Radar Antenna Array Designing for Unmanned Aerial Vehicles (UAV)

Ivaylo Nachev[1] and Peter Z. Petkov[2]

Abstract – **In this paper, application of a simple phased antenna array intended to increase the range of a radar module is presented. The radar with improved range can find an application in control of unmanned vehicles – mainly drones, but also cars and robots for civil and special purposes. The first part of this paper describes design of a patch antenna with operating frequency of 10.5GHz (Amateur radio X-band). Comparison of the simulation results with measured parameters of fabricated antenna is made. The second part of the paper describes simulation results for how these models could be multiplied and incorporated into a series or corporate feed array. The delay lines technique used for beam steering, along with for beam management algorithm are presented.**

Keywords – **autonomous vehicles, drones, radar, antenna, phased antenna array, beam scanning, delay line phase shifting**

I. INTRODUCTION

In the last years, cost-effective radar systems and modules find their wide application in many end-user products. Deployment of new radar modules can be combined with patch antennas and antennas arrays. In this way, the radar range and accuracy will increase. Given the low price of patch antennas and cheap manufacturing process, these modules are suitable for large–scale production. The antenna arrays with a scanning antenna beam finds special application in radar systems because the beam can crawl the space in front of the antenna. In this way, different objects ahead of the vehicle can be detected. This can integrate for vital application in difference autonomous vehicles – cars [1], drones [2] and robots [3]. There are many published developments with various complexity and manufacturing cost. The present paper examines the application of one of the most inexpensive ones.

II. PATCH ANTENNA

The patch antenna as a radiating elements is used, as dimensions are determined by a standard design method, well explained in [4]. The employed dielectric substrate for this design is Rogers RO4003 [5]. In order to improve the bandwidth and efficiency of antennas, a design approach called “suspended substrate” is chosen, where the thickness of the air gap between ground plane and antenna is Δ=3mm. In this method, the equivalent Dielectric constant is delivered, based on the substrate permittivity and the height of the air gap. The operating frequency is chosen to be fc = 10.525GHz (a frequency preferred in the production of small size radar modules). Therefore the free space wavelength λ is 28.50mm, and guided λg = 22.6150mm – the wavelength in the substrate.

Taking into account the abovementioned design method [4], the antenna dimensions are calculated and presented in Table 1. Figures 2 are photographs of the fabricated prototypes. Figure 3 shown the construction of the suspended substrate and the air gap.

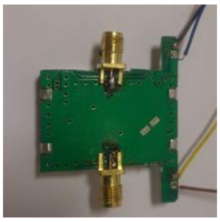

Fig. 1. The HB-100 radar module.

TABLE I
DIMENSION OF PATCH ANTENNA

	W [mm]	L [mm]	w [mm]	MS Line [mm]	Feed Line [mm]
Calculated	12.2	12.96	5.3	12.4	6.2
Adjusted after simulation	13.1	11.00	5.3	12.4	6.2

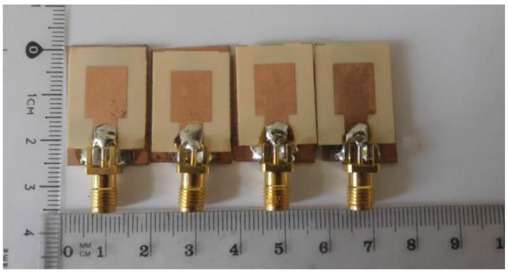

Figure 2. Fabricated patches for antenna array

Fig. 3. The realization suspended substrate

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In figures 4 is given S11 parameters of the simulated and manufactured patch antenna. The figures are quite similar, therefore regardless the handmade process imperfection, the prototyped model is quite functional. On Figure 5 the measured data of the radiation pattern of the patch for E and H plane is displayed.

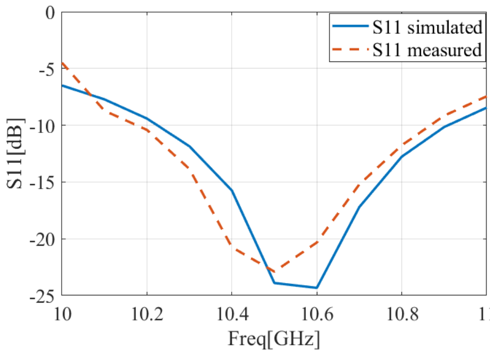

Fig. 4. S parameters of simulated and fabricated patches

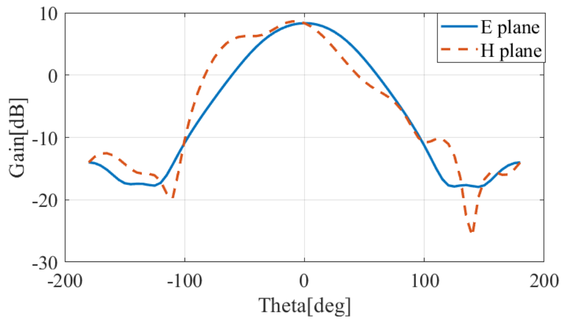

Fig. 5. Radiation pattern of patch antenna (measured)

