JOURNAL OF ELECTROMAGNETIC ENGINEERING AND SCIENCE, VOL. 18, NO. 1, 29~34, JAN. 2018

https://doi.org/10.26866/jees.2018.18.1.29
ISSN 2234-8395 (Online) · ISSN 2234-8409 (Print)

Design of a Wideband Antipodal Vivaldi Antenna with an Asymmetric Parasitic Patch

Jihoon Bang · Juneseok Lee · Jaehoon Choi*

Abstract

An antipodal Vivaldi antenna with a compact parasitic patch to overcome radiation performance degradations in the high-frequency band is proposed. For this purpose, a double asymmetric trapezoidal parasitic patch is designed and added to the aperture of an antipodal Vivaldi antenna. The patch is designed to efficiently focus the beam toward the end-fire direction at high frequencies by utilizing field coupling between the main radiating patch and the inserted parasitic patch. As a result, this technique considerably improves the gain and stability of radiation patterns at high frequencies. The proposed antenna has a peak gain greater than 9 dBi over the frequency range of 6–26.5 GHz.

Key Words: Antipodal Vivaldi Antenna, High Gain, Parasitic Antenna, Ultra-Wideband Antenna.

I. INTRODUCTION

The Vivaldi antenna has received a great deal of attention for many applications, such as satellite communications, electronic warfare systems, remote sensing, radio telescopes, radio astronomy, radar, and microwave imaging systems because of its wideband characteristic and high directivity. It has numerous advantages in terms of weight, cost, scan angle capability, ease of fabrication, and system integration. Recently, some applications have required a Vivaldi antenna with higher directivity or gain over a wider bandwidth to achieve the desired system performance such as range resolution [1, 2]. However, a conventional Vivaldi antenna has limited bandwidth because of performance degradation, including directivity or gain reduction and radiation pattern distortion at high frequencies. Numerous factors, including undesired radiation generated by unwanted currents traveling along the termination section and the phase reversal problem, contribute to these limitations. These factors stem primarily from the structural limitations of the conventional Vivaldi antenna. Therefore, a central issue in the further development of the Vivaldi antenna is to improve the directivity at higher frequencies and the stability of the radiation pattern over the frequency range. Several techniques, such as the use of dielectric lens [1, 3], directors [4, 5], and negative index metamaterial [6], have been proposed to overcome these issues. These materials are located in the aperture of the tapered slot to focus energy toward the end-fire direction. Although these methods are suitable for large antenna structures such as the horn antenna [7], they cannot be utilized in a low-profile Vivaldi antenna because of increasing complexity and a high manufacturing cost. In addressing this issue, one novel technique using an elliptical parasitic patch has improved the high-frequency radiation performance without additional complex structures such as lenses or directors [8]. However, performance improvements using this method occur over a limited frequency range, and radiation pattern distortion is present at high frequencies

---

Manuscript received October 16, 2017 ; Revised November 29, 2017 ; Accepted December 13, 2017. (ID No. 20171016-060J)
Department of Electronics and Computer Engineering, Hanyang University, Seoul, Korea.
*Corresponding Author: Jaehoon Choi (e-mail: choijh@hanyang.ac.kr)

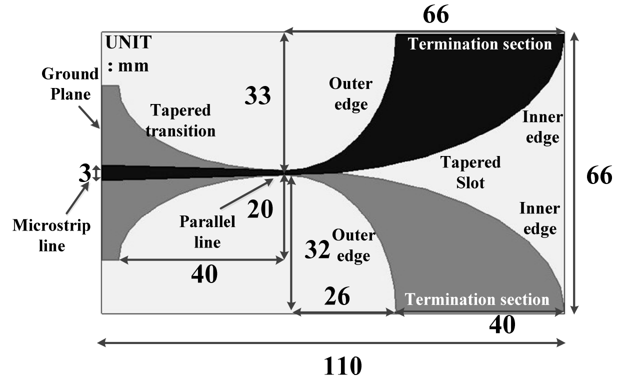
due to the increased off-axis radiation as the frequency increases, thus resulting in a poor side-lobe level and front-to-back ratio. This method also results in a reasonable enlargement of the antenna dimension.

