Conformal Transmitarray and Its Beam Scanning

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***Abstract*- A mechanically beam-scanning conformal transmitarray is developed in this paper. Firstly, a transmitarray element with three layers of identical square ring slots is proposed and its performance for different element thickness is studied. A transmission phase range of 330° with a maximum 3.6 dB loss can be achieved when the thickness is 0.508mm (only 0.04 wavelength at 25GHz). Secondly, a cylindrically conformal transmitarray is designed using the above antenna elements, realizing a 45.3% simulated antenna efficiency. Finally, the above fixed-beam conformal transmitarray is expanded to a beam scanning one. By rotating the feed horn to different positions, the main beam of the array can be switched to ±15°, ±10°, ±5° and 0°, while the whole size of this array is only 2.5 times larger than the fixed beam one. A prototype is fabricated and measured with a stable gain of about 18.7 dBi at all beam angles.**

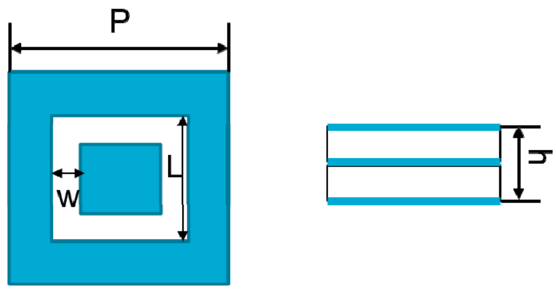
***Index Terms*—Transmitarrays, beam steering, conformal array antennas.**

I. INTRODUCTION

The last two decades have witnessed significant progress in transmitarrays due to their merits of high gain, low profile and flexible radiation performance. Generally, they are comprised of an illuminating feed source and a thin transmitting surface consisting of arrays of antenna elements. The transmission coefficients of these elements are individually designed in order to transform the spherical phase front from the feed into a planar one. Currently, the research in this area is focused on planar transmitarrays, including wideband ones [1-3], multi-band ones [4-5], and reconfigurable ones [6-9]. However, for many wireless communication platforms, such as unmanned aerial vehicles (UAV), satellites, and aircrafts, conformal antennas with high-gain are highly demanded to satisfy aerodynamic requirements. For these applications, conformal transmitarrays that can follow the shapes of various mounting platforms, are highly desired as part of the platform surface, front in particular, can accommodate the transmitarray with a feed placed behind. Unfortunately, most of the previously developed transmitarray elements are not suitable for conformal design. This is because they consist of multiple thick layers or metallic vias need to be placed between the top and bottom layers of the elements. This way, bending these structures to conform to curved surfaces is very challenging.

Another desired feature for transmitarrays is to steer the beam. One typical method to achieve electronically beam scanning for planar transmitarrays is to adjust the transmission phase of the antenna element employing PIN diodes [6-7] or varactor diodes [8-9]. However, for conformal transmitarrays with large curvature, integrating such lumped components onto a curved surface is very challenging. Therefore, mechanical tuning would be preferable for scanning the beams of conformal transmitarrays. This method can also reduce the losses and costs associated with the usage of a very large number of active elements and complicated control circuits in electronic beam scanning design.

According to the above literature review and discussion, it is found that very few work on beam scanning conformal transmitarrays has been reported. In this paper, we developed a transmitarray antenna employing a three-layer square ring slot element. The antenna is conformal to a 3-dimentional (3D) printed cylindrical surface. Furthermore, the beam scanning capability of the transmitarray is investigated. By rotating the feed horn at the feeding point, the beam can be steered to 0°, ±5°, ±10° and ±15°. A prototype is fabricated and measured. A stable gain of about 18.7 dBi at all beam angles is achieved.



(a)Top View (b) Side View

Fig. 1. Top and side views of the proposed transmitarray element (Blue part is the metal and white part is the substrate)

