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# Compact and Directional Printed Dipole Antenna Pair Conformed on a Conical Surface

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## Abstract

In this paper, a small sized transmitting and receiving conformal antenna pair is proposed on a conical surface for C-band radar applications. The antenna pair consists of printed dipole elements and a truncated reflector plane, printed on a flexible and multilayer circuit board. As the antenna pair is wrapped around a conical surface, it can fit in a very small volume, and yet sufficiently low mutual coupling between antennas can be achieved. The antenna also yields wideband characteristics with a directional radiation towards the tip of the cone. As a compact and flexible antenna, it can be well utilized in radar applications such as radio altimeters and proximity sensors.

## 1 Introduction

There is an increasing demand for compact and easy to implement antennas in airborne, spaceborne and military applications. Especially in radar systems such as radio altimeters and proximity sensors, the antenna can be expected to operate in a very small space with minimum interference from surrounding electronics. Therefore, dedicated antenna units are needed that will not only yield the desired radiation performance but also be mechanically compatible with the existing units. In this respect, flexible antennas can offer us a wide range of solutions [1].

Since flexible substrate materials can be conformed on curved surfaces, specialized designs can be developed on cylindrical and conical surfaces. Dipole elements are good candidates to be printed on flexible substrates and conformed on curved surfaces. Although a single dipole element yields an omni-directional radiation, directional radiation can also be achieved with the help of a ground plane in adequate dimensions as in the quasi-Yagi antenna [2]. Using multiple dipole elements, a phased array can also be formed and wrapped around a curved surface and thus, the energy can be transferred towards a certain direction. The size of the dipole elements can also be reduced by folding dipole arms at a certain angle, therefore an electrically small, and yet directional antenna can be constructed.

In this work, a pair of transmitting and receiving antenna is implemented on a three-layer flexible board. The flexible substrate consists of polyimide core and layers of flexible adhesive that bonds polyimide to the copper layers. Each antenna is a two-element dipole array, consisting of two face-to-face dipole elements when wrapped around a conical surface. This configuration yields an efficient pair of antennas that can be integrated well into a radar sensor unit of an airborne application in a small-sized aircraft, a spacecraft, or a missile.

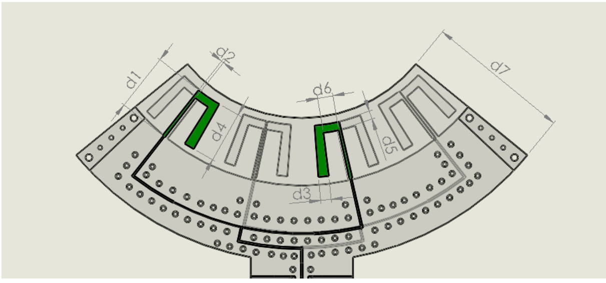
This paper is organized as follows: Section II briefly describes design and production aspects of the proposed antenna. Section III evaluates the performance of the antenna based on the measurement results. Section IV is devoted to the conclusions.

## 2 Antenna Design and The Production

In this design, dipole elements in each layer are conformally projected into lateral areas of conical frustums of different radii. Array elements are intended to face each other when the antenna is wrapped around the conical surface. Both antennas are printed on the same PCB but 90 degrees apart. In this way, E- and H-planes of the antennas become orthogonal to each other, which helps us reduce the mutual coupling between antennas. As shown in Fig. 1, half of the dipole arms for the first and second antennas are printed on the top and bottom layers, respectively. Remaining dipole arms for both antennas are printed on the middle layer, and connected to the common ground plane.

Electromagnetic simulations are performed on CST Studio Suite 2019. Following parameters are chosen for the dipole elements on the first layer: $d_1 = 7.1$ mm, $d_2 = 0.39$ mm, $d_3 = d_5 = 1.29$ mm $d_4 = 6.3$ mm, $d_6 = 1.9$ mm and $d_7 = 17.6$ mm, and similar dimensions are utilized for the dipole elements on the other layers. Note that such dimensions can be scaled in order to work at different frequencies. The depiction of the dipole elements after bending on the conical surface is given in Fig. 2. A thin-walled radome is also incorporated into the design, however not disclosed in this paper due to the confidentiality of the project. Nevertheless, radomes of different materials and shapes can be easily integrated into the antenna.

