# Conformal Transmitarrays for Unmanned Aerial Vehicles Aided 6G Networks

Abhishek Srivathsa-1RV19EC006
Chetan SM-1RV19EC042

***Abstract*—Unmanned aerial vehicles (UAVs) aided wireless communications promise to provide highspeed 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 (Gb/s) 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.**

***Keywords:*** Unmanned aerial vehicle(UAV),Printed Circuit Board(PCB),Sixth Generation Wireless(6G)

## I. Introduction

Unmanned aerial vehicles (UAVs) aided wireless communications promise to provide highspeed cost-effective wireless connectivity without needing fixed infrastructure coverage.

An antenna array is a set of multiple connected antennas which work together as a single antenna, to transmit or receive radio waves. In radio communication and avionics a conformal antenna or conformal array is a flat array antenna which is designed to follow a prescribed shape, for example a flat curving antenna which is mounted on or embedded in a curved surface. It consists of multiple individual antennas mounted on or in the curved surface which work together as a single antenna to transmit or receive radio waves.

In antenna theory, a phased array usually means an electronically scanned array, a computer-controlled array of antennas which creates a beam of radio waves that can be electronically steered to point in different directions without moving the antennas. Phase shifters are used in phased arrays.

Conformal antennas were developed in the 1980s as avionics antennas integrated into the curving skin of military aircraft to reduce aerodynamic drag, replacing conventional antenna designs which project from the aircraft surface.

In a conformal antenna, they are mounted on a curved surface, and the phase shifters also compensate for the different phase shifts caused by the varying path lengths of the radio waves due to the location of the individual antennas on the curved surface.

## II. 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.

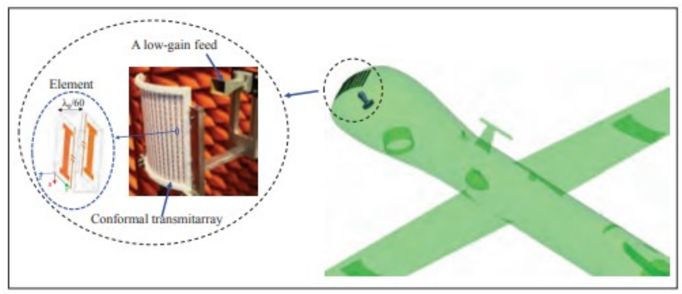


Figure 1: Schematics of a high-gain conformal transmitarray integrated with an UAV.

## III. Beam Scanning Method

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. A transmitarray is composed of a transmitting aperture with array elements and a low-gain feed source. The phases of transmission coefficients of these elements can be individually designed to offer required phase responses for a particular beam direction.

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 Huygens-element-based transmitarray given radiates a fixed beam. 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. However, for most conformal applications, it is noted that the transmitting aperture is the surface of the communication platform like the fuselage of the drone. and, hence, it cannot be easily moved or rotated. To overcome this a cylindrical transmitarray with a beam-scanning range of ±15° was designed by rotating the feeding horn only.

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 w1, and the elements on the other part is designed to radiate a beam to w2, the combined beam will be in the direction of (w1+ w2)/2. By using this technology, we design a transmitting surface 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. By

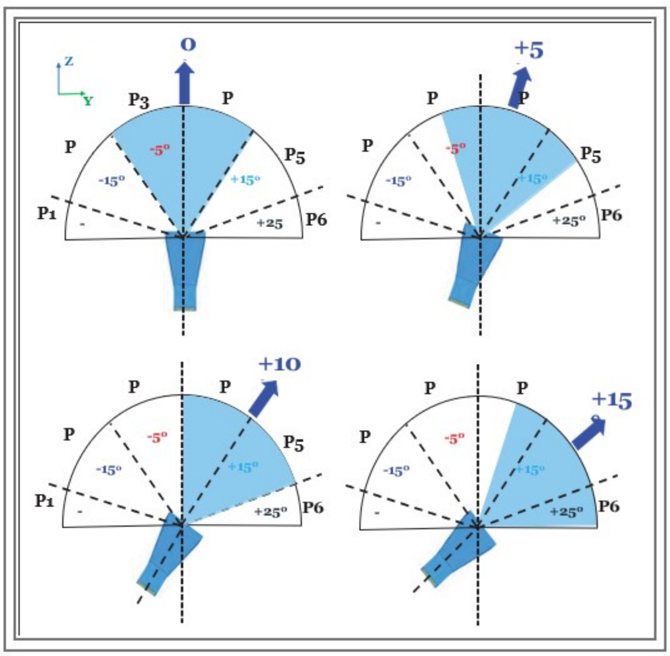


Figure 2: Beam-scanning conformal transmitarray radiating different beams.

adjusting the distance between the feeding horn and aperture, we can have an active illumination area of 72°. Since P3 and P4 can radiate beams towards –5° and 5°, respectively, a combined beam of 0° i.e. (-5+5)/2=0° is radiated. When we rotate the horn clockwise by 18°, half of P3, the entire P4 and half P5 will be illuminated. In this state, the combined beam will be radiated to 5 i.e.(-2.5+5+75)/2=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° i.e.(5+15)/2=10° . The combined beam will point to 15° when we rotate the feed by a further 18°. 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.

