Radiation Pattern of the Spherical Antenna Array Based on Archimedean Spiral

Vanja Mandrić Radivojević
Faculty of Electrical Engineering, Computer Science and Information Technology Osijek
Department of Communication
Osijek, Republic of Croatia
vanja.mandric@ferit.hr

Slavko Rupčić
Faculty of Electrical Engineering, Computer Science and Information Technology Osijek
Department of Communication
Osijek, Republic of Croatia
slavko.rupcic@ferit.hr

Nataša Nešić
College of Applied Technical Sciences Niš
Niš, Republic of Serbia
natasa.bogdanovic@vtsnis.edu.rs

Goran Benšić
Mechanical Engineering School Osijek
Osijek, Republic of Croatia
ured@ss-strojarska-tehnicka-os.skole.hr

***Abstract* — This paper describes radiation pattern measurements of the antenna array based on Archimedean spiral on a spherical surface. The analysis encompasses measurements of this antenna array with 8, 16 and 24 patch antenna elements. In addition, the calculation of radiation diagrams was made in two orthogonal planes. Calculation was made using a developed moment method program with spectral-domain approach. The measured results are compared with the calculated and show excellent matching.**

Keywords* — *spherical antenna array, radiation pattern, Archimedean spiral, loxodromic antenna array

I. INTRODUCTION

This paper deals with a low profile circular microstrip elements working in microwave range mounted on a spherical grounded surface by loxodromic distribution rule. This type of conformal antenna has good characteristics related to the radiation pattern, therefore, it was decided to construct a laboratory model of such an antenna and confirm good theoretical results achieved in [1] to [4].

Calculated radiation pattern of such an array is a result of method of moment and the spectral – domain approach [5], [6].

The second chapter deals with the main settings of forming a spiral antenna array on the spherical surface. The third chapter covers the geometric details of the antenna model's laboratory model.

Measurement and calculation results are given in chapter 4 and show great match.

The last chapter covers all the relevant conclusions of this paper as well as the possibility of continuing the research of these antennas in the future.

II. SPIRAL ANTENNA ARRANGEMENT ON THE SPHERICAL SURFACE – THEORY

It is known that variants of spiral antenna array on the conductive surface can achieve the desired radiation pattern with possibility of controlling the main lobe width and side lobe level - depending on the array application.

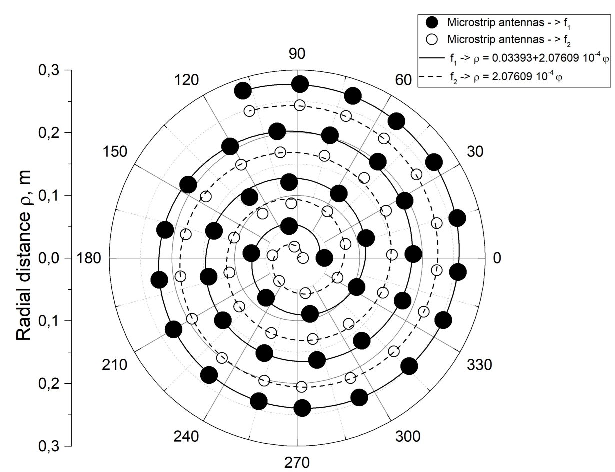


Fig. 1. Precise locations of elements based on two functions of Archimedean spiral.

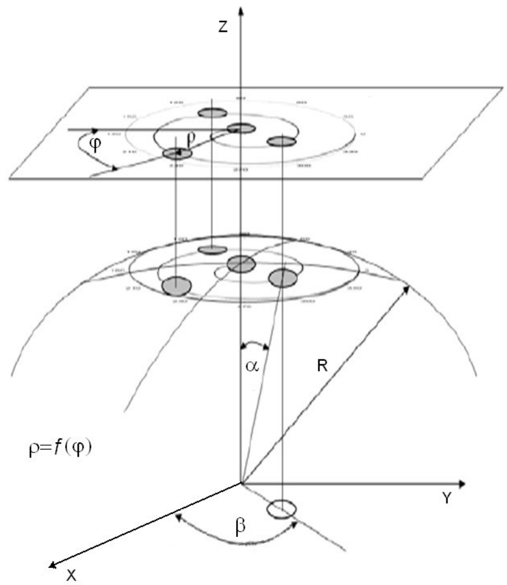


Fig. 2. The loxodromic distribution of microstrip patch antenna array [1].