In this letter, an antipodal Vivaldi antenna (AVA) with a compact parasitic patch is proposed to enhance antenna performance in areas such as the gain and stability of the radiation pattern at high frequencies. For this purpose, we design a double asymmetric trapezoidal parasitic patch that efficiently focuses the beam toward the end-fire direction and reduces the off-axis radiation at high frequencies. The proposed design is proven capable of enhancing the directivity and improving the stability of the radiation pattern at higher frequencies.

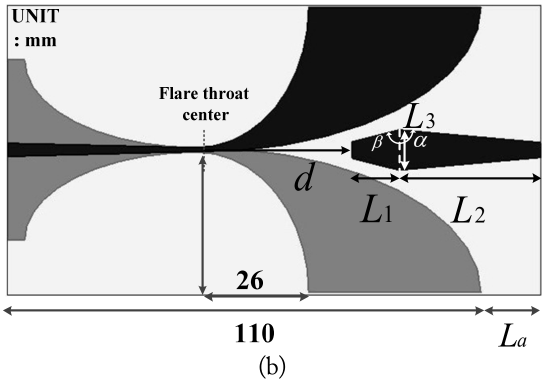
II. ANTENNA DESIGN

1. *Antenna Geometry*

Fig. 1 shows the configuration of the designed antennas. The designed Vivaldi antenna is a dual-elliptically tapered antipodal slot antenna (DETASA) [9], which is a modified form of AVA [10]. The conventional DETASA, shown in Fig. 1(a), differs from the exponentially tapered antipodal Vivaldi antenna in that the inner and outer edges of the conducting arms are all elliptically tapered [11]. The conventional DETASA comprises two main parts: a tapered slot radiator and a feed transition. The tapered slot radiator is formed by two conducting arms that are symmetrically printed on opposite sides of the dielectric substrate. The inner and outer slot tapers of the conducting arms follow the outline of a quarter ellipse with two different radii as shown in Fig. 1(a). The feed transition transforms a 50-Ω microstrip line into a parallel stripline by linearly tapering the microstrip line and elliptically tapering the ground plate to feed the tapered slot radiator. The design parameters of the conventional DETASA are identical to those presented in [8]. Fig. 1(b) illustrates the structure of the proposed DETASA with the addition of a double asymmetric trapezoidal parasitic patch in the aperture of the conventional DETASA. The size of the proposed antenna is set to 124 mm × 66 mm, of which the length is L_a mm longer than that of the conventional DETASA. The dielectric substrate is Taconic/TLC-30 with a permittivity of 3.0, tangent loss of 0.0028 and a thickness of 62 mils (1.575 mm). The inserted parasitic patch with various design parameters (L_1, L_2, L_3, α, and β) is located a distance of d away from the center of the flared throat. The parasitic patch is designed to focus the energy toward the end-fire direction over a wide bandwidth, including higher frequencies.



(a)



(b)

Fig. 1. Configurations of Vivaldi antennas: (a) conventional DETASA (without parasitic patch) and (b) proposed DETASA (with parasitic patch).

2. *Parasitic Patch Design*

Unlike a conventional DETASA, which produces fields between the inner edges of two conducting arms like a traveling wave antenna [12], the DETASA with a parasitic patch generates fields between the parasitic patch and the inner edges of two conducting arms because the fields couple to both sides of the parasitic patch. Therefore, the field distribution produced in the aperture of the Vivaldi antenna is dependent on the shape and the size of the inserted parasitic patch.