In order to feed both antennas efficiently, a rigid-flex board is utilized. The multilayer stack-up of the PCB is illustrated in Fig. 3. This is an hybrid board consists of a 5-layer rigid

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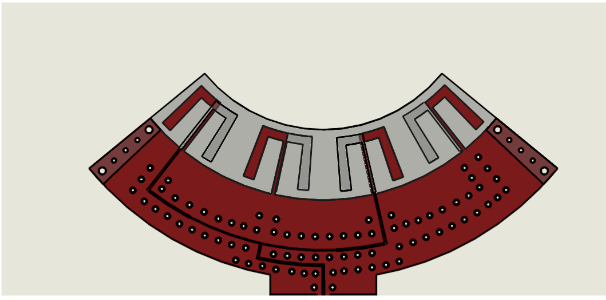

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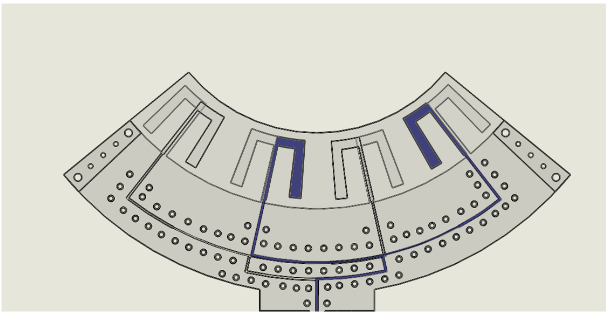

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**Figure 1.** Layers of the antenna pair. (a) Dipole elements of TX antenna on layer 1. (b) Ground plane and complementary dipole elements on layer 2. (c) Dipole elements of RX antenna on layer 3.

section and a 3-layer flexible section laminated together. In the rigid section, two coplanar waveguide lines are printed on the top layer and fed by 50 ohm SMP-type coaxial connector. These lines are then connected to the second and fourth layers with the help of vias, as depicted in Fig. 3. The substrate between second and fourth layer consists of polyimide core and flexible adhesive substance. This part protrudes from the rigid section and forms the flexible section. In the flexible section, coplanar waveguide lines on the top and bottom layers are slightly extended and connected to antennas' microstrip power divider. Thus, dipole elements on the top and bottom layers of the flexible substrate are excited. Fig. 4 shows pictures of the antenna board on a flat surface as well as on the conical surface. In the measurements, a conical surface of polypropylene is utilized.

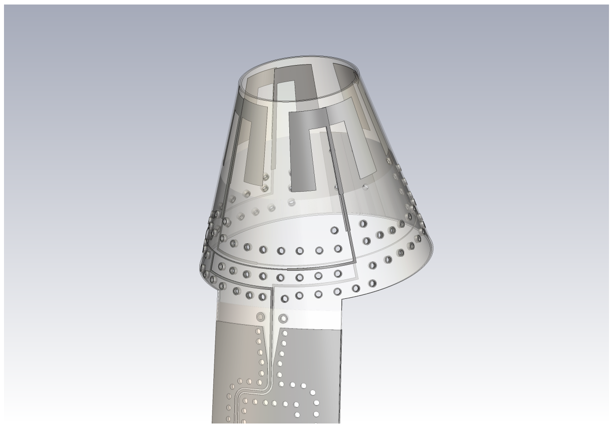


**Figure 2.** Visualization of layers when conformed on the

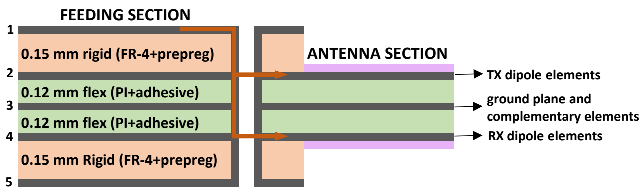
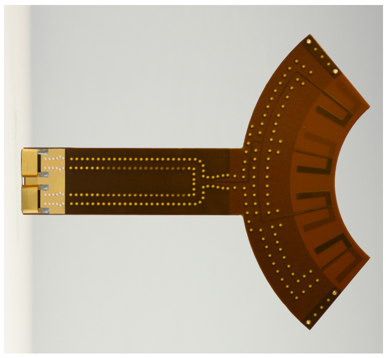



