Conformal Transmitarrays for Unmanned Aerial Vehicles Aided 6G Networks

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***Abstract*—Unmanned aerial vehicles (UAVs) aided wireless communications promise to provide high-speed cost-effective wireless connectivity without needing fixed infrastructure coverage. They are a key technology enabler for sixth generation (6G) wireless networks, where a three-dimensional coverage including space, aero and terrestrial networks are to be deployed to guarantee seamless service continuity and reliability. Owing to the aerodynamic requirements, it is highly desirable to employ conformal antennas that can follow the shapes of the UAVs to reduce the extra drag and fuel consumption. To enable hundred gigabits-per-second (Gbps) data rates and massive connectivity for 6G networks, conformal antenna arrays featured with high gains and beam scanning/multiple beams are demanded for millimeter-wave and higher-frequency-range communications. However, new challenges exist in designing and implementing high-gain conformal arrays for UAV platforms. In this article, we overview the recent advances in conformal transmitarrays for UAV-based wireless communications, introducing new design methodologies and highlighting new opportunities to be exploited.**

***Index Terms*—Conformal antennas, antenna arrays, unmanned aerial vehicle (UAV), sixth generation (6G).**

I. Introduction

While the fifth generation (5G) wireless networks are being successfully rolled out, there are already initiatives describing the roadmap towards the sixth generation (6G) along with the emerging trends, architectures, and various enabling techniques [1]. Compared with the 5G networks that are mainly for the devices on the ground, one of the most innovative 6G network features is to provide a three-dimensional (3-D) coverage, integrating terrestrial networks with airborne and space-borne networks. Unmanned aerial vehicles (UAVs), also commonly known as drones, are considered as one of the best candidates for delivering airborne networks due to their high mobility and low cost. UAV aided wireless networks can be swiftly deployed to bridge wireless communication links between satellite and terrestrial platforms/user terminals, providing seamless and pervasive connectivity at remote areas or in the event of ground network infrastructure being destroyed due to natural disasters. UAV-based wireless network is a unique characteristic of the 6G paradigm, unlocking its full potential for ubiquitous 3-D coverage.

To support hundred-Gbps to terabits-per-second (Tbps) data rates required by the 6G networks, millimeter-wave (mm-wave) systems, e.g., E band, will be more suitable for UAV aided wireless communications for interconnecting the space and terrestrial networks. Moreover, terahertz (THz) radiation (0.1-10 THz) has been widely hailed as one of the most promising technologies for 6G networks. Continuous line-of-sight transmission links to the users at the ground can be established by UAVs, which is highly demanded by THz communications considering the high path loss at THz bands. To enable mm-wave and THz communications on UAVs, large antenna arrays would be required to produce high gains to compensate for the very high path loss at these frequencies. However, the beam widths of the high-gain antennas are usually very narrow, which means only a small area can be covered. In order to communicate with a number of distributed users, mm-wave high-gain antenna arrays having beam-scanning capabilities or radiating multiple beams are highly demanded. Antenna arrays with beam-scanning capabilities can serve multiple users at different time by dynamically changing the beam directions. Multi-beam arrays fed by multiple ports can provide multiple concurrent yet independent beams to enable multi-point-to-multi-point communications. For broadcasting purposes, we may also need point-to-multi-point communications, where single-feed dual-beam/multi-beam antennas are required.

Conventional large beam-scanning/multi-beam antenna arrays may not be suitable for UAV communication systems as those arrays protrude from the UAV's fuselage. This increases drag and degrades the aerodynamics, thus leading to reduced vehicle speed and energy efficiency. On the other hand, conformal high-gain antenna arrays, which are designed to follow the mounting platform shapes, are excellent for aerodynamics and are light weight, low profile and low cost. Recently, there have been active research activities on conformal antennas at both microwave and mm-wave frequencies. In [2], an eight-element conformal phased array operating at 2.8 GHz is developed for UAV platforms with a peak antenna gain of 13.7 dBi and a ±70° scanning range. In [3], a multi-beam conformal slot array is developed at 10 GHz with a peak gain of 19.3 dBi and a ±38° scanning range. In [4], a wideband conformal phased array antenna using tightly coupled dipoles is presented from 6-18 GHz with an about 10-dBi gain and a ±60° scanning range. It can be found from the abovementioned papers that most of the current advances in

