Hindawi
International Journal of Antennas and Propagation
Volume 2018, Article ID 3684197, 6 pages
https://doi.org/10.1155/2018/3684197

Research Article

2D Gain Enhancement Based on Single-Layer SIW Corrugated Technique with Slot Array Feeder

Mingtuan Lin and Chenglong Lin

College of Electronic Science and Engineering, National University of Defense Technology, Changsha 410073, China

Correspondence should be addressed to Mingtuan Lin; linmingtuan08@163.com

Received 14 November 2017; Accepted 21 January 2018; Published 25 March 2018

Academic Editor: Chien-Jen Wang

Novel slot-array-based SIW corrugated technique is demonstrated to achieve 2D gain enhancement, namely, sharpening the beamwidths in both E-plane and H-plane. Compared to other metallic corrugated methods to realize 2D gain enhancement, the proposed design, with SIW grooves to reduce the beamwidth in E-plane and slot array to increase the directivity in H-plane, has a lower profile, weight, and design complexity, which can be easily fabricated with the common printed circuit board (PCB) technique. A prototype is designed and fabricated, with measurement presenting a low reflection coefficient less than −10 dB from 26.4 GHz to 28.2 GHz and an enhanced gain up to 18 dB. Overall, our proposed technique will be beneficial for the design of high-gain antenna in 5G wireless terminals.

1. Introduction

Ka-band has been announced to be part of the future 5G spectrum plan [1]. In comparison with other frequency candidates such as the E-, W-, and V-bands, the relatively low Ka-band poses less challenge for the 5G communication devices. Consequently, the researches of Ka-band antenna [2, 3] will be of significance for the future 5G technique.

To conquer the high loss of transmission, high-gain antenna is in demand for 5G techniques. Metallic corrugated technique is one main method to enhance the gain of antenna, which has been widely investigated [4–6]. A metallic corrugated design with rectangular waveguide feeder was reported in [7], which consists of a surface slit surrounded by periodic straight grooves. The radiated wave from the slit can be enhanced by the periodic grooves, which create in-phase superposition of the wave and improve the gain in the normal direction. Such metallic corrugated antenna has a 1D enhancement performance, that is, having a narrow beamwidth in E-plane but a wide beam pattern in H-plane. Slit array was introduced in [8] to reduce beamwidth in H-plane, with slits fed by a rectangular waveguide. Obviously, the slit array requires multiple rectangular waveguides, which increases the total weight and profile, and cannot be used in compact space of wireless terminals. Another method to achieve 2D gain enhancement [9] employed a dual metallic corrugated plate, with three radiation slots on the top layer. However, the metallic technique makes the antenna heavy and cannot be used in the wireless terminals such as mobile phone. With the implementation of SIW techniques, three-layer PCBs were utilized in [10] as a replacement of metallic material to realize high-gain antenna, whereas it only shows that the radiation enhancement of E-plane and the multiple layer technique also increases the design complexity and poses uncertain impacts during the fabrication and the installation. In our recent work [11], we proposed a novel single-layer SIW corrugated technique to achieve comparable gain enhancement as the metallic corrugated technique, based on which two low mutual coupling and high-gain multiple input and multiple out (MIMO) antennas were designed [12]. The proposed single-layer SIW corrugated technique is easy for fabrication and is more suitable for wireless terminal antennas.

The novelty of this paper is the slot-array-based SIW corrugated technique to achieve 2D radiation enhancement, that is, increasing the directivity of both E-plane and H-

