# Conical-Beam Circularly-Polarized Microstrip Antenna Array for Ceiling Mount Doppler Sensors

Izabela Slomian, Krzysztof Wincza, and Slawomir Gruszczynski

***Abstract*—A conical-beam circularly-polarized microstrip antenna array composed of four square-shaped radiating elements has been proposed. In the presented antenna array all of radiating elements are fed with equal-amplitude and in-phase signals and the excitation signal is guided to the center of the array through the via, to achieve both appropriate polarization properties and the conical radiation pattern. The paper includes the design details as well as simulation and measurement results of the manufactured antenna array designated for ceiling mount Doppler sensors operating at 10.5 GHz.**

***Index Terms*—Microstrip antenna array, circular polarization, conical-beam antenna.**

## I. Introduction

In recent years the progress in electronics is forcing the minimization of all of mobile devices' components as well as the reduction of their power consumption. Therefore, the microstrip technology [1]-[3] became popular in the field of antenna design, due to the low profile, low weight, easiness of design and possibility of integration with hardware. Also, microstrip technology allows customizing a variety of antenna properties. There have been reported microstrip antennas exhibiting high gain [4], wide bandwidth [5], multi-bandwidth [6], linear or circular polarization [7], series-fed [8]-[11] or parallel-fed antenna arrays [12], [13], multi-beam antennas [14]-[17], etc. One of particularly useful type of antenna is a circularly-polarized antenna with conical beam [18]-[27]. Circularly polarized antennas are commonly utilized in applications, in which the polarization of transmitter/receiver is unknown. Moreover, due to the change of polarization direction of reflected waves the multipath propagation is significantly reduced, therefore, the circularly polarized antennas are preferred in of links, in which the line of sight (LOS) is planned. When the circularly polarized antenna produces also conical beam radiation pattern it compensated the communication distance differences. Such antennas are often used in the indoor ceiling-mount microwave sensors exhibiting uniform coverage problem. In [18] a non-planar conical-beam circularly polarized antenna has been proposed. It utilized four inclined linear-antenna elements and a circular reflector. The other non-planar solution exhibiting desired far-field performance was presented in [20] and achieved with the use of spherical slot array antenna. In [22] the planar two-arm spiral antenna was shown, which utilized an aperture on the ground plane. Although such approach ensures wide bandwidth and good radiation properties it occupies significant amount of space and requires usage of an electromagnetic wave absorber. Some examples of sequentially-rotated conical-beam circularly-polarized microstrip antenna arrays were described in [21], [23] and [26], in which the circularly-polarized radiating elements were appropriately located and excited. Another circularly-polarized antenna producing conical-beam was described in [26] and was composed of four sequentially-rotated L-patches with the shorting walls.

In this paper we propose a compact double-layer circularly-polarized conical-beam microstrip antenna array. The presented antenna array is composed of four sequentially rotated circularly-polarized antenna elements fed with in-phase signals guided through the matching circuit and the via to the center of the antenna array. The applied radiating elements are circularly polarized thanks to the appropriate coupling of each of radiating elements with their bended feeding lines. The proposed antenna array features such advantages as compact size and easiness of design. The paper presents the detailed design description of the antenna array concept and the results of both electromagnetic simulations and measurements of the manufactured antenna array operating in 10.5 GHz frequency range designated for indoor Doppler sensors.

## II. Antenna Concept

In order to achieve a conical-beam circularly-polarized antenna, the array of four sequentially-rotated radiating elements has been used.

To improve the properties of generated circular polarization of the antenna array, the circularly-polarized radiating elements have to be applied. Because of the available-space limitations the radiating elements had to be placed very close to each other. By combining these demands the radiating elements which have been applied are made as a square radiating elements fed with the microstrip line directly connected to the element and guided to its corner in very low distance. The coupling between this line and the patch resulted in achieving a circular polarization. Such an radiating element is relatively easy to design and perfectly fits in square antenna array. It has to be noted that although such an approach ensures that the circular polarization is generated within relatively narrow band, the presented

