Design of microstrip phased array for autonomous flying vehicles

Peter Z. Petkov[1], Rosen Vitanov[2] and Ivaylo Nachev[3]

Abstract – **In this paper considers patches designed for a doppler radar allowing him enchanced coverage and beam-steering capabilities is presented. Design of antennas is based the idea of integrating them in HB100 module, provides small physical package, low price and high reliability, makes it possible for a autonomous flying vehicle to autodetect obstacles in flight without need of changing position or orientation.**

Keywords – **radar, antenna, patch antenna, patch array, phased array, transmission line phase shifter, quadcopter, autonomous flying vehicle**

I. Introduction

We are witnessing a technological boom, where more and more automatic devices do complex operations and services in areas, recently possible only for humans. Autonomous flights by unmanned air vehicles (UAV) is one of those. The great challenge is to detect and overcome and obstacle in midflight, without being interrupted. For this purpose – a microwave radar is used with enhanced range and integrated beam-steering functionality is implemented. In this way UAV may test the upcoming trace for any obstacles and avoid collisions during a flight.

Most antennas have a fixed radiation pattern, which is a inconvenience, when used in drones, because it should stop in one place and test the area by turning around using its propellers. A practical solution to this problem is usage of array antenna with scan.

In this case most appropriate is to use a series patch array. It may sweep the direction of the beam by varying electronically the phase of the radiating element, thereby producing a moving pattern with no moving parts.

II. Corporate Feed Network Patch Array Design

An important step when designing patch antenna is to take into account dielectric substance on which patches are made. The employed substrate for the proposed design is Rogers RO 4003 with thickness h=0.508mm and Dissipation factor $\tan\delta = 0.0027$**.** In order to improve the bandwidth and efficiency of antennas, a design method called “suspended substrate” is chosen, where the thickness of the gap between ground plane and antenna is Δ=1mm. In this method we use the equivalent Dielectric constant (7). Distribution of the elements of the simulated model, as with radars frequency f_c = 10.525GHz we have wavelength λ = 28.50mm, and λ_g = 22.6150mm. For calculation of antenna dimensions a straightforward basic algorithm is proposed:

Step 1: Calculation of width (W): Width of the Micro strip antenna is given by the equation:

$$W = \frac{c}{2fc}\left(\frac{\varepsilon_r + 1}{2}\right)^{-\frac{1}{2}} = 12.2208mm, \frac{W}{h} > 1 \qquad (1)$$

Where c is the speed of the light c=3*10^8, ε_r is a dielectric constant of substrate, f_c is radar frequency and h is substrate thickness.

Step 2: Calculation of Effective Length (L): Length of the microstrip radiator is given by:

$$L = \frac{c}{2fc\sqrt{\varepsilon_r}} = 11.3mm \qquad (2)$$

Where f_c is radar frequency and ε_{eff} is effectively dielectric constant of substrate

Step 3. Calculation of the Length extension (L_{ext}): The actual length is obtained by the equation (accounting for the fringing fields):

$$L_{ext} = 0.412h\frac{(\varepsilon_{eff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{eff} - 0.258)(\frac{W}{h} + 8)} = 0.8825mm \qquad (3)$$

Step 4: Calculation of the actual length of the Patch (L_{eff}): The actual length of the patch is given by:

$$L_{eff} = L + 2L_{\exp} = 12.9650mm \qquad (4)$$

Determination of effective dielectric permittivity ε_{eff}:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 10\frac{h}{W}\right)^{0.5} = 1.5886 \qquad (5)$$

The length of the guided wave:

[1] Peter Z. Petkov is Associate Professor with the Faculty of Telecommunications at Technical University of Sofia, 8 Kl. Ohridski Blvd, Sofia 1000, Bulgaria, E-mail: pjpetkov@tu-sofia.bg.

[2] Rosen Vitanov is PhD student with the Faculty of Telecommunications at Technical University of Sofia, 8 Kl. Ohridski Blvd, Sofia 1000, Bulgaria, E-mail: rosenvitanov@gmail.com

[3] Ivaylo Nachev is a student at Faculty of Telecommunications at Technical University of Sofia, 8 Kl. Ohridski Blvd, Sofia 1000, Bulgaria, E-mail: ivaylonachev@yahoo.com

$$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{eff}}} = \frac{c}{fc\sqrt{\varepsilon_{eff}}} = 22.6150mm \qquad (6)$$

Influence of the gap is taken into account:

$$\varepsilon_{r\,eq} = \frac{\varepsilon_r * (h + \Delta)}{\varepsilon_r + h * \Delta} = 1.72 \qquad (7)$$

Where ε_r is a dielectric constant of substrate and Δ is thickness of the gap. The new dielectric constant in technology with suspended substrate is marked with $\varepsilon_r eq$, where the characteristics of the air are also taken into account.