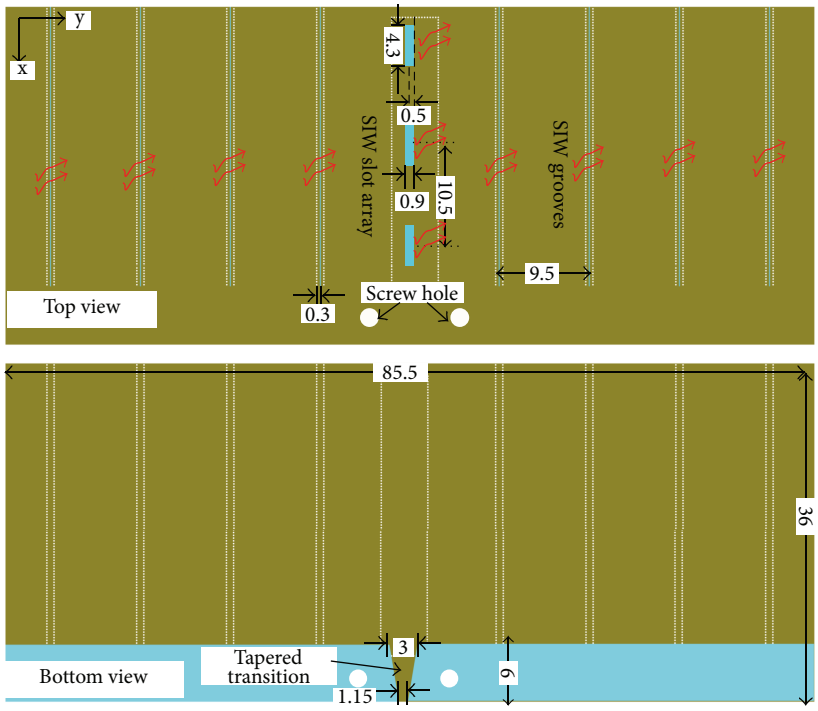


Figure 1: The layout of the proposed antenna. All the dimensions are in mm.

plane, which can further increase the gain. To the best of our knowledge, our design is the first one antenna among the corrugated methods to achieve 2D radiation enhancement with only a single-layer PCB, which is of significance for the high-gain antenna in 5G wireless terminals.

2. Antenna Structure

The layout of proposed antenna, with a dimension 85.5 mm × 36 mm, is shown in Figure 1, which is comprised of two main parts, namely, a SIW slot array feeder (three slots) and four couples of periodic SIW grooves. The dimensions of SIW groove is 30 mm × 0.3 mm. To feed the SIW slot array, a tapered microstrip line transition at the bottom is utilized, which is followed by a 2.92 mm end launch connector. The central frequency of the design is 27.6 GHz. For parallel grooves, aligned slots can achieve better radiation enhancement than slots on two sides of central line of waveguide. Therefore, three slots are aligned in only one side of central line, with a wavelength distance between each other. Having low loss in mm-band, Rogers 5880, with dielectric constant 2.2, is chosen as the substrate. To better satisfy the common criteria used in corrugated technique, that is, $h/\lambda = 0.25$, where h is the thickness and λ is the wavelength, our design uses 1.575 mm thickness level substrate. The diameter of SIW vias is 0.4 mm, and the distance of every two vias is 0.6 mm. The structure parameters of SIW slot array, SIW grooves, and transition are optimized as shown in Figure 1 to have a good impedance matching while keeping high-gain performance.

The mechanism of gain enhancement of the proposed antenna is as follows. The SIW grooves are to enhance the gain in E-plane, while the slot array increases the directivity in H-plane. Specifically, the radiated wave from the SIW slot array travels along $-y$ and $+y$ directions, which creates in-phase electric field inside the grooves. Because of the in-phase superposition of the electric field, the radiation pattern can be enhanced.