II. FIXED-BEAM CONFORMAL TRANSMITARRAY

As shown in Fig. 1, the transmitarray element consists of three layers of identical square ring slots. The unit cell size P is 5.6 mm and the thickness of unit element is h. The width and the length of the slot are w and L, respectively. w is chosen to be 0.8 mm in this work. When varying the values of L from 3.5 mm to 5.41 mm, the transmission phase of the element can be changed. Furthermore, it is found that the unit thickness h has a strong effect on the transmission coefficient of the element. In order to utilize this element for a conformal design, a parametric study of h on the transmission coefficient is conducted, as given in Fig. 2. The element is simulated using the Floquet method with master–slave boundaries of 3D electromagnetic (EM) simulation software HFSS. It can be seen from Fig. 2 the thicker unit performs better than the thinner one in terms of the phase range, loss, and linearity of the phase curve. More specifically, when h equals to 2.5 mm, a 340° phase range with a maximum 3 dB loss is realized. While for the 0.508-mm one, a transmission phase range of 330° is achieved with a maximum 3.6 dB loss. Furthermore, the slope of the phase curve is more linear when *h* is larger (2.5 mm). A unit cell with a more linear phase curve has a potential to reduce the phase error and to enable a large gain bandwidth. Therefore, the thicker unit element is preferred for transmitarray design. However, for the conformal transmitarray, the PCB boards with a thickness of more than 1 mm will be easily broken when it is bent. Therefore, for the final conformal beam steering transmitarray shown in Section III, *h* is chosen to be 0.508 mm which is about 0.04 λ_0 at 25 GHz, even though the element performance is not as good as thicker one. The element's transmission coefficient is found to be stable for different incident angles. Due to the limited space, this information will be presented in the conference.

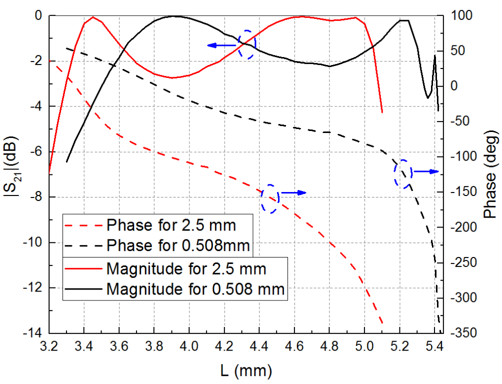
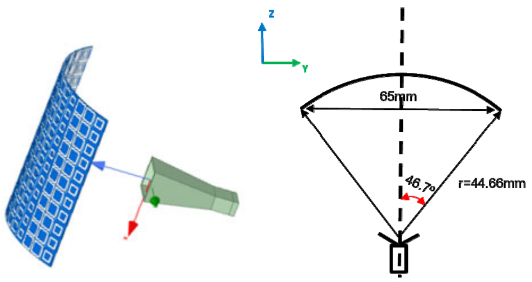


Fig. 2. Transmission performance of the planar transmitarray element with different *h* values.



(a) (b)

Fig. 3. Cylindrical conformal transmitarray 3D model.

Based on the above element design, a fixed-beam conformal transmitarray is developed and simulated at 25 GHz. Fig. 3 (a) and (b) show the 3D structure and the top view of the antenna with a prime focus, respectively. The phase compensation for the conformal design is based on the planar transmitarray for a main beam directed to *z* axis. The antenna consists of 13×11=143 elements with a thickness of 2.5 mm. The cross section of the transmitting surface is 65 mm × 61.6 mm. The feeding source is a standard gain horn LB-28-10-C-KF from A-INFO and is placed in the center of the cylindrical surface. The aperture edge illumination is around -10 dB with a half subtended angle of 46.7° for the conformal transmitting surface.

The simulated radiation patterns for both E and H planes are given in Fig.4. The peak gain of the transmitarray is 21.4dB at 25 GHz. The 3-dB gain bandwidth is 16.9%. The antenna efficiency is 45.3% considering the gain calculated by the aperture cross section size.

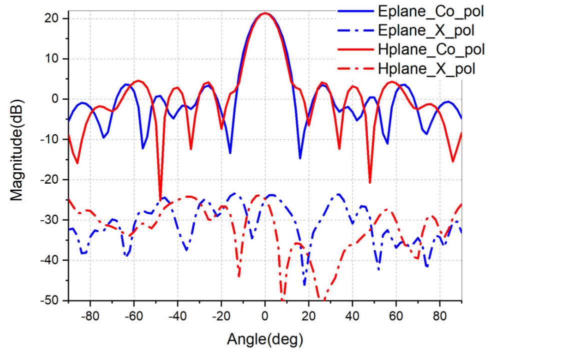
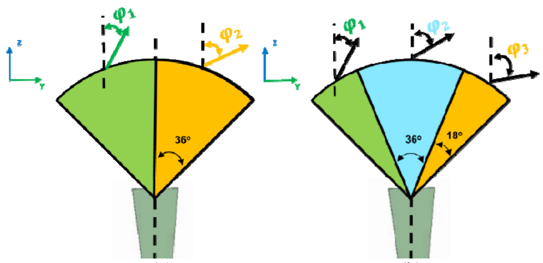