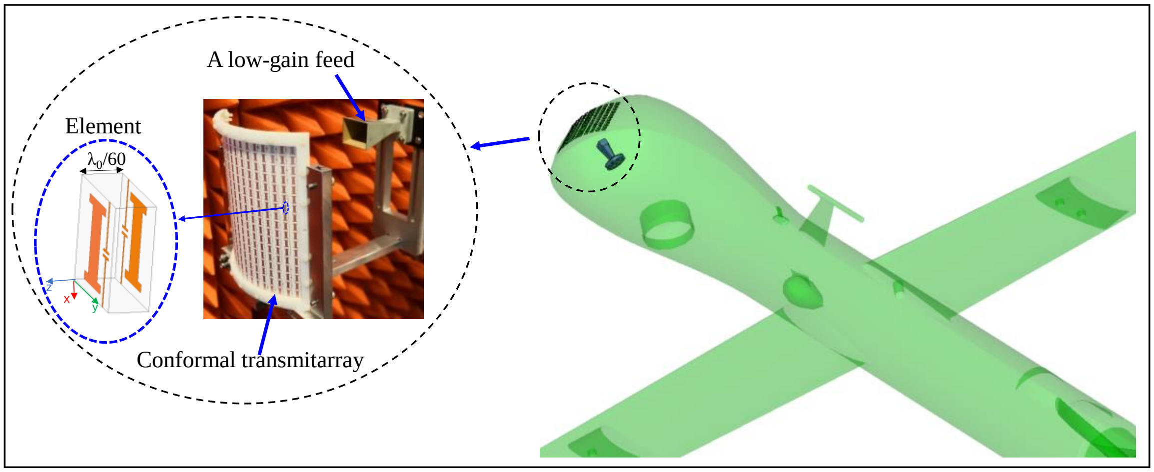

Fig. 1 Schematics of a high-gain conformal transmitarray integrated with an UAV.

conformal antennas are below 20 GHz with a gain lower than 20 dBi. High-gain conformal arrays at mm-wave bands which are highly demanded by 5G and beyond systems are still in its infancy. In [5], a 60-GHz conformal array is presented with a beam switching between ±34°. However, the realized gain is only 9.6 dBi, which may significantly limit its applications in mm-wave or higher bands. At mm-wave or higher bands, there are several factors that may affect the gain and the beam-scanning range of conformal arrays.

Feeding network

An antenna array typically employs a feeding network to connect all the array elements and to achieve beam-scanning capabilities. Usually, there are two types of feeding networks, i.e., transmission-line based feeding networks and spatial feeding networks. The transmission-line based ones, e.g., employed by phased arrays, have metals printed on dielectric substrates, which may show significantly high loss for a large size array at mm-wave or higher bands. On the other hand, the spatial feeding networks as found in reflectarrays or transmitarrays do not have this issue.

Beam scanning method

At microwave bands, electronic switches, e.g., PIN didoes are usually used for beam switching or beam scanning of planar antennas. However, they are found to have much higher loss at mm-wave bands. Furthermore, for conformal antennas with a large curvature, it will be very difficult to solder switches on to the curved surfaces. As evidenced by [5], the loss from the switches on curved platforms at 60 GHz is more than 7 dB due to the stretch of the metal. Therefore, at E-band or above, a mechanical method for beam switching is a competitive option. Compared with the electronic beam scanning, which incorporates a large quantity of electronic switches and their controlling circuits, the mechanical method has much lower loss and cost, although the scanning speed is lower.

From the above analysis, it appears that to realize high-gain beam-scanning/multi-beam conformal arrays, conformal transmitarray antennas serve as a great candidate for UAV platforms in 6G applications. A transmitarray is composed of a transmitting aperture with array elements and a low-gain feed source as shown in Fig. 1. The phases of transmission coefficients of these elements can be individually designed to offer required phase responses for a particular beam direction. This way, the aperture has the ability to radiate a high-gain needle radiation beam compared to the low-gain feed source. It is an appealing choice for UAV-based 6G applications as it utilizes spatial feedings to mitigate the drawbacks of phased arrays that need expensive and lossy beamforming networks. Furthermore, conformal transmitarrays are particularly suitable for airborne platforms because a part of the platform surface can serve as the transmitting aperture with a feed placed inside the platform.