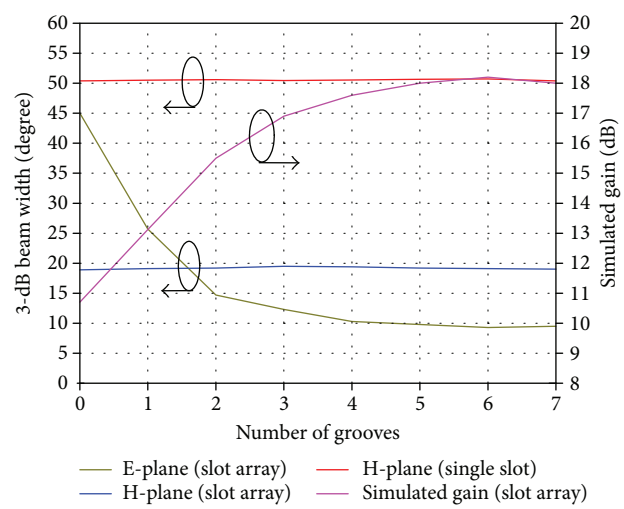
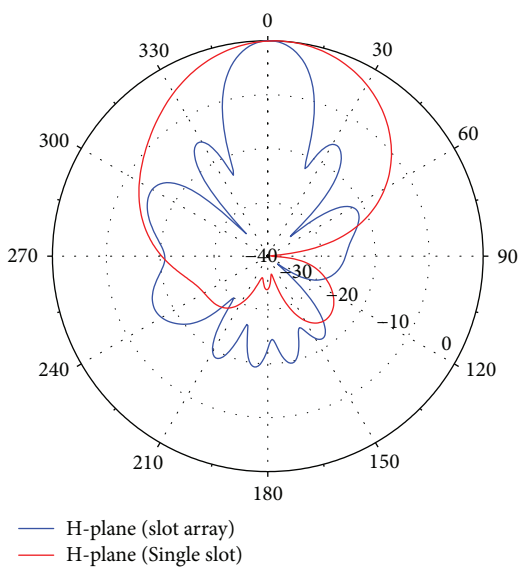


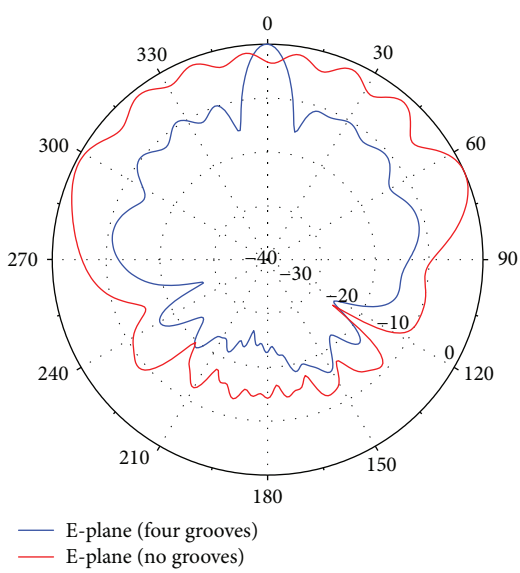
Figure 2: 3 dB beamwidth and gain for different groove numbers in each side.

3. Performance Analyses

Before the introduction of the simulation results of slot-array-based SIW corrugated antenna with four couples of grooves, the influence of the groove number on the SIW corrugated antenna is investigated first, which is shown in Figure 2. Please note that the groove number in the figure



(a)



(b)

Figure 3: Radiation pattern comparisons between (a) the slot-array-based and single-slot-based SIW corrugated antennas and (b) slot-array-based SIW corrugated antenna and slot array antenna on a flat surface.

refers to the number in each side rather than two sides. It can be seen that the simulated gain increases with the number of grooves for slot-array-based SIW corrugated antenna, while 3 dB beamwidth in E-plane shows a contrast trend, having a narrow beamwidth for large number of grooves. Also, it can be found that the gain does not increase significantly when the number of grooves is larger than 4 and the beamwidth does not decrease a lot as well. The more number of grooves, the larger size the antenna has. To trade off the size and the enhanced gain, 4 grooves in each side of the SIW corrugated antenna are chosen in our design. The 3 dB beamwidth in H-plane is also shown in Figure 2, from which a narrow beamwidth (around 19°) of slot-array-based SIW corrugated antenna can be observed compared to a wide