Fig. 4. Simulated radiation patterns of the conformal transmitarray at 25GHz



(a) (b)

Fig. 5 One sector of beam steering transmitarray: (a) two parts; (b) three parts

III. MECHANICALLY BEAM-SCANNING CONFORMAL TRANSMITARRAY

For the transmitarray developed in last section, it radiates a fixed beam. In this section, a mechanically beam scanning method is studied by rotating the feed horn only. As shown in Fig. 5, the transmitting surface reported in Section II is divided into two parts or three parts. Each part directs the beam to a specific direction. For example, if the beam of one part is directed to $\varphi 1$, and the other part is to $\varphi 2$, the combined beam is directed to $(\varphi 1+ \varphi 2)/2$. It should be pointed out that the two beams cannot be separated far away and be too narrow in order to avoid a split beam. In this work, a step of about 10° is found to be an optimum value. In some cases, the transmitting surface can have three parts including one big part and two small ones, as shown in Fig. 5 (b). Then the combined beam will be directed to $(\varphi 2 + (\varphi 1/2 + \varphi 3/2))/2$.

The configuration of the beam-scanning transmitarray is shown in Fig. 6. It includes six parts marked as *a1*, *a2*, *a3*, *b1*, *b2*, *b3*. The beam direction for each part is also shown in Fig. 6. Its size is 2.5 times larger than that of the fixed-beam one reported in Section II. The feed gain horn LB-28-15-C-KF from A-INFO with 12.2 dB gain at 25 GHz is placed in the center. There are seven operating states for the transmitarray. For each state, a transmitting surface with a 72° subtended angle is illuminated by the standard gain horn, resulting in a -10 dB edge illumination. This way, the adjacent transmitarray surface parts will have minimum effects on the active surface. As shown in Fig. 6, by rotating the gain horn to four positions, the main beam of the antenna can be directed to 0°, -5°, -10°, and -15°, respectively. The main beam can be directed to 5°, 10°, 15°, when the feed horn is rotated clockwisely, due to the structural symmetry.

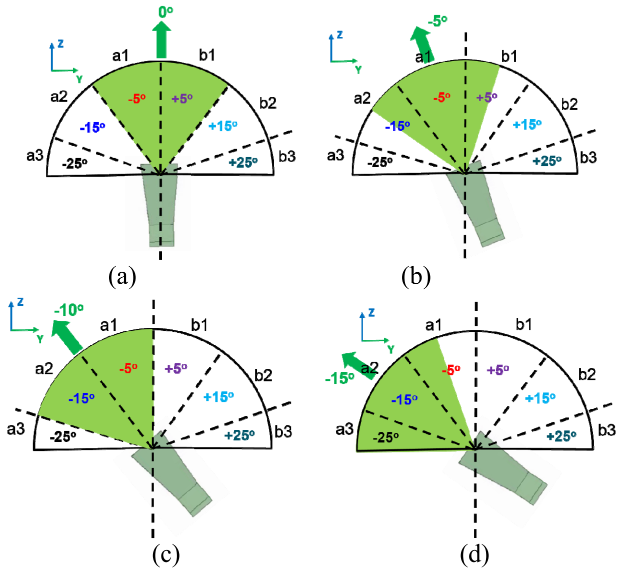


Fig. 6 Different operating states of the conformal transmitarray corresponding to different beam directions: (a) 0°; (b) -5°; (c) -10°; (d) -15°

To verify the beam-scanning method discussed above, a beam-scanning conformal transmitarray prototype at 25 GHz is designed, fabricated and measured. For this prototype, the 0.508-mm thick unit element is used for the ease of bending. Each layer of the unfolded transmitting surface was fabricated using standard PCB technology. Then the two surfaces are laminated together and are attached to a 3D printed cylindrical frame. Photograph of the prototype is shown in Fig.7.