The objective of this paper is to give an overview of our work on conformal transmitarrays including the design challenges, the technologies to develop high-efficiency conformal transmitarrays and their beam-scanning or multi-beam realizations. Furthermore, we will present a new sub-THz beam scanning conformal transmitarray and a new single-feed dual-beam conformal transmitarray. At the end, we will discuss the new opportunities for future research. It should be noted that for the conformal transmitarray prototypes presented in the following sections, we chose the cylinder as the platform since prototypes can be printed using standard PCB technologies and bent onto the curved platform. Theoretically, the developed technologies can be employed to a wide variety of curved surfaces, e.g., a frustum cone-like platform and a part of a hemisphere. Due to the page limit, the results on these platforms are not given in this paper.

II. Challenges for Conformal Transmitarrays

To be conformal, a transmitarray must be designed to follow the shape of the platform on which it is mounted, e.g., UAVs and aircrafts. Currently, the direct ink printing technology can be used to print metals on curved surfaces. However, it is a technically difficult and expensive task to print metal on multi-layer curved surfaces. Another feasible method to realize a conformal transmitarray is to use a transmitting aperture with ultra-thin array elements. Generally, the thickness of these elements should be less than 0.5 mm. Then, the aperture can be bent to a pre-defined curved platform to achieve the desired conformal configuration.

To date, most of the reported transmitarrays, however, employ multi-layer element models. More specifically, for those elements, there are at least two dielectric substrates with three metal layers. The elements' total thickness is in the range of 0.4 -1.0 λ_0, where λ_0 is the wavelength in free space. On the one hand, these elements are too thick to be bent onto curved surfaces. Although using high-dielectric substrates might reduce the array elements' thickness, the antenna's aperture efficiency could drop significantly as the loss is higher for high-dielectric substrates. Compressing the total thickness of the array elements could be another way to develop thin elements. However, it may reduce the transmission efficiency because the transmission loss for thinner elements is usually higher than that for their thicker counterparts. On the other hand, multi-layer structures may not be suitable for conformal arrays. This is because it is very costly and challenging to align and attach multi-layer elements, especially for mm-wave or THz arrays. Therefore, to achieve easy implementations and high efficiencies of transmitarrays, the first key challenge is to design ultra-thin dual-layer transmitarray elements without sacrificing the aperture efficiency.

Another important challenge for conformal transmitarrays is to scan the beam. As commented before, using electronic devices is not practical, especially at higher mm-wave bands. Consequently, the mechanical beam scanning approach has attracted substantial attention. A Ka-band transmitarray that can scan its beam from 0° to 50° is developed [6] by sliding its feed or transmitting aperture. However, the developed method is only applicable for planar transmitarrays. The conformal transmitarrays with beam-scanning capabilities are still lacking.

III. Ultra-thin Dual-layer Huygens Element and Its Applications in Transmitarray

For transmitarray elements, the amplitudes of their transmission coefficients should be as high as possible to minimize the element loss, thus ensuring a high aperture efficiency. Furthermore, the phases of the transmission coefficients should be varied to provide the required phase compensations along the aperture. Since Huygens elements [7] have the ability to realize a total transmission with adjustable phases, they are excellent candidates for transmitarrays. However, it is found that many published Huygens elements are developed using multi-layer substrates. In [8], a Huygens element with three metal layers is developed. The first and third layers are connected with metallic vias to establish a current loop for a magnetic response. An electric response is created by the radiator on the second layer. The element has a thickness of 3 mm at 10 GHz (0.1 λ_0 at 10 GHz). Using similar ideas, another three-layer Huygens element is presented in [9]. One electric dipole is found in the middle layer and one magnetic dipole is created by the first and third layers. The total element's thickness is 0.4 mm (0.1 λ_0 at 77 GHz). As discussed in Section II, dual-layer elements are demanded by conformal transmitarrays. Actually, some two-layer Huygens elements [10] have been reported. However, the design needs numerous discrete printed circuit board (PCB) tiles to be stacked to form an array. This significantly increases the complexity when assembling a large transmitarray.