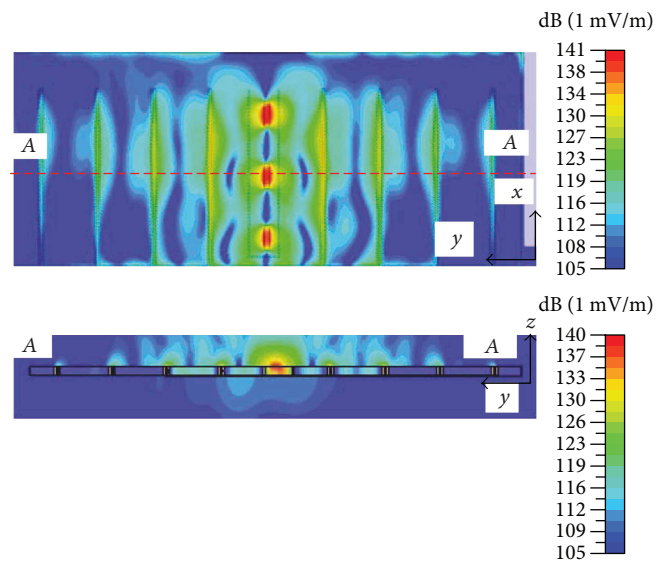


Figure 4: Field distributions from top view and its cross-sectional view along line AA_1.

beamwidth (around 51°) of the SIW corrugated antenna with a single slot. This is consistent with the normalized radiation pattern of H-plane in Figure 3(a). Obviously, the implementation of the slot array in SIW corrugated antenna sharpens the beamwidth in H-plane. Comparisons of radiation pattern between the slot-array-based SIW corrugated antenna and slot array antenna on a flat surface are shown in Figure 3(b), from which a narrow beamwidth of E-plane can be achieved. It is noted that more ripples in E-plane occur than in H-plane. That is because the phase responses of SIW grooves are only quasi-in-phase; therefore, ripples appear in other directions. While for slot array, it is easy to ensure exact in-phase responses for three slots; thus, the ripples of H-plane are relatively pure. Benefiting from the in-phase superposition of SIW corrugations and the slot array, our proposed slot-array-based SIW corrugated antenna can realize 2D gain enhancement. The field distributions of top view and its cross-sectional view along line AA_1 in Figure 4 show that in-phase field inside the groove is excited by the in-phase slot array. The in-phase superposition of grooves and slot array enhances the gain in both E-plane and H-plane.

A tapered transition on the top would increase the cross polarization. Therefore, the transition is located at the bottom. Comparison of S-parameter and cross polarization performance with transition at the back and front is shown in Figure 5. It can be seen from Figure 5(a) that the transition location does not affect reflection coefficient a lot, while the cross polarizations within the half power beamwidth (HPBW) in E-plane and H-plane are suppressed when back transition is employed, exhibiting a good linear polarization as shown in Figure 5(b).

4. Measurement Results

The fabricated antenna is shown in Figure 6, which is compact enough to be installed in mobile phone. The

