23, 2014. Date of publication August 15, 2014; date of current version January 15, 2015. This work was supported by the National Space Lab (NSL) Program under the Korea Science and Engineering Foundation funded by the Ministry of Education, Science and Technology under Grant No. S10801000159-08A010015910.

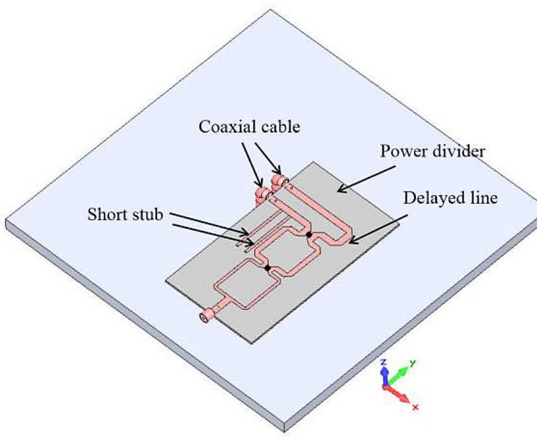
The authors are with the School of Electronics, Telecommunication and Computer Engineering, Korea Aerospace University, Goyang 412-791, Korea (e-mail: jwlee1@hau.ac.kr; jwlee1@kau.ac.kr).

Color versions of one or more of the figures in this letter are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/LAWP.2014.2347998

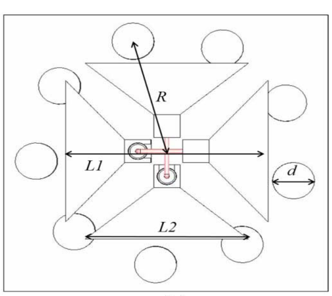


(a)

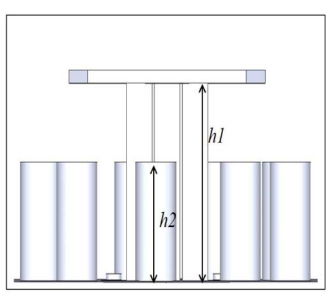


(b)

Fig. 1. Proposed S-band turnstile antenna. (a) Radiator part with parasitic elements (b) Feeding part on the bottom side.



(a)



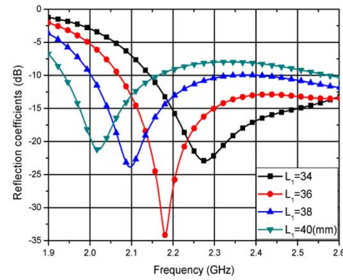
(b)

Fig. 2. Radiator part. (a) Top view. (b) Side view.

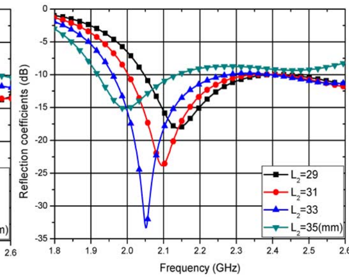
divider. In order to protect the antenna from a vibration occurring in aerospace environments, the connection between the elements and the ground plane is securely made with a screw.

B. Electrical Performance and Parameter Optimization

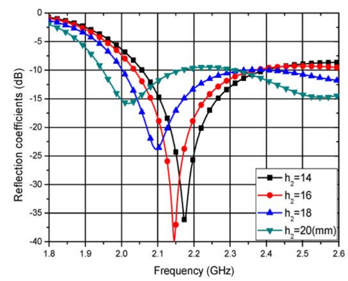
As shown in Fig. 2, the cylindrical parasitic elements are aligned around the main radiator of the bowtie-shaped dipoles. It is expected that these parasitic elements harmonized with bowtie-shaped radiators generate positive effects on the radiation pattern and axial-ratio beamwidth. First of all, in order to clarify the resonance of the proposed antenna at the target frequency, it is necessary to evaluate the electrical performances of the only radiating elements without a power divider at the desired frequency. Fig. 3(a)–(d) shows the reflection coefficients as a function of the antenna parameters $L1$, $L2$, $h2$, and R, respectively. As expected from Fig. 3(a), it can be conjectured that the length of dipole-like antenna, $L1$, is the most important parameter for determining and shifting the resonant frequency. As an optimum value, the length $L1$ has been set to 36 mm as shown in Table I. From Fig. 3(b) and (c), it can be estimated that even if the effects of $L2$ and $h2$ are not as important to the shift of the resonant frequency as that of $L1$, a small frequency shift may be obtained from the variations of $L2$ and $h2$. However, the effect of the radius, R, of parasitic elements on the resonant