Connection between radiating antenna and phase delay line control system is achieved using SMA connectors with imedance Z_0=50Ω which is low enough to not interfere with antenna`s parameters.

In table 1 are presented the values obtained for dimensions of the antenna components. Fig.1 shows simulation model of corporate feed network patch array. [1] [2][3]

TABLE 1
VALUES OBTAINED FOR DIMENSIONS OF THE ANTENNA COMPONENTS

	W [mm]	L_{eff} [mm]
Calculated	12.2	12.96
After simulation	13.8	11

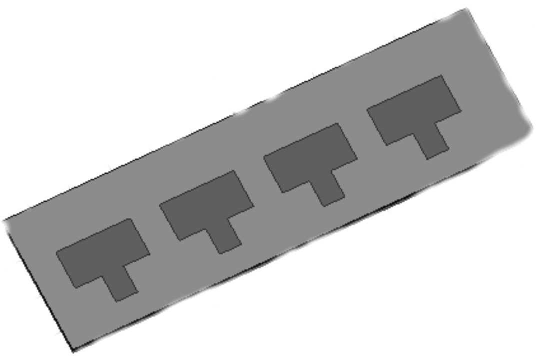

Fig. 1 corporate feed patch array – simulation model

III. TRANSMISSION LINE PHASE SHIFTER

Described phased antenna array uses a hybrid T junction system that divides the input power in 4 equal parts. In this paper is described how - by changing electric length of microstrip lines (ML), changes the phases of fed signals, thus steering the beam (fig.2). It is required to change the position of the beam in 3 different degrees: -15; 0; +15 deg. page.

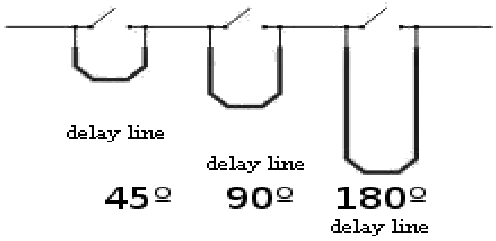

Fig. 2. Switched line phase shifter

In the switched-line phase shifter, phase shifting is obtained by varying the length of the antenna feed line. The phase delay in the feed line is calculated from:

$$L_{effective\ length} = \frac{\beta c}{2\pi f\sqrt{\varepsilon_{eff}}} \approx 2.877mm \qquad (8)$$

$L_{effective\ length}$ - Change in length;
β - Propagation constant;
c - Speed of light;
ε_{eff} - Effective dielectric constant;
f - Operating frequency;

Formula (8), leads to conclusion that phase differences between each patch should be 2.877mm, and using electromagnetic simulator equals 45 deg. That's confirm from simulations in the design process Simulation showed best results with each phase line doubled the length on the previous. This is shown in table 2. [4][5]

TABLE 2
RELETION BETWEEN BRAM STEERING AND PATCH PHASES

Bean steering	Patch1	Patch2	Patch3	Patch4
0^{O}	0^{O}	0^{O}	0^{O}	0^{O}
$+15^{O}$	0^{O}	45^{O}	90^{O}	180^{O}
-15^{O}	180^{O}	90^{O}	45^{O}	0^{O}

IV. PHASE DELAY LINE CONTROL SYSTEM

On figure 3 a graphical relation between radiating antenna, feed, pahse delay lines and hybrid T junctions is shown. Building such a system requires input power to be divided in 4 eaqual parts, described below. Initially, the signal „P" enters at the input point (1). Then, using a 50 Ohm microwave line (2) is passed to the first T junction (3), designed to divide the energy into two equal parts „P / 2". This is accomplished by two 100 Ohm MLs(4). Then the impedance is again converted to 50 Ohm (6) by step – work like impedance transformer (5). The energy separation is repeated again by a second group of f T junctions (7) to 100 Ohm microwave liness (8), the final result is „P / 4". Using ML (9), the impedance is again lowered to 50 Ohms and „P / 4" passes through delay line (10) to the radiating element. Beam steering is accomplished by switching betwen microstrip lines with different lengths , using PIN diodes. This leads to required beam scanning (tabl. 2).