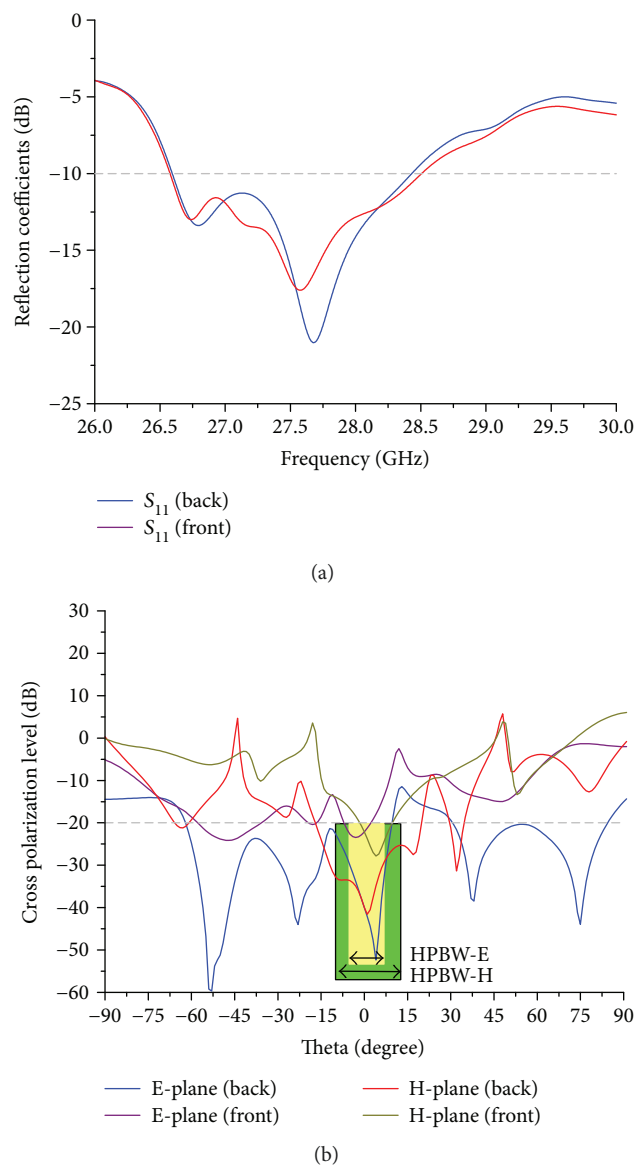


Figure 5: (a) The reflection coefficients and (b) cross polarization levels for different transition positions.

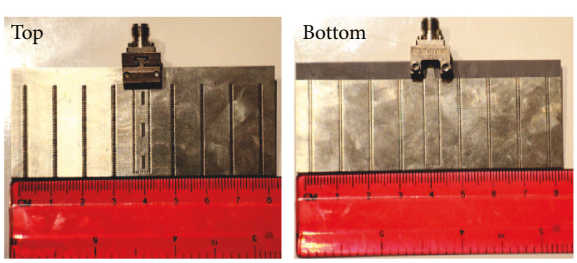


Figure 6: Fabricated antenna.

transition is connected with a 2.92 mm end launch connector, which can be installed and reinstalled easily and does not need any soldering processing, providing great flexibleness for the antenna assembly. To prevent oxidation of the copper surface, the PCB has been preprocessed by the hot-air solder leveling (HASL) technique.

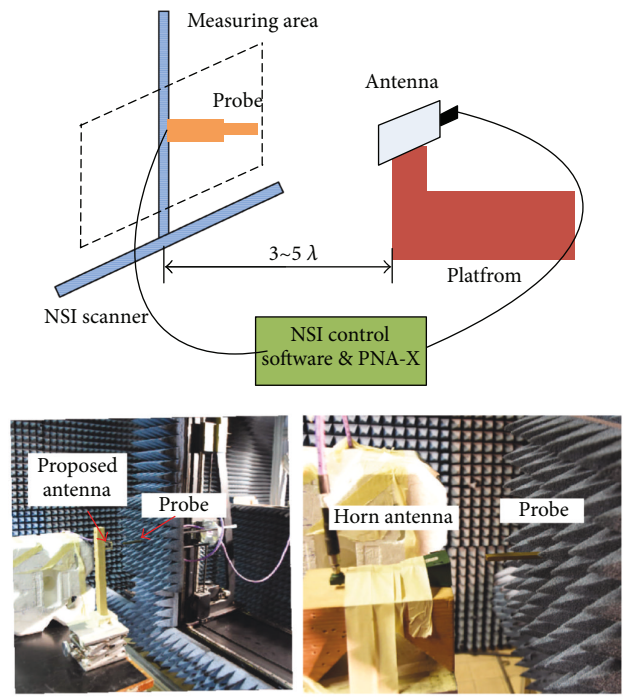


Figure 7: Measurement setup.

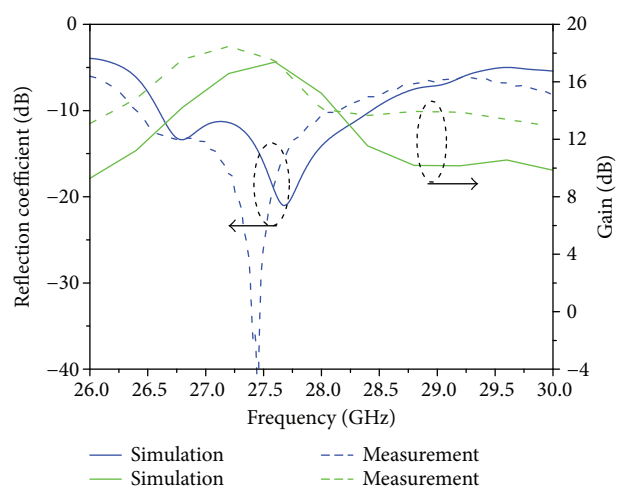


Figure 8: The simulated and measured S_{11} and gain.