The reasons for designing the parasitic patch in a double asymmetric trapezoidal shape are as follows. (1) To ensure that the field is well coupled to both sides of the parasitic patch, the left trapezoid is arranged opposite to the end-fire direction so that the sides of the left trapezoid of the parasitic patch have an increasing profile similar to that of the inner edge of the conducting arm. (2) At the same time, to transform the E-field distribution produced at the aperture of the antenna into a plane-like wave form, the right trapezoid of the parasitic patch is designed such that its sides have a decreasing profile towards the end-fire direction. Unlike other shapes such as elliptical [8] and rectangular, the double asymmetric trapezoidal shape has a degree of freedom in determining the profile ratio. This degree of freedom enables the beam to focus while reducing the off-axis radiation more effectively over wider frequency ranges. However, the fields cannot be coupled suitably to the parasitic patch if the size of the parasitic patch is extremely larger than the wavelength. For this purpose, the size (L_1, L_2, and L_3), angle

Table 1. Design parameters of the proposed parasitic patch

Parameter	Value	Parameter	Value
L_1	8.8 mm	α	76°
L_2	35.2 mm	β	85°
L_3	8.08 mm	d	36 mm
L_a	14 mm		

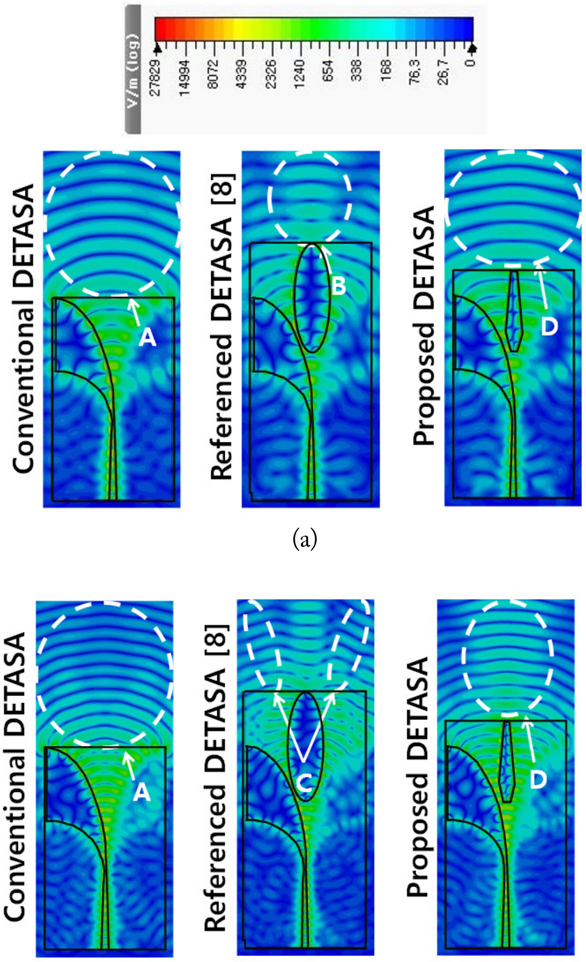
(α and β), and position (d) of the parasitic patch are optimized through a parametric study and the final design parameters are listed in Table 1.

To investigate the effect of the inserted parasitic patch, simulated electric field distributions in the near-field region of three antennas (conventional DETASA without a patch, referenced DETASA with the parasitic ellipse presented in [8], and the proposed DETASA) at 15 GHz and 22 GHz are shown in Fig. 2. The simulated current distribution of the proposed Vivaldi antenna at a high frequency of 22 GHz is illustrated in Fig. 3. The simulation is performed using the CST Microwave Studio software (2017 version 15.0; CTS Computer Simulation Technology GmbH, Darmstadt, Germany). As shown in Figs. 2 and 3, the radiation of the proposed Vivaldi antenna is more focused toward the end-fire direction at high frequencies than those of the other two Vivaldi antennas because of the strong electromagnetic field coupling between the man radiating element and the inserted parasitic patch. Clearly, the conventional DETASA generates spherical-like waves at both frequencies, as shown in region A of Fig. 2, and the off-axis radiation results in low directivity. Conversely, the proposed DETASA generates plane-like waves at both frequencies, as shown in region D of Fig. 2. Most of the energy is radiated toward the end-fire (axis) direction with a little off-axis radiation, thus resulting in high directivity at those frequencies. The referenced DETASA generates plane-like waves relatively well at 15 GHz but not at 22 GHz, as shown in regions B and C of Fig. 2.