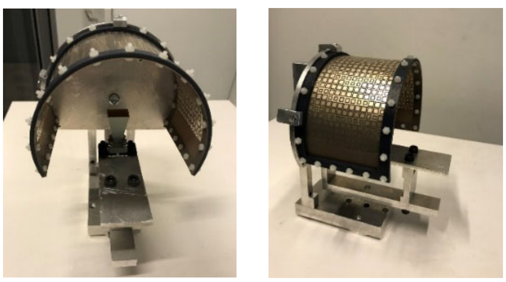


Fig. 7 Photograph of the reconfigurable transmitarray prototype

The measured input reflection coefficients are below -10dB for all states from 24GHz to 26GHz. This is omitted in this paper due to the limited space. The H-plane radiation patterns at 25GHz were measured for seven different positions of the gain horn as displayed in Fig. 8. It can be seen that a stable gain value of about 18.7 dBi is achieved at all angles. Therefore, the scan loss of this mechanically reconfigurable conformal transmitarray is very small.

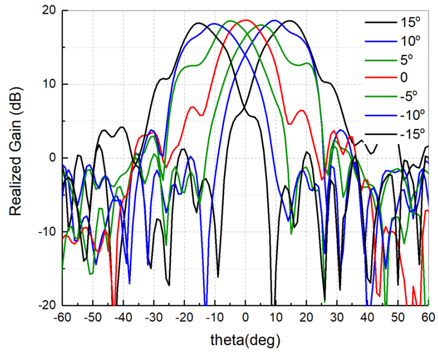


Fig. 8 Measured H-plane radiation patterns at 25 GHz for different states of the transmitarray.

IV. CONCLUSION

A new beam scanning conformal transmitarray is developed in this paper. By using a very thin (0.04 wavelength at 25GHz) antenna element, the transmitting surface can be easily attached to a cylindrical surface. Furthermore, a mechanically beam scanning method is developed for the conformal transmitarray. By rotating the feed horn, the main beam of the array can be switched to ±15°, ±10°, ±5° and 0° with a relatively flat gain of 18.7dBi for all the beam angles.

REFERENCES

[1] A. H. Abdelrahman, A. Z. Elsherbeni, and F. Yang, “High Gain and Broadband Transmitarray Antenna Using Triple-Layer Spiral Dipole Elements,” *IEEE Antennas Wireless Propag. Lett.*, vol. 13, pp. 1288–1291, 2014.

[2] P.-Y. Feng, S.-W. Qu, and S. Yang, “Octave Bandwidth Transmitarrays With a Flat Gain,” *IEEE Trans. Antennas Propag.*, vol. 66, no. 10, pp. 5231–5238, Oct. 2018.

[3] Q. Luo, S. Gao, M. Sobhy, and X. Yang, “Wideband Transmitarray With Reduced Profile,” *IEEE Antennas Wireless Propag. Lett.*, vol. 17, no. 3, pp. 450–453, Mar. 2018

[4] K. T. Pham, R. Sauleau, E. Fourn, F. Diaby, A. Clemente and L. Dussopt, "Dual-band transmitarrays with dual-linear polarization at Ka band,"*IEEE Trans. Antennas Propag.*, vol. 65, no. 12, pp. 7009-7018, Dec. 2017.

[5] A. Aziz , F. Yang, S. Xu, and M. Li, “An Efficient Dual-Band Orthogonally Polarized Transmitarray Design Using Three-Dipole Elements”, *IEEE Antennas Wireless Propag. Lett.*, vol. 17, no. 2, pp. 319–322, Feb. 2018.

[6] A. Clemente, L. Dussopt, R. Sauleau, P. Potier, and P. Pouliguen, “Wideband 400-Element Electronically Reconfigurable Transmitarray in X Band,” *IEEE Trans. Antennas Propag.*, vol. 61, no. 10, pp. 5017–5026, Oct. 2013.

[7] C. Huang, W. Pan, X. Luo, “Low-Loss Circularly Polarized Transmitarray for Beam Steering Application,” *IEEE Trans. Antennas Propag.*, vol. 64, no. 16, pp. 4471–4476, Oct. 2016.

[8] J. Y. Lau and S. V. Hum, “A wideband reconfigurable transmitarray element,” *IEEE Trans. Antennas Propag.*, vol. 60, no. 3, pp. 1303–1311, 2012.

[9] J. G. Nicholls, and S. V. Hum, “Full-Space Electronic Beam-steering Transmitarray With Integrated Leak-Wave Feed,” *IEEE Trans. Antennas Propag.*, vol. 64, no. 8, pp. 3410–3422, 2016