**Figure 3.** Stack-up of the PCB.



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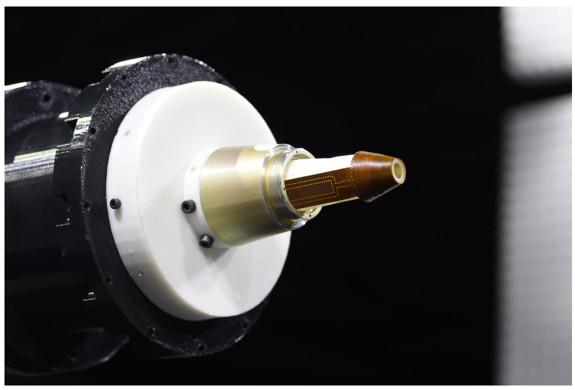

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**Figure 4.** The picture of the produced antenna pair. (a) On flat surface. (b) Conformed on the conical surface.

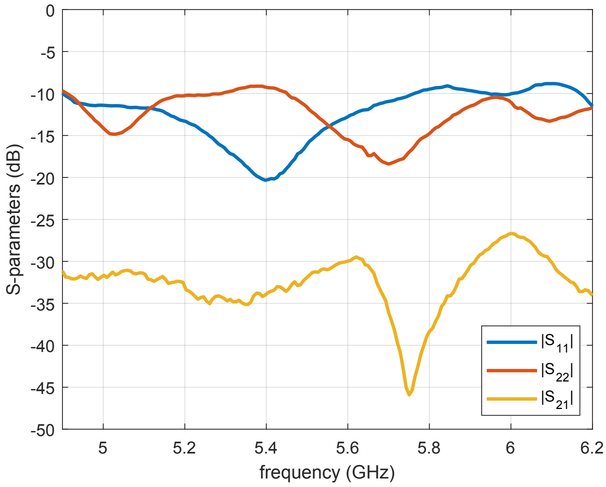



**Figure 5.** S-parameters of the antenna pair.

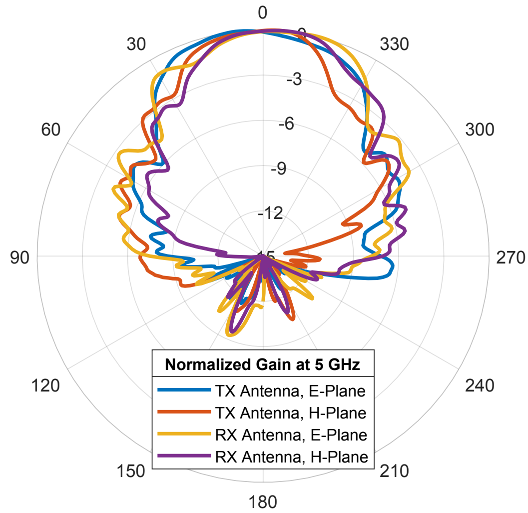
## 3 Antenna Performance

The electrical performance of the antenna is evaluated on vector network analyzer. Radiation patterns for both antennas are measured in anechoic chamber. In the following results, the first port can be considered as the input port of the transmitting antenna and the second port as the input port of the receiving antenna. As seen from Fig. 5, VSWR<2 impedance bandwidth for both antennas is about 1 GHz. In this respect, both antenna shows wideband characteristics. Besides this, mutual coupling between TX and RX antenna (i.e., $|S_{21}|$) is found below -30 dB within the bandwidth of interest.