The difference in the bandwidth between the simulated and the fabricated antennas is mainly due to imperfections of the air gap, constructed with a simple spacers.

III. The Scanning Radar Antenna

This method of designing patch antennas array can be considered as an advanced version of the series feed antenna array methods. It is important to keep distance ϵ[0.4λ ÷ 0.7λ] between the centres of radiating elements. In figure 6 is shown the simulated antenna array model. The feed networks for this kind of antenna includes microstrip lines, quarter wave transformers and hybrid T-junctions [6].

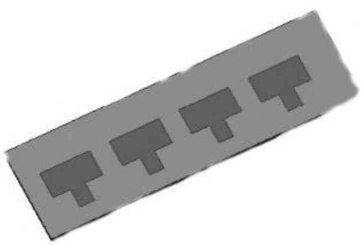

Fig. 6. Simulated model of antenna array

The feed network include implementation of Butler matrix for realization of beamforming. The Butler matrix consists N input with N output port. The design of Butler matrix constructed by combined of hybrid coupler, phase shifter and crossover [8]. The values of the typical Butler matrix is presented on table 1.

Table II
Values of Butler Matrix

Patch element	I	II	III	IV
port	I	II	III	IV
electrical length extensions	45º	90 º	135 º	190 º
electrical length extensions	135 º	0 º	225 º	90 º
electrical length extensions	190 º	135 º	90 º	45 º
electrical length extensions	90 º	225 º	0 º	135 º

Table III
Relation between beam steering and patches phases

Beam sreeting	Patch 1	Patch 2	Patch 3	Patch 4
0º	0º	0º	0º	0º
-10º	45º	90º	135º	190º
+10	190º	135º	90º	45º

Below is described the scan angles of the beamforming. The original goal is beam steering of +-10deg, therefore the abovementioned Butler matrix can satisfy this requirement.

On figure 7 is shown realization od delay line, fooled equation 1.

$$L_{delay\ line} = \theta + L \qquad (1)$$

Where θ is the increased electrical length of microstrip line and L is the length of the line without extension.

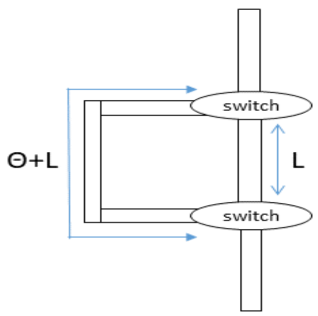

Fig. 7. Delay line realization

On figure 8 a graphical relation between radiating antenna, feed, phase shifter delay lines and hybrid T junctions is shown. Building such a system requires input power to be divided in four equal parts. Beam steering is accomplished by switching between microstrip lines with different lengths , using PIN diodes or different models RF switches, in this case we can use pin diodes switches. To do this, it is necessary to use two diodes connected in series to increase the coupling factors due to the high frequency. This leads to required beam scanning (table. 4)[9][10][11][12].

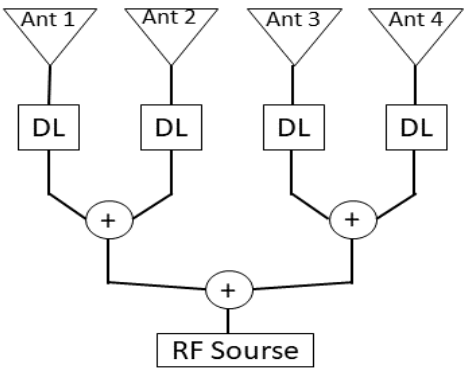

Fig. 8. The corporate feed network model

IV. Simulation results

The patches and antenna array are simulation with openEMS (open source electromagnetic simulator). In figure 9 is displayed the return loss of the array elements and S11 on the input of antenna system. Figure 10, shows azimuth and elevation radiation pattern on normal mode. Figure 11 shown the beam in different scanning cases including a alternative solution for implementing scanning beamforming using 3 and 4 row of Butler matrix. Table 4 presented a comparison of gains in beam`s different state.