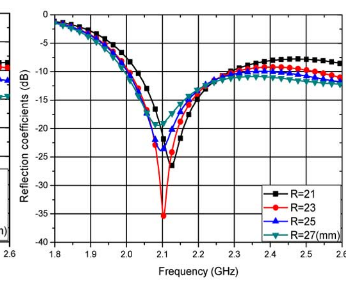
(a)



(b)



(c)

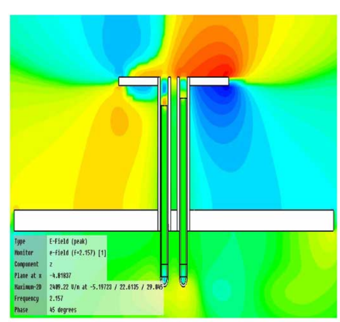


(d)

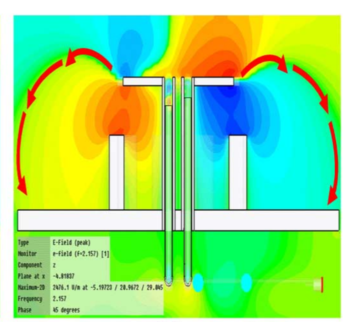
Fig. 3. Reflection coefficients with the variation of radiating elements while the other parameters remain unchanged. (a) According to the variation of the height, $L1$. (b) According to the variation of the horizontal lengths, $L2$. (c) According to the variation of the height, $h2$. (d) According to the variation of the horizontal lengths, R.

TABLE I
PARAMETERS AND VALUES OF THE RADIATOR

Geometry	*L1* (mm)	*L2* (mm)	*h1* (mm)	*h2* (mm)	*R* (mm)	*d* (mm)
Fig. 3(a)	34 ~ 40	31	30	18	25	8
Fig. 3(b)	36	29 ~ 35	30	18	25	8
Fig. 3(c)	36	31	30	14 ~ 20	25	8
Fig. 3(d)	36	31	30	18	21 ~ 27	8



(a)



(b)

Fig. 4. E-field distribution around radiator (a) without parasitic elements and (b) with parasitic elements.

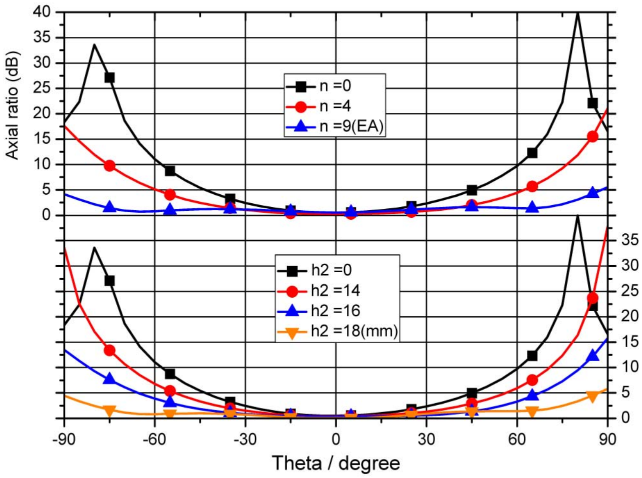


Fig. 5. Axial ratios according to the number of parasitic elements and variation of $h2$ at $f = 2200$ MHz ($L1 = 36$ mm, $L2 = 31$ mm, $h1 = 30$ mm, $R = 25$ mm, $d = 8$ mm).