For the ease of implementations of conformal transmitarrays, we present an ultra-thin two-layer Huygens element [11]. As shown in Fig. 1, the developed Huygens element has only one substrate with two metal layers printed on both sides. The substrate permittivity is 3.5 and its thickness is 0.5 mm, which is about $\lambda_0/60$ at 10 GHz. In the center of the substrate, 'I' shape patches are printed on both sides of the substrate. Besides, two pairs of head-to-head parasitic 'T' shape strips are added on both layers, but at diagonal positions. When the proposed Huygens element is illuminated by an x-polarized incidence wave, the currents on two 'I' shape patches show opposite directions, which can mimic a current loop and produce a magnetic response. Meanwhile, the currents on the parasitic 'T' strips have the same direction with the incidence wave, which will generate an electric response. Based on the Huygens element theory [8], it is known that each specific transmitting phase corresponds to a pair of electric and magnetic surface impedances. By varying the parameters of the elements, the required electric and magnetic impedances can be achieved to enable a total transmission with a desired transmission phase. In the design process, the magnetic response will be developed first by designing the 'I' shape patches. After that, the two 'T' shape stubs will be determined for electric responses. Finally, we developed eight elements to support a 3-bit quantized phase distribution to cover a 360° range.

Using the proposed Huygens element, we design a cylindrical conformal transmitarray. It consists of 16×17=272 elements with a cross-sectional area of 121.3 mm×144.5 mm. The standard PCB technology is used to fabricate the unfolded planar transmitting surface. A cylindrical frame is fabricated with a 3-D printing technology. Finally, the ultra-thin transmitting aperture is bent and attached onto the frame. We use a standard gain horn A-INFO LB-75-10 to feed the transmitarray. A photo of the fabricated prototype is given in Fig. 1. The antenna measurement was conducted in a MVG compact range. Good agreement is found between simulation and measurement. A peak realized gain of 20.6 dBi is achieved with a 47.4% aperture efficiency. The aperture efficiency is calculated as the ratio of the antenna realized gain and the directivity calculated from the array aperture. It is comparable to the state-of-the-art high-efficiency planar transmitarrays. Therefore, we successfully address the first challenge by developing a two-layer Huygens element for a high-efficiency conformal transmitarray.

IV. Beam Scanning Conformal Transmitarray

The Huygens-element-based transmitarray given in Section III radiates a fixed beam. As discussed in the conformal transmitarray challenges, mechanical beam scanning is suitable for conformal antennas due to the difficulties of soldering electronic switches on a curved surface to achieve an electronic beam scanning. One possible solution for mechanical beam scanning is to rotate the transmitting aperture and its feeding horn together, thereby leading to different beams. However, for most conformal applications, it is noted that the transmitting aperture is the surface of the communication platform and, hence, it cannot be easily moved. Considering this practical scenario, we developed a cylindrical transmitarray with a beam-scanning range of ±15° by rotating the feeding horn only [12].

For a fixed beam transmitarray, all the array elements are designed for a beam pointing to a specific angle. In order to scan the beam, the elements of the transmitting aperture can be designed to radiate different beams. For example, the transmitting aperture can be split into two parts from the center. If the elements on one part are developed to radiate a beam to an angle of $\varphi 1$, and the elements on the other part is designed to radiate a beam to $\varphi 2$, the combined beam will be in the direction of $(\varphi 1+ \varphi 2)/2$. By using this technology, we design a transmitting surface as given in Fig. 2, having six parts as *P1*, *P2*, *P3*, *P4*, *P5*, *P6*. The elements on each part are for radiating beams to different directions in the y-z plane.

For parts *P2*, *P3*, *P4*, *P5*, the subtended angles are 36° and they are 18° for *P1* and *P6*. As a result, the entire transmitting aperture is half a circle with a 180° subtended angle. In the center of the transmitarray, a feeding horn A-INFO LB-28-15 is used to illuminate the aperture. The horn has a 12.2-dBi gain at 25 GHz. By adjusting the distance between the feeding horn and aperture, we can have an active illumination area of 72°, which means each area has an -10 dB illumination taper between the center and edge. For the adjacent parts of the transmitarray outside the active areas, the illumination intensity is very small and considered to have no effect on the active parts. For this design, a three-layer square-slot element is employed as the transmitarray element. The length of the slot can be changed to vary the transmission phase. There are 15×13 elements in each 72° transmitting surface.

As given in Fig. 2, the two parts *P3* and *P4* of the transmitting aperture are illuminated when the feed horn is pointed along z axis. They are marked as blue areas. Since these two parts can radiate beams towards -5° and 5°, respectively, a combined beam of 0° is radiated. When we rotate the horn clockwisely by 18°, half *P3*, the entire *P4* and half *P5* will be illuminated. In this state, the combined beam will be radiated to 5°.