Fig. 6 illustrates measured radiation characteristics of the antenna. In Fig. 6a and 6b, normalized radiation gains of TX and RX antenna are plotted on principle E- and H-planes. At 5 GHz, 3-dB beamwidth angles for both antennas are 72° and 65°, along E-, and H- planes respectively. However as frequency increases, the beamwidth becomes wider. At 5.4 GHz, 3-dB beamwidth angles of the TX antenna are 100° and 90°, along E-, and H- planes respectively. For the RX antenna, 105° and 100° of beamwidth angles are measured along E-, and H- planes, respectively. In Fig. 6c, the maximum realized gain measured within the band is given. Although the antenna suffers from a power loss of approximately 2.5 dB along 7 cm long feedline due to the lossy substrate, the overall performance of the antenna seems very promising, especially for radar sensor applications.

## 4 Conclusion

In this work, a compact antenna pair is designed and implemented on a 3-layer flexible PCB. Besides the two-element array configuration utilized with microstrip power divider, the ground plane, as it extends towards the back of the antenna and completely surrounds the conical surface, has made the beam directional towards the tip of the cone. The antenna could also be made more directional by adding

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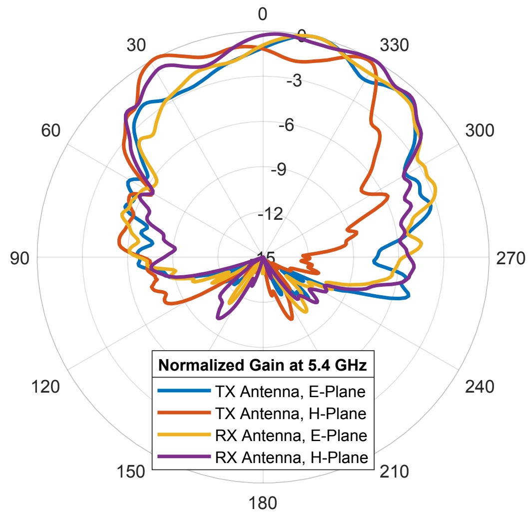


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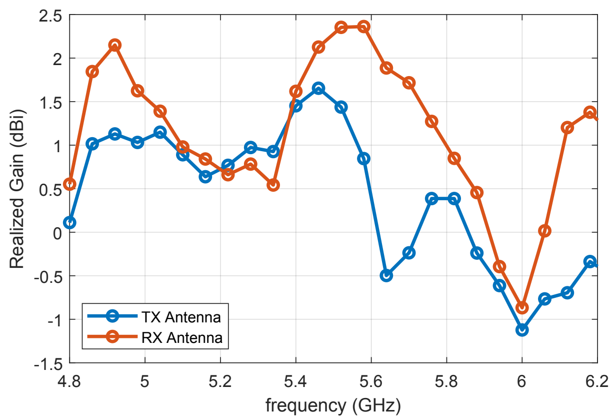


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**Figure 6.** Radiation characteristics. (a) Normalized radiation pattern at 5 GHz. (b) Normalized radiation pattern at 5.4 GHz. (c) Maximum realized gain values with respect to the frequency.

director elements as in the quasi-yagi antenna. Since we choose to keep the conical height small, proposed geometry is preferred in the final design. As dipole arms are also bent 90 degrees, diameters of the conical surface is kept as small as possible within the operation band. The proposed antenna pair could have also been applied to a cylindrical surface instead. It might pave the way for an easier design since physical dimensions on a conical surface correspond to different angular dimensions at different heights. Nevertheless, conforming the antenna onto conical surface yield a very generic design. Such antenna can be utilized at the tip of an aircraft, spacecraft and missile.

In radar applications such as radio altimeters and proximity sensors, mutual coupling between TX and RX units must be as low as possible. Otherwise, nearby targets may not be detected, or false alarms may occur due to the radiation received by the RX antenna directly from the TX antenna. To circumvent this pitfall, the detection threshold can be increased but in this case, distant targets may not be detected as well. Although antennas are in a very close vicinity of each other, the proposed antenna pair offers mutual coupling below -30 dB, which is sufficiently low for these types of applications. As a result, we have successfully implemented a flexible and small-sized antenna pair that yields directional radiation and wideband characteristics with low mutual coupling. Although the proposed antenna is intended for radar applications, it can be integrated easily into a wide variety of RF applications.

## 5 Acknowledgements

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