One can expect radiation performance degradation at high frequencies in the referenced DETASA.

III. RESULTS AND ANALYSIS

A prototype of the antenna is fabricated and tested. Fig. 4 shows the fabricated prototype. A 50-Ω SMA connector is used to feed the antenna. The simulated and measured reflection coefficients of the conventional (without a parasitic patch) and the proposed (with a parasitic patch) Vivaldi antennas are shown in Fig. 5. The measured results are given up to 26.5 GHz only because of the frequency limit of the SMA connector. As illustrated in Fig. 5, inserting the parasitic patch affects the reflection coefficient, but the −10 dB reflection coefficient bandwidth is not significantly changed. On the other hand, the inserted parasitic patch strikingly enhances the gain as shown in



(a)

(b)

Fig. 2. Electric field distributions of three DETASA configurations: (a) 15 GHz and (b) 22 GHz.

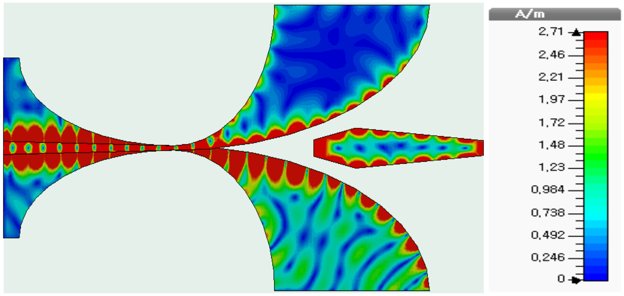
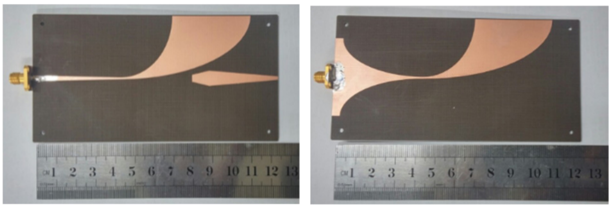


Fig. 3. Current distribution of the designed antennas at 22 GHz (phase: 0°).



(a) (b)

Fig. 4. Photograph of the fabricated prototype. (a) Top view and (b) bottom view.

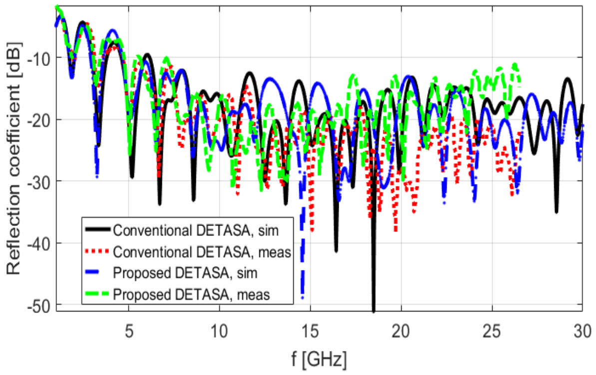
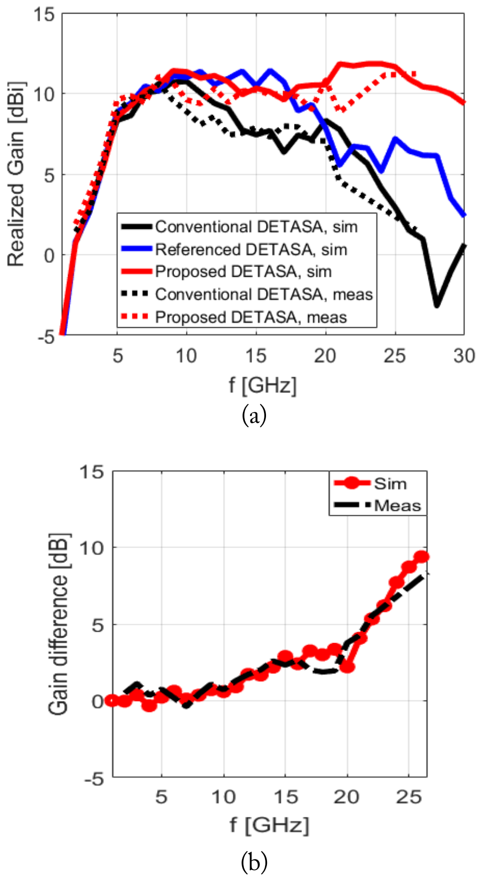