Similarly, when we continue rotating the feed horn by 18°, parts *P4* and *P5* will be illuminated to radiate a combined beam towards 10°. The combined beam will point to 15° when we rotate the feed by a further 18°. When we rotate the feed horn anti-clockwisely, the antenna will scan its main beam to -5°, -10°, -15°, respectively.

In order to validate the proposed beam-scanning technology, we designed the above transmitting aperture at 25 GHz on Rogers DiClad 880 substrate. The substrate permittivity is 2.2 and its thickness is 0.5 mm. A picture of the prototype is shown in Fig. 3. We used standard PCB technology to print a planar transmitarray aperture and bent it to be conformal to a cylindrical frame. The gain horn can be rotated in the horizontal plane to illuminate the parts required, leading to a scanned beam at the same plane. Fig. 3 shows the measured H-plane gain curves at 25 GHz. Since the beam scanning is achieved using mechanical method, the beams for all the directions have a

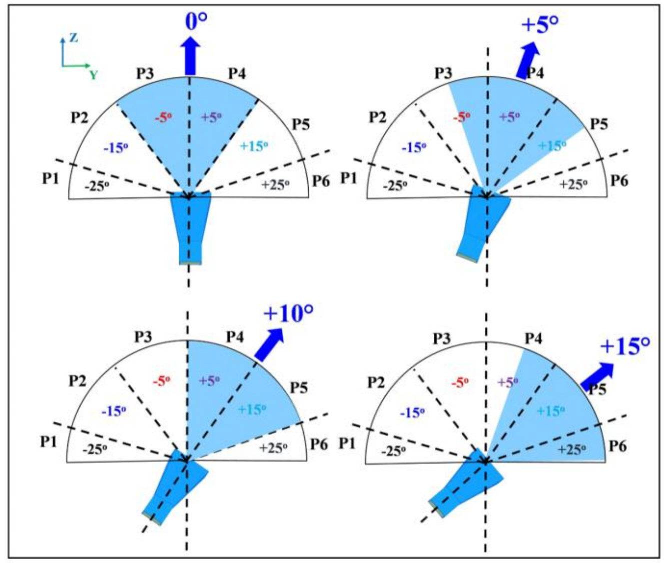

Fig. 2 Beam-scanning conformal transmitarray radiating different beams.

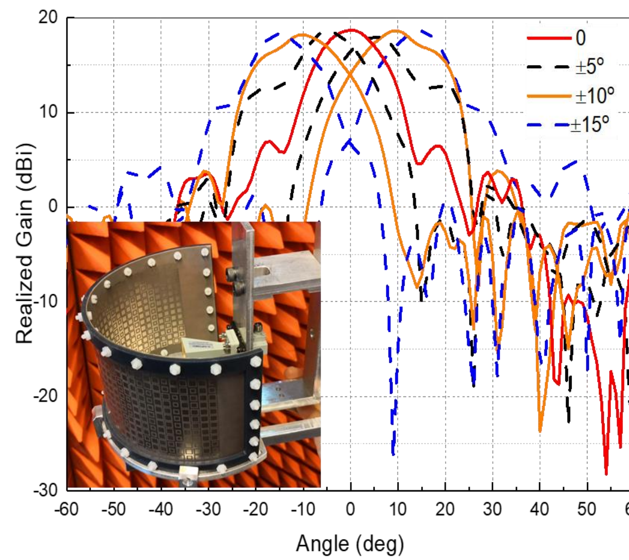

Fig. 3 Beam-scanning conformal transmitarray prototype and its radiation property.

stable realized gain of 18.7 dBi. It should be pointed out that the aperture efficiency of the antenna is low, as for each beam, only a small part of the entire transmitting aperture is actively illuminated. This is targeted at applications where an antenna radome is used as a part of the communication platform, and the aperture efficiency may not be a main concern. For example, the bottom of an UAV can be used for a transmitarray with a large electrical size at mm-wave frequencies.