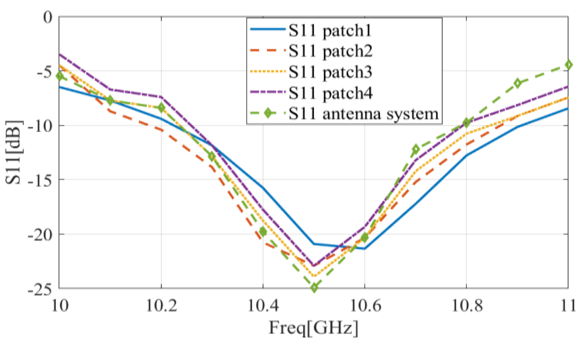

Fig. 9. S11 parameters

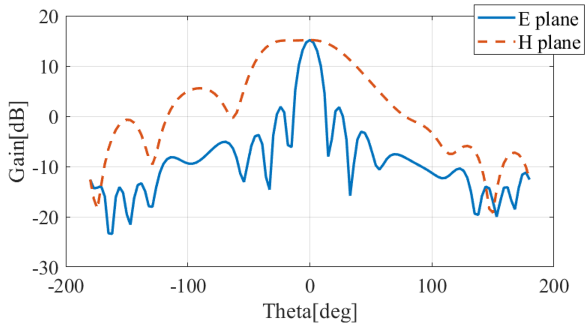

Fig. 10. Radiation Pattern 0 deg work mode

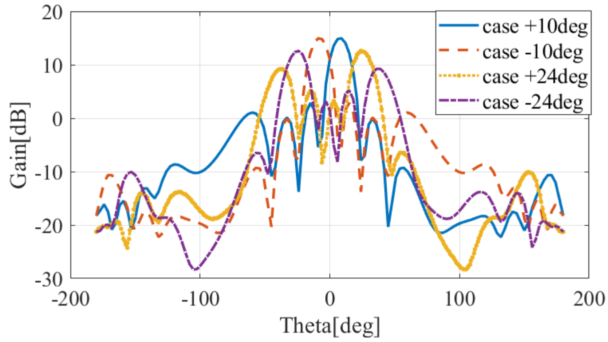

Fig. 11. Radiation Pattern in scanning modes on H plane (Azimuth)

Table IV
Comparison of gains on beam different state

	Gain [dB]
Patch array 0°	15.3
Patch array -10°	14.95
Patch array + 10°	14.89
Patch array -24°	12.85
Patch array + 24°	12.55

From figure 10 and table 4 we see the level of extra beam in case 2 is to high. Which would lead to incorrect information in scanning mode. The advantage of using the 3 and 4 row of Butler matrix is a biggest scanning angles than using 1 and 2 row of the same matrix. The disadvantage in this case are advent of extra beams with high gain, renders the method inapplicable to radar applications in the present case. It is possible to rely on this method only when quickly enabling states, and software to monitoring used status. With a more complex feed network and used advanced scanning software, it is possible to make a radar antenna with all four states presented on figure 11. However, antennas with similar broadcasting diagrams may find application in MIMO[14] and 5G[15] systems where multi beams propagation is a desirable effect.

V. Sample algorithm for beam forming control code and control of Autonomous Vehicles

As addition to the beam steering antenna array, authors propose a simple algorithm for programmable controllers to perform scanning for targets. Fig.12 shown algorithm block diagram of the code for beam forming control. The algorithm is fundamental in the movement of Autonomous Vehicles when moving along preset coordinates without human intervention. The main thing in the proposed algorithm is that the scanning beam detects an object in front of it. When detecting an object in front of one of the states of the radiation diagram, the moving structure moves in the opposite direction in order to avoid a collision.