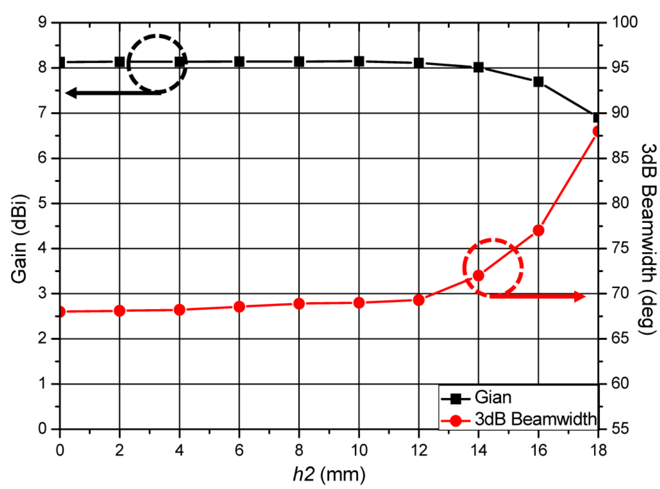
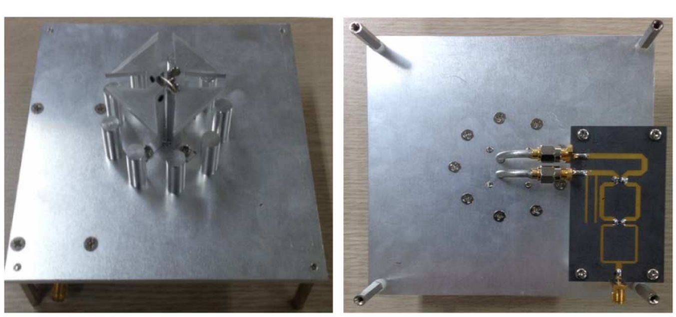


Fig. 6. Gain and 3-dB Beamwidth according to the variation of $h2$ when $f = 2200$ MHz ($L1 = 36$ mm, $L2 = 31$ mm, $h1 = 30$ mm, $R = 25$ mm, $d = 8$ mm, $n = 9$ EA).



(a) (b)

Fig. 7. The fabricated turnstile antenna working at S-Band (a) Top-view, (b) Bottom-view showing power divider.

frequency may be ignored. All of the simulations and the parameter optimizations have been carried out using the commercially available full-electromagnetic (EM) software CST MWS.

C. Radiation Pattern and Axial Ratio

Fig. 4 delineates the electric field distributions near the main radiator with/without parasitic elements by using commercially available software, CST MWS. As shown in Fig. 4, it can