V. Elliptical Shaped Transmitarray for Wide-angle Beam Scanning

In the last section, the beam scanning is achieved by rotating the feeding horn at the centre of the transmitarray. This type of scanning is suitable for applications requiring fast beam changing in a limited scanning range since the horn rotates at a fixed position. However, it has drawbacks of a small beam scanning range and a low aperture efficiency. In order to enlarge the beam scanning range, we developed a cylindrical

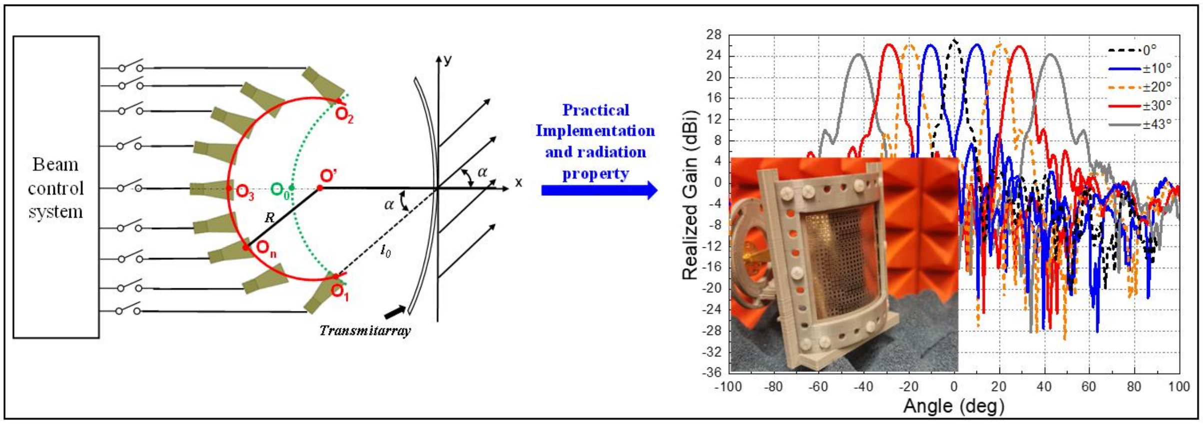

Fig. 4 Conformal transmitarray schematic and its practical implementation.

elliptical shaped transmitarray for a wide-angle beam scanning by sliding the horn along a focal arc [13]. The shape of the transmitting surface is employed as an extra degree of freedom for the beam-scanning design, together with an optimization method on the feed positions. If multiple feeding horns are used at the same time, it can also radiate multiple independent beams.

Fig. 4 shows the schematics of the wide-angle beam scanning transmitarray with a cylindrical elliptical shaped radiating aperture, i.e., it has an elliptical-arc cross section along xoy plane and a straight contour along xoz plane. As indicated in Fig. 4, O_1 and O_2 are chosen as two symmetrical focal points for the desired largest beam radiation angles at α=±45°, and the feed offset angles at these two points are defined equal to the beam radiation angles. The focal length l_0 is determined by the transmitting aperture size and the radiation patterns of feed horns. The transmitarray shape and element phase distributions are regarded as two unknowns. By calculating phase compensations for two beams towards ±45° from the focal points O_1 and O_2, two equations can be formed to solve the two unknowns. Consequently, the transmitarray profile along xoy plane and its phase distribution can be derived.

Once we have obtained the contour of the transmitting aperture and the phase compensation, the focal arc for arbitrary beam angles between ±45° can be calculated. The traditional focal arc has a constant focal length l_0 as marked with green-dot line in Fig. 4. However, in the previous derivations, phase compensations are implemented only for ideal radiations towards two directions (±45°). Therefore, phase errors exist for other directions, e.g., boresight radiation. To mitigate this error and to ensure good radiations along xoz (vertical) plane, a feed movement is conducted to realize an optimal boresight beam. A refocusing arc is achieved subsequently as marked with red-solid line in Fig. 4, which shows a radius R with respect to the centre at O'. It can be seen that different beam directions will require different focal lengths. This is different from other reported work using a constant focal length for all the beams. By positioning the feeding source at a random point O_n along the refocusing arc, an oblique radiation beam can be obtained. When a feed gain horn is moving along the final refocusing arc, the shaped transmitarray can radiate different beams to different directions, thereby providing a beam scanning. Also, it can achieve a multi-beam radiation when multiple gain horns feed the transmitarray simultaneously.

A transmitarray prototype composed of 25×23=575 elements is designed with the maximal beam directions at ±45° at 70.5 GHz. Here a three-layer square-slot element is used for verification. Fig. 4 shows the fabricated prototype and the measured radiation patterns with a beam-scanning range of ±43°. Considering boresight radiation beams, a measured 3-dB gain bandwidth of 12.3% is achieved from 65.7 GHz to 74.3 GHz. The peak gain value is 27 dBi at 70.5 GHz. The maximum beam-scanning loss is 2.7 dB at 70.5 GHz. The realized gain values at 70.5 GHz for 0° and ±43° are 27 dBi and 24.3 dBi, respectively. For other frequencies within the operating band, the beam-scanning loss is in a range of 2.3 dB to 2.7 dB. Compared with many other reported work, the developed shaped transmitarray can realize a wider beam coverage with a small scanning loss. Meanwhile, an aperture efficiency of 34% is achieved.