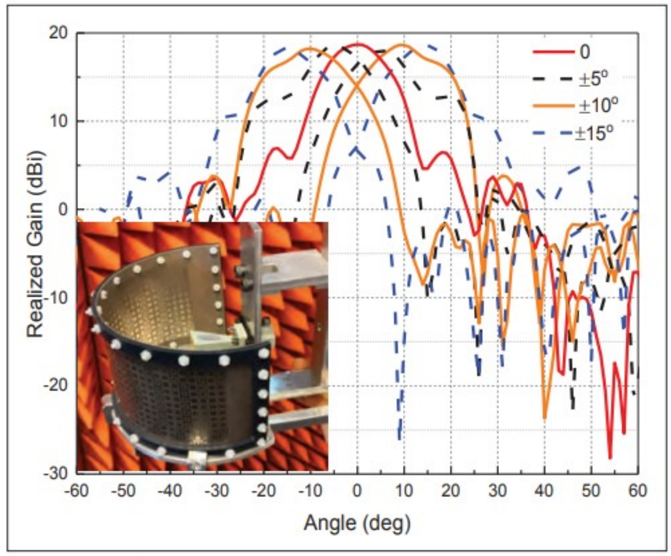


Figure 3: Beam-scanning conformal transmitarray prototype and its radiation property.

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 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.

## IV. Challenges for Conformal Transmitarrays

A conformal transmitarray must be designed to follow the shape of the platform on which it is mounted, e.g., UAVs and aircrafts. 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 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. Most of the reported transmitarrays, however, employ multi-layer element models. In these 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 lambda, where lambda is the wavelength in free space. On the one hand, these elements are too thick to be bent onto curved surfaces. 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 thicker elements. On the other hand, multi-layer structures may not be suitable for conformal arrays because it is very costly and challenging to align and attach multi-layer elements. 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.

## V. Elliptical Shaped Transmitarray For Wide Angle Beam Scanning

Beam scanning achieved by rotating the feeding horn at the centre of the transmitarray has limited scanning range since the horn rotates at a fixed position. In order to enlarge the beam scanning range, cylindrical elliptical shaped transmitarray was developed for a wide-angle beam scanning by sliding the horn along a focal arc. The scanning method can be applied to other

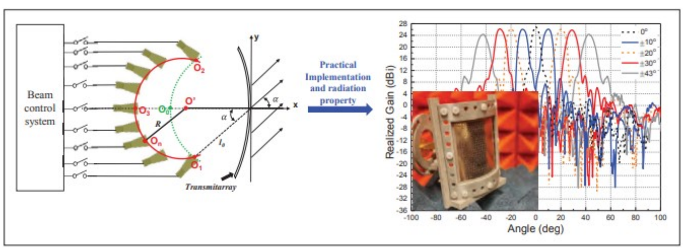


Figure 4: Conformal transmitarray schematic and its practical implementation.

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 earlier.

Figure 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, O1 and O2 are chosen as two symmetrical focal points for the desired largest beam radiation angles at alpha= ±45°, and the feed offset angles at these two points are defined equal to the beam radiation angles. The focal length IO 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 O1 and O2, two equations can be formed to solve the two unknowns. Consequently, the transmitarray profile along xoy plane and its phase distribution can be derived.

## VI. 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 article, 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.

## References

[1] M Giordani, "An empirical study on system level aspects of internet of things (iot)," *IEEE Communications Magazine*, vol. 58, pp. 55–61, Mar. 2020.

[2] L.-Z. S. Pei-Yuan Qin and Y. J. Guo, "Conformal transmitarrays for unmanned aerial vehicles aided 6g networks," *IEEE Communications Magazine*, vol. 60, no. 1, pp. 14–20, Jan. 2022.

[3] V. Semkin, "Beam switching conformal antenna array for mm-wave communications," vol. 15, 2016, pp. 28–31.

[4] K. Chen, "A reconfigurable active huygens' metalens," *Adv. Mater.*, vol. 29, no. 17, 2017.

[5] Y. Liu, "A multibeam cylindrically conformal slot array antenna based on a modified rotman lens," *IEEE Trans. Antennas Propag.*, vol. 66, pp. 3441–52, Jul. 2018.