To measure the radiation patterns of antenna, near field scanner (NSI) as shown in Figure 7 is employed to obtain the near field results first, which are then converted to the far field radiation patterns. The distance between the probe and the antenna is around 3~5 wavelengths. Regarding gain measurement, a standard gain rectangular horn antenna (model 22240-20) was measured as the benchmark before the measurement of the proposed antenna, as shown in Figure 7. By comparing these two results, the gain of antenna can be obtained. The simulated and measured reflection coefficients and gain of the proposed design are plotted in Figure 8. The measurement results show that it has low reflection coefficients less than −10 dB and high gain above 14 dB from 26.4 GHz to 28.2 GHz, with the highest gain up

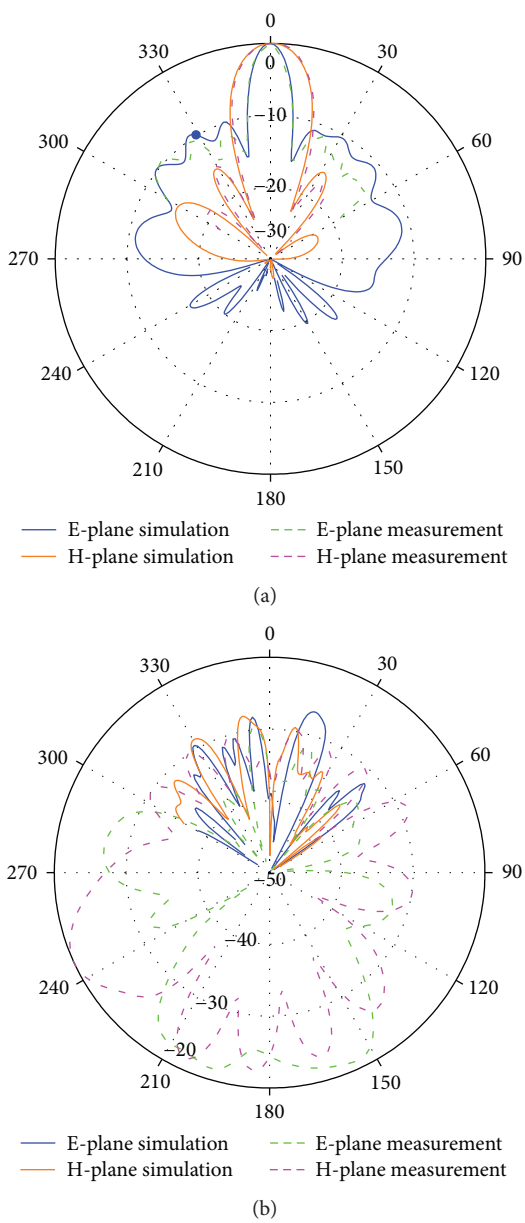


Figure 9: The simulated and measured radiation patterns at 27.6 GHz. (a) Coplanar polarization. (b) Cross polarization.

to 18 dB at 27.2 GHz, indicating a distinguished radiation enhancement. Compared to the simulation results, the bandwidth has about 0.2 GHz (0.7%) offset towards lower frequency, while the gain is a bit higher. The discrepancy of the bandwidth is due to the joint influence of HASL processing, the displacement of the pin of connector, and the tighten levels between the pin and PCB board, while the multiple scattering between the probe and antenna or the metal connector may lead a higher gain.