In this work, a single feed gain horn is used and moved along the focal arc to achieve a mechanical beam scanning. The mechanical scanning has the merits of low loss and low cost compared to the electronic counterpart. However, it has a lower scanning speed. If a fast beam scanning is required, one can employ multiple feeds placed at different positions corresponding to different beams. Electronic switches can be used to activate each individual feed to radiate the required beam, as illustrated in Fig. 4. By using such a smart beam control system, one can achieve electronic beam steering for conformal transmitarrays.

It should be noted that the developed beam scanning method can be applied to other array elements. Since THz is considered to be a major part of 6G networks, we have designed a sub-THz beam scanning conformal transmitarray using the Huygens element discussed in Section III. The element performance is almost unchanged with a 3-bit full phase range and low transmission loss at 150 GHz. By following the design methodology discussed above, an elliptical beam scanning transmitarray at 150 GHz is designed, as shown in Fig. 5. It consists of 18×13=234 elements with a cross-sectional size of 9.72 mm×7.36 mm. With one feed horn moving along the focal arc, different radiation beams can be obtained. Five radiation patterns corresponding to five feeding positions are simulated at 0°, ±20° and ±40°, respectively. The scanning loss is only 1.3 dB with a maximum gain of 19.2 dBi at boresight. The maximum aperture efficiency is 37%.

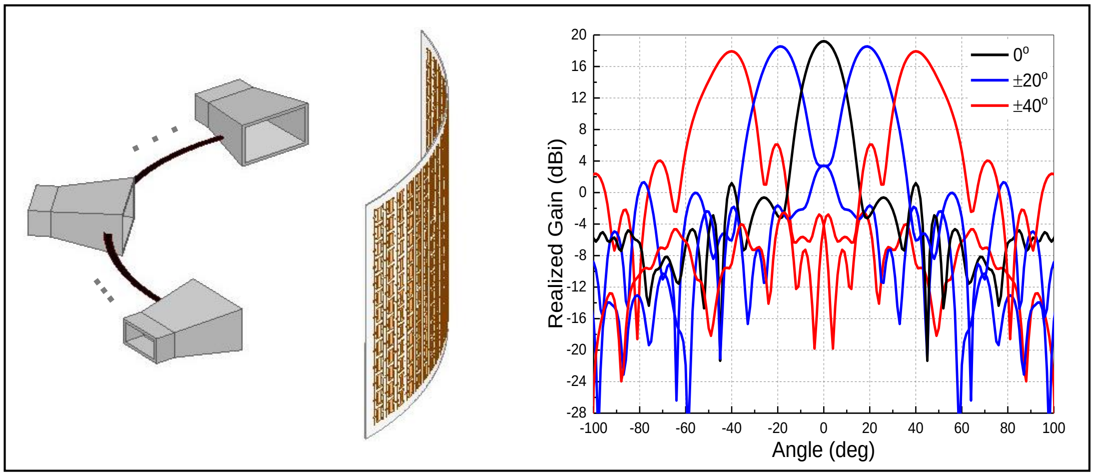

Fig. 5 Schematic of a beam-scanning transmitarray at 150 GHz.

VI. Single Feed Dual-Beam Conformal Transmitarray

Section V presents the advances in beam-scanning or multi-beam conformal transmitarrays using a sliding single feed or multiple feeds, respectively. As introduced in Section I, for broadcasting purpose, single-feed dual-beam/multi-beam antennas are also demanded to enable point-to-multi-point communications. In this section, we present our latest development on a dual-beam conformal transmitarray. To date, there are mainly two methods for single-feed dual-/multi-beam transmitarrays, including optimization algorithms [14] and superposition methods [15]. As introduced in [14], a particle swarm optimization (PSO) method is applied along with a phase-variable four-metal-layer element to achieve a dual-beam radiation pattern at ±25° with peak gains of around 23 dBi. In [15], a typical direct analysis method of superposition principle is demonstrated to form multiple beams in a simpler way. A dual-beam transmitarray composed of five-metal-layer elements is designed with beam directions of ±20° and a peak gain of 15.64 dBic. So far, there is no mature technologies reported for single-feed dual-beam/multi-beam conformal transmitarrays. The abovementioned algorithms or employed elements are neither suitable for conformal structures.