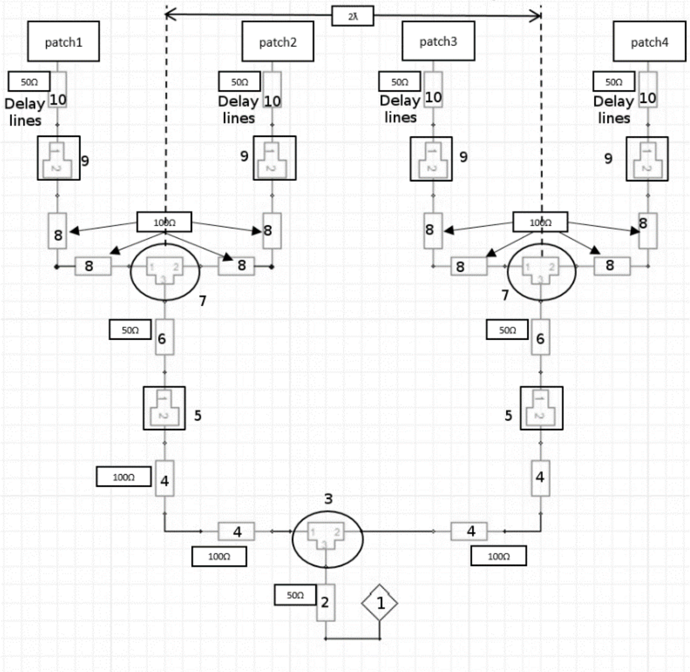

Fig. 3. Block diagram of radiating antenna

V. SIMULATIONS RESULT

Shown are results from simulations. In fig. 4 is displayed the return loss of the antenna. Figure 5, shows elevation radiation pattern. Figs. 6a, 6b,6c show represent the beam in azimuth, steered a the three available angles – 0 deg, -15 degs and +15 degs. In table 3, a comparison of gains in beam`s different state.

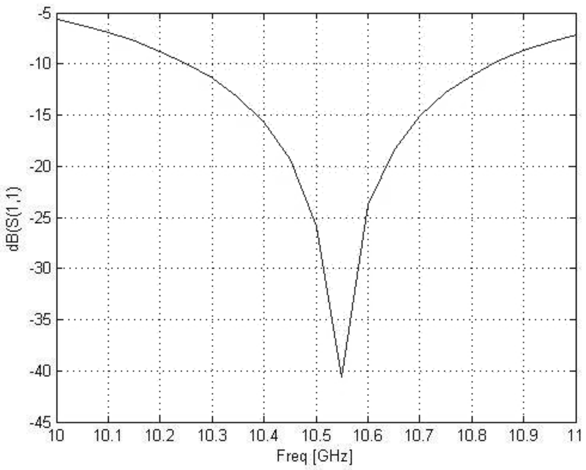

Fig. 4. Antenna bandwidth (S11)