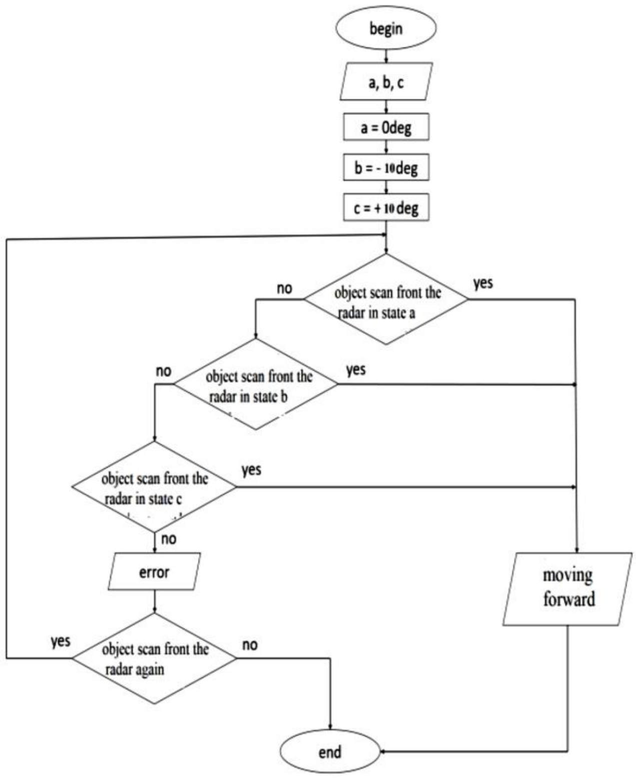

Fig. 12. Algorithm block diagram ofthe code for radar scanning process.

VI. Conclusion

Simulated, designed and analyzed patch antenna integrated into an electronic scanning antenna array presented in this article. The used methodology can be used for design of a patch antenna arrays for different radar applications. Designed antennas are suitable for modifying and increase scopes of some existing radar modules operating at that frequency. An example of such a radar is a HB100 radar module[13]. Advantage of design antenna in this paper under the stock radar antenna is a beam scanning. The radar antenna array disadvantage are the high cost, complicated feed network and limited beam tilt. Modified radars with antenna array can be implemented in different autonomous vehicles like a small robots, drones and various radar systems for civil and specialized application.

Acknowledgement

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References

[1] Chatterjee, Sreejit. "A 77 GHz BCB Based High Performance Antenna Array for Autonomous Vehicle Radars." (2018).
[2] Tonetti, Stefania, et al. "Distributed control of antenna array with formation of UAVs." IFAC Proceedings Volumes 44.1 (2011): 7848-7853.
[3] Kanayama, Yutaka, et al. "A stable tracking control method for an autonomous mobile robot." Proceedings., IEEE International Conference on Robotics and Automation. IEEE, 1990.
[4] Balanis A. Constantine, Antenna Theory: Analysis and Design, 3rd Edition, ISBN-13: 978-0471667827
[5] Rogers RO4003 specification: https://www.mirrorsemi.com/pdf/Rogers_RO4003C_Data_Sheet.pdf
[6] J R James & P S Hall, "Handbook of microstrip antennas ", 1993, ISBN:0 86341 150 9
[7] M. Gachev, Microstrip Schemes, ISBN 978-954-580-298-0.
[8] Chang, Chia-Chan, Ruey-Hsuan Lee, and Ting-Yen Shih. "Design of a beam switching/steering butler matrix for phased array system." IEEE Transactions on Antennas and Propagation 58.2 (2009): 367-374.
[9] Iliev Ilia, Kolev Stanio and Manev Stoicho Reduction of the frequency offset influence in OFDM using an optimal PRS coding and MLSD Internat Journal of Research in Computer and Communication Technology, vol. 3, issues 1
[10] Carrasco, Eduardo, Mariano Barba, and José A. Encinar. "X-band reflectarray antenna with switching-beam using PIN diodes and gathered elements." IEEE Transactions on Antennas and Propagation 60.12 (2012): 5700-5708.
[11] Akhtar A., Mateen Alahi H., Sehnan M., ""Simulation of Phased Arrays with Rectangular Microstrip Patches on Photonic Crystal Substrates", 2012.10.12
[12] J. Ehmouda, Z. Briqech, and A. Amer, "Steered Microstrip Phased Array Antennas", World Academy of Science, Engineering and Technology, issue: 49, 2009, p. 321 - p. 323
[13] Akhtar A., Mateen Alahi H., Sehnan M., ""Simulation of Phased
[14] HB 100 radar module datasheet https://www.limpkin.fr/public/HB100/HB100_Microwave_Sensor_Module_Datasheet.pdf
[15] Iliev, Ilia Georgiev, and Mende Budzevski. "Concatenated "MMSE-Sequential Search" Algorithm for Multi User Detection in SDMA Uplink." ICEST 2011 3 (2011): 591-594.
[16] Sharawi, Mohammad S., Muhammad Ikram, and Atif Shamim. "A two concentric slot loop based connected array MIMO antenna system for 4G/5G terminals." IEEE Transactions on antennas and propagation 65.12 (2017): 6679-6686.