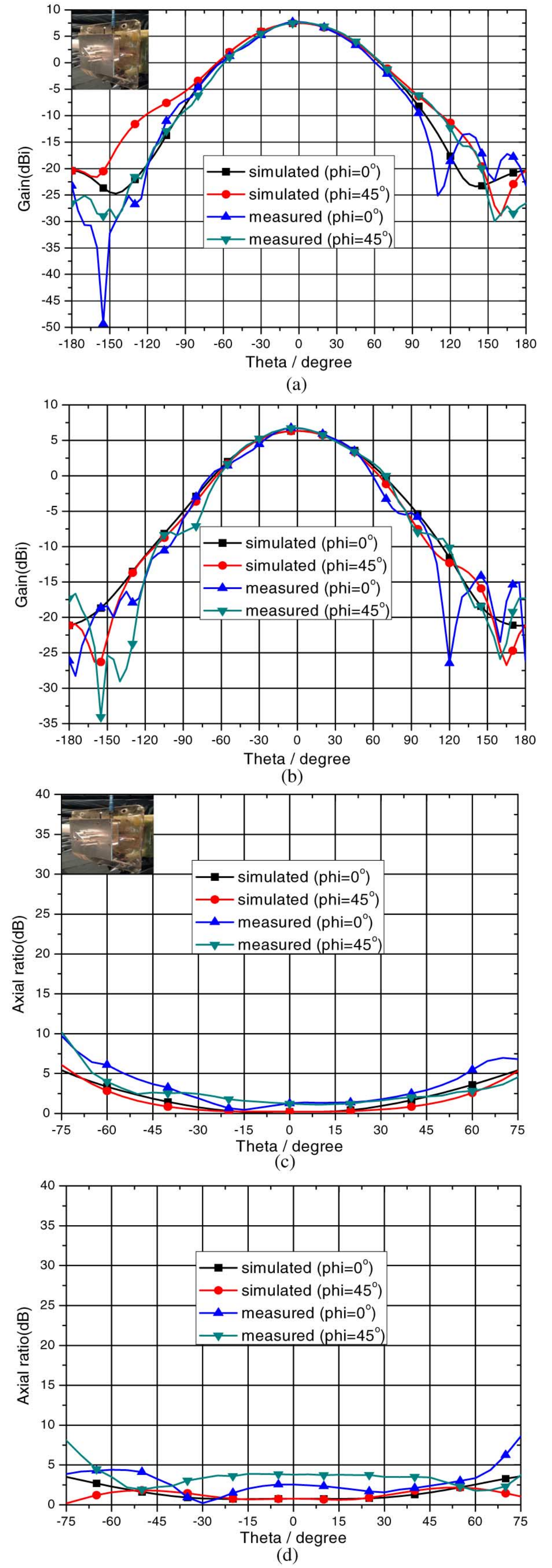


Fig. 8. Compared RHCP gain and axial ratio characteristics at the center frequency of receiving and transmitting (a) f = 2075 MHz, (b) f = 2245 MHz, (c) f = 2075 MHz, (d) f = 2245 MHz ($L1 = 36$ mm, $L2 = 31$ mm, $h1 = 30$ mm, $h2 = 18$ mm, $R = 25$ mm, $d = 8$ mm, $n = 9$ EA).

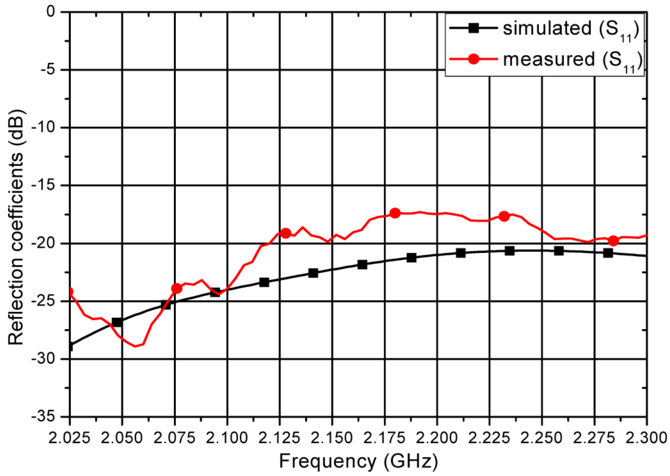


Fig. 9. Simulated and measured reflection coefficients of the proposed antenna.

be seen that the cylindrical parasitic elements aligned around the main radiator have an effect on the total radiation pattern, which leads to the wave propagation in the broadside direction [9], [10]. According to the simulation results, Fig. 5 depicts the axial ratios as a function of the number of parasitic elements and the height of parasitic elements. In the case of $n = 0$, the axial-ratio beamwidth satisfying the criterion of under 5 dB is $\pm 45^\circ$, while increasing the number of parasitic elements accomplishes the enhancement of axial-ratio beamwidth. It can be estimated from Fig. 5 that the optimum number and the height of the parasitic elements for the beamwidth of $\pm 90^\circ$ under 5 dB reference is 9 and 18 mm, respectively. The full-EM-based simulation results of Fig. 6 show the gain and 3-dB beamwidth according to the variation of the height, $h2$, of parasitic elements. It is seen that the gain and 3-dB beamwidth have little change until $h2$ approaches 14 mm. After that, the gain decreases and the 3-dB beamwidth becomes wider, respectively, as conjectured from Fig. 6.