Fig. 5. Simulated and measured reflection coefficients of the conventional (without parasitic patch) and the proposed (with parasitic patch) DETASAs.

Fig. 6, which shows the simulated and measured realized gain variations with frequency for the three antennas and the gain differences between the conventional and proposed DETASAs. Some deviations exist between the simulated and the measured realized gain, which is possibly due to alignment errors between the antenna under test and the referenced antenna. The simulated and measured gain improvements indicate good agreement as shown in Fig. 6(b). Note that the gain of the proposed DETASA is significantly improved at higher frequencies above 20 GHz in contrast to those of the other two designed antennas. Even with the reduced antenna size compared with the referenced DETASA, the gain of the proposed DETASA shows similar improvement over the lower frequency range, with a significant improvement of above 20 GHz. As a result, the double trapezoidal parasitic patch enables gains greater than 9 dBi in the frequency range of 6–26.5 GHz. The simulated E-plane electric field patterns for three antennas at 22 GHz are shown in Fig. 7. The field pattern of the proposed antenna is well formed to generate end-fire radiation toward the axial direction of the slot aperture at 22 GHz, unlike the other two antennas. The measured E-plane radiation patterns of the referenced [8] and the proposed Vivaldi antennas are illustrated in Fig. 8. At low frequencies, No notable difference is observed between the measured radiation patterns of the two DETASAs. For frequencies of 18–21 GHz, the gain is quite improved (2–3 dB), and the directivity and gain are enhanced significantly for frequencies above 22 GHz.



(a)

(b)

Fig. 6. (a) Simulated and measured realized gain in the end-fire direction for the three designed antennas. (b) Simulated and measured gain difference between the conventional and the proposed DETASAs.

IV. CONCLUSION

An AVA with a compact parasitic patch to overcome the radiation performance degradations in the high frequency band is proposed. For this purpose, a double asymmetric trapezoidal parasitic patch is designed and added in the aperture of an AVA, which is intended to focus the beam efficiently toward the end-fire direction at higher frequencies by utilizing the electromagnetic coupling between the main radiation patch and the inserted parasitic patch. As a result, the proposed Vivaldi antenna shows a notably improved gain (or directivity) at frequencies above 20 GHz and a stable radiation pattern over the wide frequency range without the requirement of an additional complex structure.