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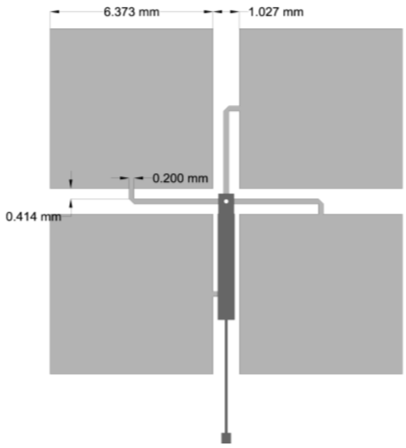
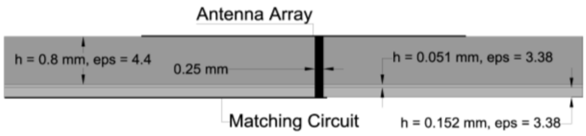
approach is suitable for application in Doppler.

To obtain a null at boresight the beams produced by particular radiating elements in the array have to cancel one another at this angle, therefore, in opposite to the broadside-beam antenna arrays, the radiating elements which are oriented in the same manner should be fed out-of-phase. However, the 180-deg phase shift might be easily performed by rotating one of two radiating elements. This solution preserves the symmetry of the array, because there is no need of introducing any additional phase shifters. Additionally, the excitation signal guided through the via to the center of the array ensures that the elements with the corporate feeding network exhibit the center symmetry, as shown in Fig. 1a, where the antenna array layout is presented. Such connection acts also as four-way power divider, therefore, this solution is most suitable for antenna elements having input impedance equal 200 Ohm, since the impedance of the input port is four times lower than the impedance at the inputs of four radiating elements.




(a)




(b)

Fig. 1. The proposed conical-beam circularly-polarized microstrip antenna array operating in 10.5 GHz frequency range. The antenna layout (a) and the cross-sectional view of the employed layer structure (b).

## III. Electromagnetic Simulations

The concept presented in the previous section has been verified with the design of 10.5 GHz microstrip antenna array utilizing two laminate layers: FR-4 laminate (*eps* = 4.4, *h* = 0.8 mm, t = 35 um) and Arlon 25N (*eps* = 3.38, *h* = 0.152 mm, *t* = 17.5 um), bonded together with a prepreg (eps = 3.38, *h*~=0.051 mm), as shown in Fig. 1(b).

The basic square-shaped radiating element is 6.373 mm long and is fed at the center of one of its edges with 0.2-mm wide microstrip line ($Z_0$ = 120 Ohm). The microstrip line feeding the patch has been further guided along the edge of the radiating element in a 0.414-mm distance to obtain the circular polarization. The simulated reflection coefficient of the radiating element matched to 120 Ohm and the radiation pattern obtained at 10.42 GHz are shown in Fig. 2 and Fig. 3, respectively, and the RHCP gain as well as the axial ratio obtained at boresight are presented in Fig. 4. It is noticed that the best axial ratio is achieved at 10.42 GHz and the RHCP gain at this frequency reaches 6 dBi. The reflection coefficient of the radiating element is rather poor, however, the close location of other elements in the antenna array have also influence on the achieved reflection coefficient, therefore, this problem would be handled at the stage of designing matching circuit for the antenna array. The beamwidth at 5 dB is wider than 130 deg and the cross-polar is better than 15 dB at 45 deg from boresight for both principal cut-planes.

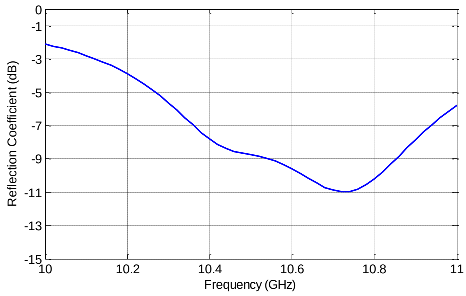



Fig. 2. Simulated reflection coefficient of the proposed radiating element matched to 120 Ohm.

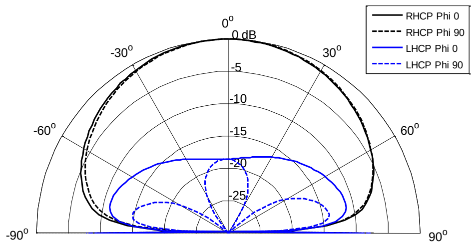



Fig. 3. Simulated radiation patterns of the proposed radiating element obtained at 10.42 GHz.