III. Experiment Results

Fig. 7 shows the fabricated turnstile antenna operating as an S-band satellite antenna. On the bottom side, the Wilkinson power divider with two stubs is mounted to generate a 90° phase difference at two output ports, which is essential for circular polarization (CP). Fig. 8 shows the comparison between the measured and simulated results in terms of right-hand CP (RHCP) gain and AR beamwidth with good agreement. In addition, the target band of $2025 \sim 2290$ MHz is achieved with the required electrical performances of 3-dB beamwidth above average 85° and axial ratios under 5 dB at $\theta = \pm 60^\circ$. Finally, it can be expected from Fig. 9 that the measured and simulated reflection coefficients will give a good agreement and satisfy the required specification within the interested frequencies.

IV. Conclusion

By adopting cylindrical parasitic elements to horizontally bowtie-shaped dipole antennas with a power divider, a wide 3-dB beamwidth and an enhancement of AR beamwidth is obtained with a good agreement between simulation and measured data. From the listed results, it can be ensured that the proposed antenna having parasitic elements and its arrays may be used in TT&C satellite communication applications.

References

[1] Y. G. Jang and D. H. Lee*, Satellite System Design Engineering*. Seoul, Korea: KyungMoon, 1997.

[2] A. M. El-Tager, M. A. Eleiwa, and M. I. Salama, "A circularly polarized dual-frequency square patch antenna for TT&C satellite applications," in *Proc. Prog. Electromagn. Res. Symp.*, Beijing, China, Mar. 2009, pp. 23–27.

[3] A. Takacs, N. J. G. Fonseca, and H. Aubert, "Height reduction of the axial-mode open-ended quadrifilar helical antenna," *IEEE Antennas Wireless Propag. Lett.*, vol. 9, pp. 942–945, 2010.

[4] K. F. A. Hussein, "Conical linear spiral antenna for tracking, telemetry and command of low earth orbit satellites," *Prog. Electromagn. Res. C*, vol. 291, pp. 97–107, 2012.

[5] E.-C. Choi, J. W. Lee, and T.-K. Lee, "Modified S-band satellite antenna with isoflux pattern and circularly polarized wide beamwidth," *IEEE Antennas Wireless Propag. Lett.*, vol. 12, pp. 1319–1322, 2013.

[6] K.-J. Lee, D.-J. Woo, T.-K. Lee, and J.-W. Lee, "Circularly polarized antenna with wide axial-ratio bandwidth," (in Korean) *J. Korea Electromagn. Eng. Soc.*, vol. 21, no. 7, pp. 842–848, Jul. 2010.

[7] S. X. Ta, J. J. Han, I. Park, and R. W. Ziolkowski, "Wide-beam circularly polarized crossed scythe-shaped dipoles for global navigation satellite systems," *J. Electromagn. Eng. Sci.*, vol. 13, no. 4, pp. 224–232, Dec. 2013.

[8] J. Zhang, H.-C. Yang, and D. Yang, "Design of a new high-gain circularly polarized antenna for inmarsat communications," *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 350–353, 2012.

[9] J.-S. Lee, C.-W. Oh, G.-J. Seo, and S.-H. Oh, "Design of S-band turnstile antenna using the parasitic monopole," (in Korean) *J. Korea Electromagn. Eng. Soc.*, vol. 17, no. 11, pp. 1083–1088, Nov. 2010.

[10] E.-C. Choi, J. W. Lee, and T.-K. Lee, "An axial ratio beamwidth enhancement of S-band satellite antenna with parasitic elements," in *Proc. Asia-Pacific Microw. Conf.*, Coex, Seoul, Korea, Nov. 2013.