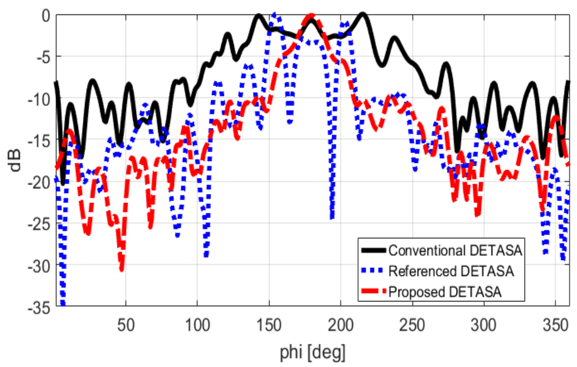
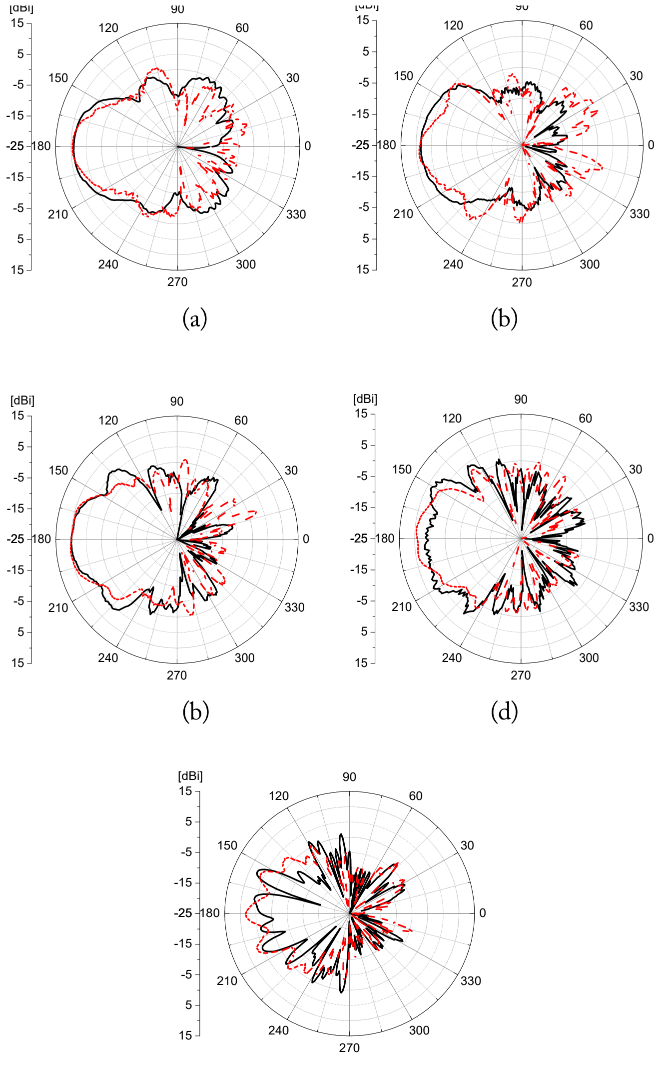


Fig. 7. Simulated E-plane electric field pattern for the three designed antennas at 22 GHz.



(a) (b)

(b) (d)

(e)

Fig. 8. Measured E-plane radiation patterns of the referenced DETASA [8] (solid line) and the proposed DETASA (dashed line) at (a) 6 GHz, (b) 10 GHz, (c) 12 GHz, (d) 18 GHz, and (e) 22 GHz.

This work was supported by Advanced Track for the state-of-the-art Technology of an Earth Resources Industry with an ICT Application of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea (No. 20174010201170) and by the National Research Foundation of Korea Grant funded by the Korean Government.

This work was supported by the Ministry of Science, ICT and Future Planning, Korea, under the Information Technology Research Center support program (No. IITP-2017-2012-0-00628) supervised by the Institute for Information & Communications Technology Promotion (IITP).

REFERENCES

[1] M. Moosazadeh, S. Kharkovsky, and J. Toby Case, "Microwave and millimetre wave antipodal Vivaldi antenna with trapezoid-shaped dielectric lens for imaging of construction materials," *IET Microwaves, Antennas & Propagation*, vol. 10, no. 3, pp. 301–309, 2016.

[2] M. Moosazadeh, S. Kharkovsky, J. Toby Case, and B. Samali, "Miniaturized UWB antipodal Vivaldi antenna and its application for detection of void inside concrete Specimens," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 1317–1320, 2016.