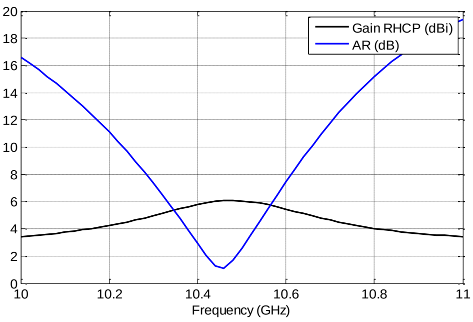



Fig. 4. Simulated gain and axial ratio of the proposed radiating element obtained at boresight.

The described radiating element has been used for the design of the antenna array. The radiating elements are placed 7.4 mm apart which relates to 0,247 of free-space wavelength at 10.42 GHz. At the center of the array, in the place where feeding microstrip lines are connected, a metallization pad has been placed having 0.6 mm diameter, to facilitate the drilling for 0.25-mm via. Such a probe-fed antenna array is matched to approximately 10 Ohm and it required the design of matching circuit. Due to necessity of stacking two laminate layers with prepreg the Arlon 25N laminate having the same dielectric constant as the utilized prepreg was used for the matching circuit. To minimize the inductance introduced by the via a thin laminate has been chosen. The matching circuit for the antenna composed of the array of four radiating elements has been composed of three sections of quarter-wave impedance transformers. All dimensions of the designed antenna array are shown in Fig. 1a. The results of the electromagnetic simulations of the antenna array are shown in Fig. 5-Fig. 7 showing the reflection coefficient of the antenna matched to 50 Ohm, radiation patterns obtained at 10.56 GHz as well as RHCP gain and axial ratio obtained at 45 deg from boresight. The best reflection coefficient has been reported at 10.48 GHz and equal -45 dB. The 10-dB bandwidth is better than 220 MHz and the 15-dB bandwidth equal approximately 170 MHz. The obtained radiation pattern exhibit very good polarization properties of the antenna showing the cross-polar better than 35 dB at 45 deg from boresight and excellent conical-beam pattern. The best axial ratio at 45 deg from boresight is achieved at 10.42 GHz and the obtained gain is better than 3 dBi in the bandwidth, in which axial ratio is better than 3 dB at RHCP.

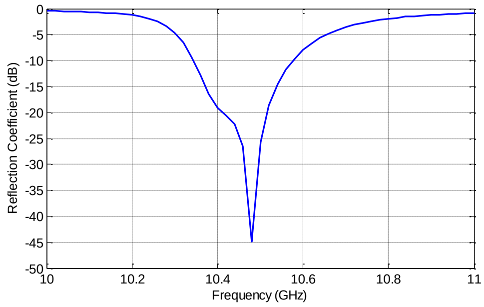
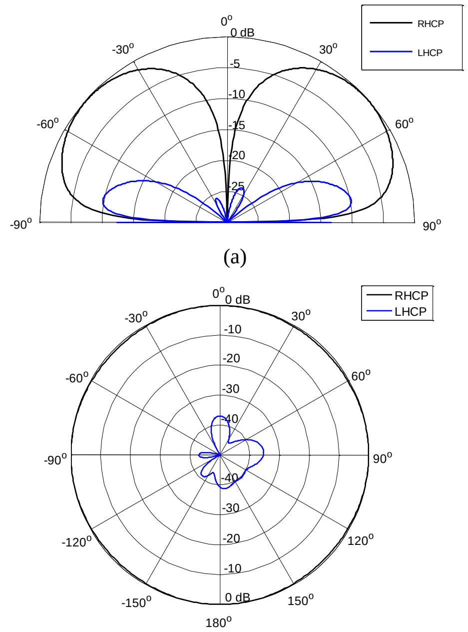



Fig. 5. Simulated reflection coefficient of the proposed antenna array matched to 50 Ohm.




(a)

(b)

Fig. 6. Simulated radiation patterns of the proposed antenna array obtained at 10.42 GHz. Radiation patterns obtained at XZ-plane (a) and radiation patterns obtained at XY-plane (b).