Basically, there are two challenges that need to be addressed in order to develop a dual-beam conformal transmitarray. Firstly, as mentioned before, we need to find ultra-thin elements for the ease of bending. Secondly, for the ultra-thin elements, it is found that their performance is dependent on the incident angle of the illuminating waves. Therefore, during the 3-D simulation, oblique incidence needs to be considered when calculating the elements' phases. Our work in the dual-beam design has proposed a feasible solution addressing the above two challenges by using the ultra-thin Huygens elements in Section III. Furthermore, in the 3-D array construction, as shown in the inset of Fig. 6, the oblique incidence angle θ is considered by separating the straight section (along xoz plane) into 8 small sections marked as A, B, to H. Each element is designed considering different oblique incidence waves for a

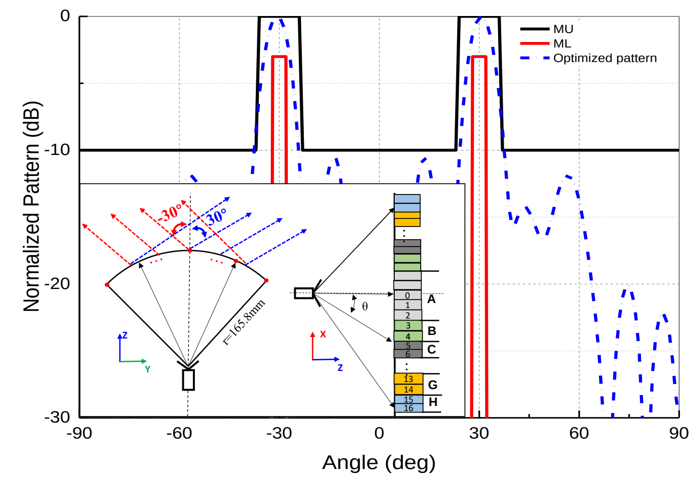

Fig. 6 Defined masks and the simulated normalized radiation patterns of the dual-beam conformal transmitarray.

desired phase value. Along yoz plane, all elements are illuminated with normal incident waves, hence no oblique incidence is involved.

In this section, we present a conformal transmitarray using PSO method to radiate two beams at ±30°. A far-field radiation mask and the corresponding cost function are defined to control the desired beam shapes and sidelobe levels. The optimal solution comes with the minimal value of the cost function after a large amount of iterative procedures. To optimize the desired radiation patterns, two masks are defined as MU and ML separately as shown in Fig. 6. The upper mask MU limits the desired sidelobe levels as -10 dB in the regions out of ±24°~±36°, and the lower mask ML defines the lower boundary of main beam as -3 dB within ±27°~±33°. Since the conformal transmitarray has a cylindrical shape, we only optimize the elements along the middle horizontal curve of the cylinder. Then, we use the elements on this curve as the base to calculate other elements along the straight contour by employing the phase compensation methods for traditional planar transmitarrays.

In order to validate the proposed methodology, we design a dual-beam conformal cylindrical transmitarray with two beams at ±30°. The conformal array includes 32×33=1056 elements with a cross-sectional area of 243 mm×281 mm. We use the same element discussed in Section III, providing a 3-bit quantized phase only modulation. The simulated normalized radiation pattern is shown in Fig. 6. Dual beams are found at ±30° with a peak gain of 18 dBi at 10 GHz.

VII. CONCLUSION

Owing to their aerodynamic performance, conformal transmitarrays find a wide range of applications in airborne networks using UAVs or aircrafts as platforms in 6G networks. In this paper, we have discussed the technical challenges in single- and dual-beam conformal transmitarrays and offered a number of practical solutions for beam-scanning conformal transmitarrays. To date, research in conformal transmitarrays is still in its infancy. Consequently, the ideas presented are meant to inspire more innovations in this area. Novel, thin, high-transmission-efficiency and wideband elements are required to improve the performance of transmitarrays. Another important topic is the realization of individually steerable multi-beam conformal transmitarrays with highly integrated smart feeds. Besides, folded conformal transmitarrays is another promising topic, since it would be attractive if the overall profile of the conformal transmitarray can be reduced. We expect to see some progress to be made in this area in the near future.

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