The simulated and measured far field radiation patterns at 27.6 GHz are depicted in Figure 9. The measured HPBW of E-plane and H-plane are 9.8° and 19.4°, respectively, showing a good directional performance. Comparing Figures 9(a) and 9(b), it can be observed that the cross polarization in the 3 dB beamwidth of E-plane and H-plane is more than 20 dB below the coplanar polarization, indicating highly pure linear polarization. And the measured side lobe levels of E-plane and H-plane are about −10 dB and −15 dB. Overall, the simulation results agree well with the measurement data. Compared with the conventional 2D metallic corrugated technique [8], our proposed technique can achieve comparable performance with only substrate structure and lower profile, which makes the corrugated antenna suitable for more compact applications.

5. Conclusions

A novel Ka-band SIW-slot-array-based corrugated antenna with narrow beamwidth and high gain was elaborated in this study. In comparison with other metallic methods to realize 2D gain enhancement that require dual metallic layers or multiple rectangular waveguides, our proposed technique can achieve equivalent performance with only a single-layer substrate and can be fed by common coaxial connector, which has lower profile, design complexity, and weight. As the metallic corrugated antenna cannot be installed in the wireless terminals such as mobile phone, our proposed technique can help solve the installation problem with an easy PCB fabrication, which is beneficial for high-gain antenna for 5G technology.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] A. Ghosh, T. A. Thomas, M. C. Cudak et al., "Millimeter-wave enhanced local area systems: a high-data-rate approach for future wireless networks," *IEEE Journal on Selected Areas in Communications*, vol. 32, no. 6, pp. 1152–1163, 2014.

[2] R. Lenormand, A. Hirsch, J.-L. Almeida, A. Valero-Nogueira, J. I. Herranz-Herruzo, and D. Renaud, "Compact switchable RHCP/LHCP mobile Ka-band antenna," in *2012 15 International Symposium on Antenna Technology and Applied Electromagnetics*, pp. 1–6, Toulouse, France, 2012.

[3] S.-J. Park, D.-H. Shin, and S.-O. Park, "Low side-lobe substrate-integrated-waveguide antenna array using broadband unequal feeding network for millimeter-wave handset device," *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 3, pp. 923–932, 2016.

[4] C. Huang, Z. Zhao, and X. Luo, "Application of "bull's eye" corrugated grooves integrated with artificially soft surfaces structure in the patch antenna to improve radiation performance," *Microwave and Optical Technology Letters*, vol. 51, no. 7, pp. 1676–1679, 2009.

[5] M. J. Lockyear, A. P. Hibbins, J. R. Sambles, and C. R. Lawrence, "Surface-topography-induced enhanced transmission and directivity of microwave radiation through a subwavelength circular metal aperture," *Applied Physics Letters*, vol. 84, no. 12, pp. 2040–2042, 2004.

[6] M. Beruete, M. Sorolla, I. Campillo et al., "Enhanced millimeter wave transmission through quasioptical subwavelength perforated plates," *IEEE Transactions on Antennas and Propagation*, vol. 53, no. 6, pp. 1897–1903, 2005.

[7] M. Beruete, I. Campillo, J. Dolado et al., "Low-profile corrugated feeder antenna," *IEEE Antennas and Wireless Propagation Letters*, vol. 4, pp. 378–380, 2005.

[8] C. Huang, C. Du, and X. Luo, "A waveguide slit array antenna fabricated with subwavelength periodic grooves," *Applied Physics Letters*, vol. 91, no. 14, article 143512, 2007.

[9] S. Alkaraki, Y. Gao, and C. Parini, "Dual-layer corrugated plate antenna," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 2086–2089, 2017.

[10] M. M. Honari, R. Mirzavand, H. Saghlatoon, and P. Mousavi, "A dual-band low-profile aperture antenna with substrate-integrated waveguide grooves," *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 4, pp. 1561–1566, 2016.

[11] M. Lin, Z. Guo, P. Liu, and Y. Gao, "Single-layer SIW corrugated technique for gain enhancement," in *2017 International Conference on Electromagnetics in Advanced Applications (ICEAA)*, pp. 619–621, Verona, Italy, 2017.

[12] M. Lin, P. Liu, and Z. Guo, "Gain-enhanced ka-band MIMO antennas based on the SIW corrugated technique," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 3083–3087, 2017.