## IV. Measurement Results

The antenna array has been manufactured and measured. The photograph oh the antenna layers before assembling is shown in Fig. 8. The microstrip transmission line has been extended to reduce the influence of the brass connector on the acquired radiation patterns introducing, however, additional losses. The measurement results are presented in Fig. 9-Fig. 11 showing the reflection coefficient, RHCP radiation pattern as well as RHCP gain and axial ratio. The 10-dB bandwidth equal approximately 850 MHz. The radiation pattern obtained at 10.2 GHz shows null at the boresight which corresponds to the results of calculations. The measured axial ratio is the best at 10.2 GHz and the RHCP gain at this frequency equal approximately 2 dBi. The reason for the discrepancies between the simulated and measured gain might be the inaccuracy of the performed simulations which assumed infinite ground plane and 0-mm-thick metallization layers.

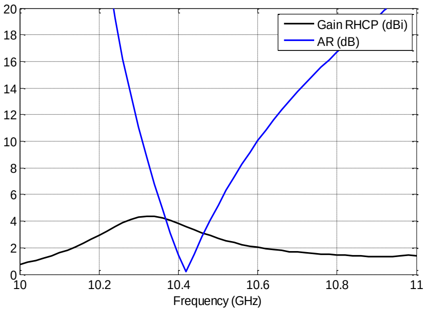



Fig. 7. Simulated gain and axial ratio of the proposed antenna array obtained at 45 deg from boresight.

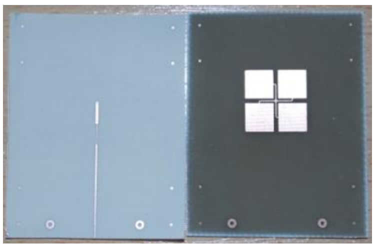


Fig. 8. Photograph of the manufactured antenna array before assembling.

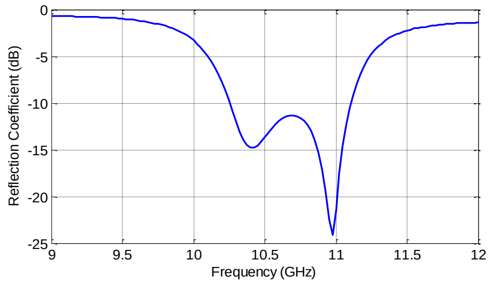



Fig. 9. Measured reflection coefficient of the proposed antenna array.

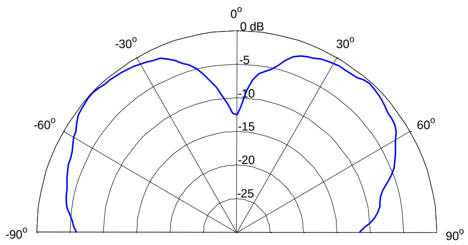


Fig. 10. Measured radiation patterns of the proposed antenna array obtained at 10.2 GHz.

## V. Conclusions

The conical-beam circularly-polarized microstrip antenna array has been developed, manufactured and measured. The desired radiation patterns featuring a null at boresight have been achieved by the in-phase connection of sequentially rotated circularly-polarized square radiating elements. The achieved circular polarization of the antenna array has been improved by applying four circularly polarized antenna elements in which the circular polarization has been generated by taking advantage of the coupling between a square patch and the feeding line. Both simulation and measurement results show potential utility of application of such antennas in modern ceiling-mounted microwave Doppler sensors.

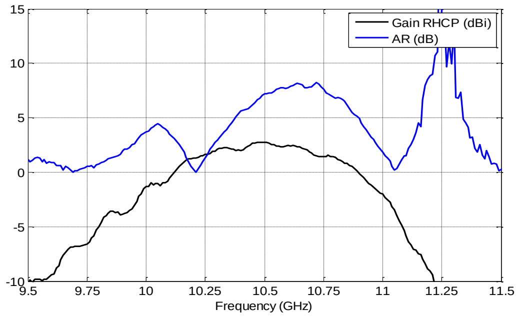



Fig. 11. Measured gain and axial ratio of the proposed antenna array obtained approximately 45 deg from boresight.

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