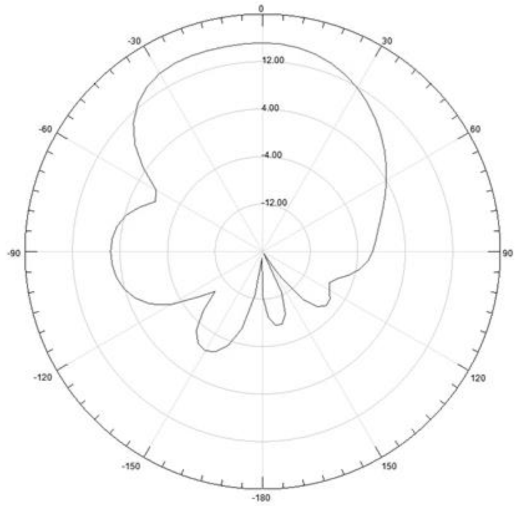

Fig. 5. Radiation Pattern elevation

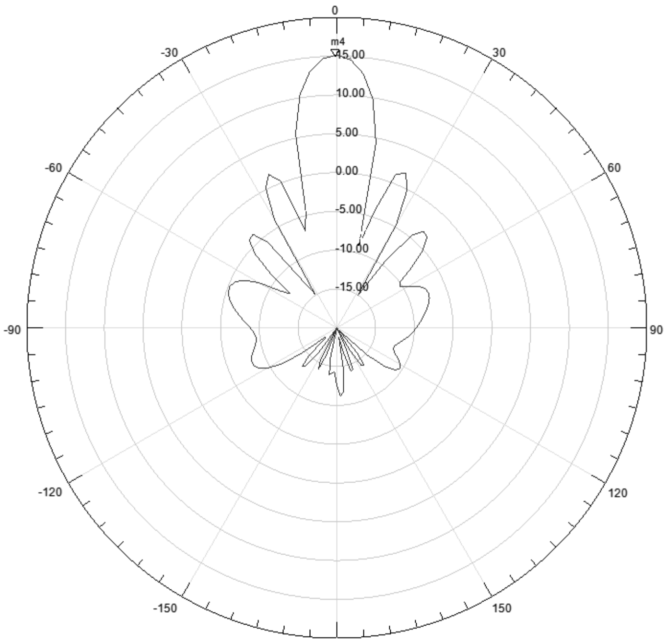

Fig. 6a. Radiation Pattern azimuth 0deg.

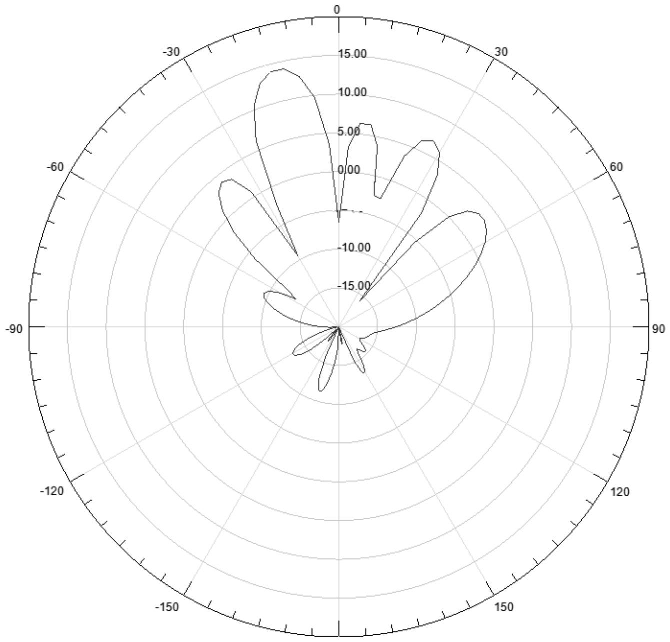

Fig. 6b. Radiation Pattern azimuth -15deg.

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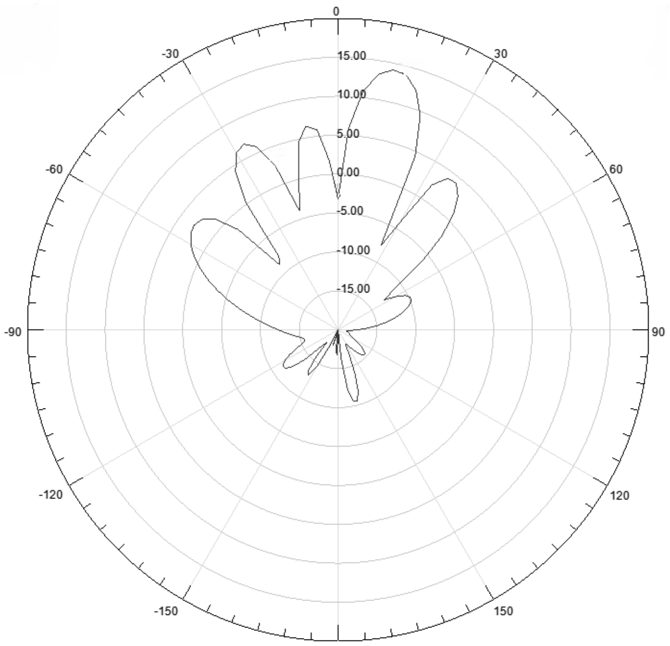

Fig. 6c. Radiation Pattern azimuth +15deg.

TABLE 3
COMPARISION OF GAINS IN BEAMS DIFFERENT STATE

	Gain[dB]
Patch array 0deg.	15.1
Patch array -15deg	14.7
Patch array +15deg	14.67

VI. Conclusion

Using microwave delay line phase shift in systems such as considered allows an electronic scan of the antenna beam. Integrated antennas in the HB100 module can be used for automatic and non-intrusive obstacle detection system for quadcopters and other unmanned vehicles.

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