[3] Z. Akhter, B. N. Abhijith, and M. J. Akhtar, "Hemisphere lens-loaded Vivaldi antenna for time domain microwave imaging of concealed objects," *Journal of Electromagnetic Waves and Application*, vol. 30, no. 9, pp. 1183–1197, 2016.

[4] J. Lei, G. Fu, L. Yang, and D. Fu, "A modified balanced antipodal Vivaldi antenna with improved radiation characteristics," *Microwave and Optical Technology Letters*, vol. 55, no. 6, pp. 1321–1325, 2013.

[5] J. Bourqui, M. Okoniewski, and E. C. Fear, "Balanced antipodal Vivaldi antenna with dielectric director for near-field microwave imaging," *IEEE Transactions on Antennas and Propagation*, vol. 58, no. 7, pp. 2318–2326, 2010.

[6] A. R. H. Alhawari, A. Ismail, M. A. Mahdi, and R. S. A. Raja Abdullah, "Antipodal Vivaldi antenna performance booster exploiting snug-in negative index metamaterial," *Progress in Electromagnetics Research*, vol. 27, pp. 265–279, 2012.

[7] P. Duangtang, P. Mesawad, and R. Wongsan, "Creating a gain enhancement technique for a conical horn antenna by adding a wiremedium structure at the aperture," *Journal of Electromagnetic Engineering and Science*, vol. 16, no. 2, pp. 134–142, 2016.

[8] I. T. Nassar and T. M. Weller, "A novel method for improving antipodal Vivaldi antenna performance," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 7, pp. 3321–3324, 2015.

[9] J. D. S. Langley, P. S. Hall, and P. Newham, "Balanced antipodal Vivaldi antenna for wide bandwidth phased arrays," *IEE Proceedings-Microwaves, Antennas and Propagation*, vol. 143, no. 2, pp. 97–102, 1996.

[10] E. Gazit, "Improved design of the Vivaldi antenna," *IEE Proceedings H (Microwaves, Antennas and Propagation)*, vol. 135, no. 2, pp. 89–92, 1988.

[11] X. Qing, Z. N. Chen, and M. Y. W. Chia, "Dual elliptically tapered antipodal slot antenna loaded by curved terminations for ultrawideband applications," *Radio Science*, vol. 41, no. 6, pp. 1–14, 2006.

[12] M. A. Matin, *Ultra Wideband Communications: Novel Trends-Antennas and Propagation*. Rijeka, Croatia: InTech, 2011.

Jihoon Bang

received his B.S. degree in information and communication engineering from Dongyang Mirae University, Seoul, Korea, in 2016. He is currently working toward his unified M.S. and Ph.D. degrees in electronics and computer engineering at Hanyang University. Seoul, Korea. His research interests are antenna design and microwave circuit design.

Juneseok Lee

received his B.S. degree in electronics and computer engineering from Chungnam National University, Daejeon, Korea, in 2010 and M.S. degree from the Department of Electrical Engineering at the University of Queensland, Brisbane, Australia, in 2011. He is currently undertaking his Ph.D. research at Hanyang University, Seoul, Korea. His research interests are RF components including antenna design, wireless communication systems, wireless power transferring, and wireless body area networks.

Jaehoon Choi

received his B.S. degree from Hanyang University, Korea, and his M.S. and Ph.D. degrees from Ohio State University, Ohio, in 1980, 1986, and 1989, respectively. From 1989–1991, he was a research analyst with the Telecommunication Research Center at Arizona State University, Tempe, Arizona. He worked for Korea Telecom as a team leader of the Satellite Communication Division from 1991 to 1995. Since 1995, he has been a professor in the Department of Electronic Engineering at Hanyang University, Korea. He has published more than 200 peer-reviewed journal articles and contributed to numerous conference proceedings. He holds over 50 patents. His research interests include antennas, microwave circuit design, and EMC. His current research is mainly focused on the design of compact, multi-band antennas for mobile wireless communication, and other biomedical applications.