Generally, the spiral configuration of antenna array (Figure 1) is chosen whenthere is a large number of antenna elements, *N*. Such a number of elements gives us the ability to excite a certain group of elementary antennas around the radius of the maximum radiation and thereby direct the information (energy) in a given direction or receive information from one of the desired directions. The number and layout of excited elementary antennas determines the shape of the radiation pattern. Each of the excited elements has the same amplitude and frequency range but a different phase shift (PHASED) for positive discrimination of the desired direction of radiation.

The power divider is used for simultaneous power distribution between 16 feed branches, where equal amplitude and out of phase signals are required. The phase shifters (based on PS 196-315 chip) controls the phase of the signals at each radiating element to form a beam at the desired direction.

The main goals of this paper are to make a spiral antenna array based on the Archimedean spiral, to measure radiation patterns of different subarrays and to verify the resulting diagrams obtained by calculations.

Fig. 2. plots the mapping of the Archimedean spiral on the spherical surface giving the positions of the elements on the sphere.

III. SPIRAL ANTENNA ARRANGEMENT ON THE SPHERICAL SURFACE – LABORATORY MODEL

Laboratory model was created according to the rules described in the previous chapter. As it can be seen in Figure 3, 40 elements were mounted on the spherical grounded surface.

Fig. 3. Laboratory model of the spiral antenna array.

The surface was made as a semi-spherical aluminum surface 30 cm in diameter. Elements are circular microstrip antennas and were separated from the spherical surface by silicon material ($\varepsilon_r \approx 2.5$).

Minimal distance of $\lambda/2$ between two elements was respected. Resonant frequency of each element was 1.622 GHz (Figure 4). These parameters are comprised in Table I.

Normalized radiation patterns were also calculated at the frequency f = 1.622 GHz for *E* and *H* plane. Model design parameters are given in Table I and Table II. It is important to note that subarrays of 8, 16 and 24 elements were activated during measurement (certain subarrays are shown in Figure 6).

The design of the spiral antenna array is extremely demanding from the uniform performance, the precise position of the element and the position of the excitation aspects. In addition, a special problem is the excitement of elements.

TABLE I. ANTENNA ARRAY PARAMETERS

Spiral antenna array				
Sphere radius, cm	Sphere material	Substrate material	Microstrip antenna radius, cm	Microstrip antenna material
30	Aluminum	Silicon	2.65	Copper
Number of elements in array	Element distance	Working frequency, GHz	Array Average S_{11}, dB	Type of spiral curve
40	$\lambda/2$	1.622	-30.00	Archim.

Thus, this paper deals with antenna array arranged by Archimedean spiral rule (Figure 1. and expression (1)) (Archimedean spiral is the locus of points corresponding to the locations over time of a point moving away from a fixed point with a constant speed along a line which rotates with constant angular velocity [1]).

Formally, spiral is given by the following formula:

$$\rho = a \cdot \varphi^{n}, \text{ m} \tag{1}$$

where a stands for positive real number ($a > 0$). Special case for $n = 1$ gives us an Archimedean spiral [7].

The laboratory model of the loxodromic antenna array is based on Archimedean spiral (1), and its equation is:

$$\rho = 0.03393 + 2.07609 \text{ E-4 } \cdot \varphi, \text{ m} \tag{2}$$

It is obvious that this relation describes a linear link of the spiral angle φ and radial distance ρ. However, the equation differs from the Archimedean spiral for a radial displacement of 0.03393 meters. This tells us that each radial distance was shifted to the Archimedean spiral ratio by that amount. Further, no element is set in position (0.0) (North pole).

Angle alpha is the elevation angle position, while angle beta is the azimuthal angle of the position of the element on the spherical surface and is equal to Archimedean angle φ. These angles are determined by mapping the position of the Archimedean spiral from the plane to the spherical surface as shown in Figure 2:

$$\alpha = (180/\pi) \cdot \rho \cdot R, \ deg \tag{3}$$

$$\beta = \varphi, deg \tag{4}$$

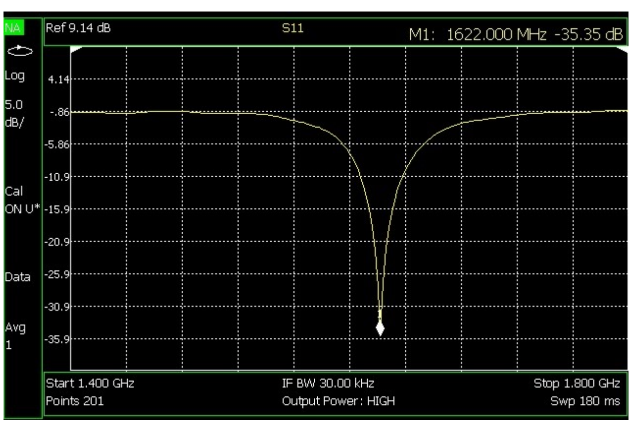


Fig. 4. Elementary antenna measured (typical) S_{11} diagram of the spiral antenna array (position 24): *fc=1.622 GHz; S_{11}= -35.35 dB; BW=34 MHz*

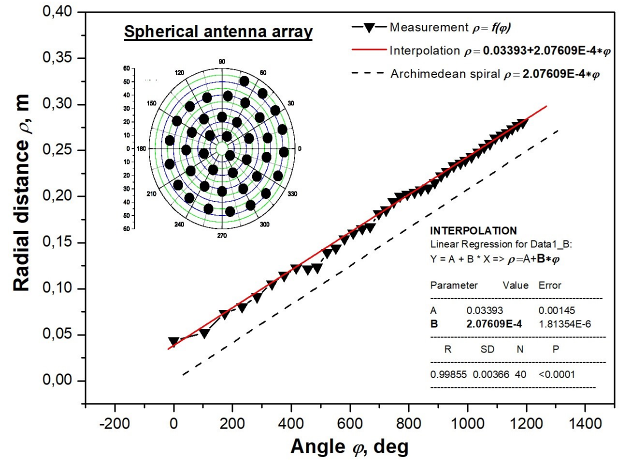


Fig. 5. Verification of elemental antennas positions of the loxodromic antenna array based on Archimedean spiral

where R is the diameter of the spherical surface.

Figure 5 shows the orderly matching of the curves showing the antenna array arrangement in the sphere with the theoretical Archimedean spiral, where φ is the azimuthal angle and ρ is radial distance of the element position.

The interpolation line shows deviations of the antenna's individual positions relative to the Archimedean spiral with a shift.

The excitation points of each element (supplied by a coaxial cable) are positioned on parallel lines of the spherical surface. This ensures that all elements are equally polarized in relation to each other.

In order to reduce measurement errors due to geometric inaccuracies, the position deviations of the laboratory model were introduced into the computer routine.

The basic elements are made as circular microstrip antennas on the silicon substrate.

The reflection coefficients, the resonant frequency, and the operating range of all of these elements are approximately equal and shown in Figure 4. However, the peak value of the S_{11} parameter varies from -26.3 dB to -35.5 dB (average values -30 dB).

IV. RADIATION PATTERN MEASUREMENTS AND VERIFICATION OF THEORETICAL RESULTS

This paper presents three different antenna subarrays with: 8, 16 and 24 elements. For each combination, a simulation of the radiation pattern was calculated and compared with measured results. Potential discrepancies in the calculated and measured

TABLE II. ELEMENT POSITIONS ON THE SPHERICAL SURFACE

Number of antennas	Alphas, degrees	Betas, degrees
1	8.3	0
2	10	104
3	14	174
4	15.4	232
5	17.5	283
6	20.1	334
7	21.9	376
8	23.4	417
9	23.2	456
10	23.6	488
11	26.6	522
12	27.6	552
13	29.5	580
14	30.7	611
15	31.6	641
16	32	668
17	34.7	698
18	35.4	722
19	37.1	748
20	38.3	770
21	38.7	795
22	39.1	819
23	39.6	841
24	40	866
25	41.2	888
26	42.5	909
27	43.4	930
28	44.6	953
29	45.2	975
30	45.7	992
31	46.5	1014
32	47.5	1036
33	48.4	1057
34	49.2	1075
35	50.3	1094
36	50.9	1115
37	51.5	1134
38	52.2	1151
39	53	1169
40	53.6	1188

results of the radiation pattern, appear due to non-ideal measurement conditions. Measurement chamber was a chamber with electromagnetic echo. Table III shows values of relevant parameters of the radiation pattern – main lobe width (beam width - BW_{-3dB}) where the electric field strength decreases by 3 dB and values of theoretical/measured differences.

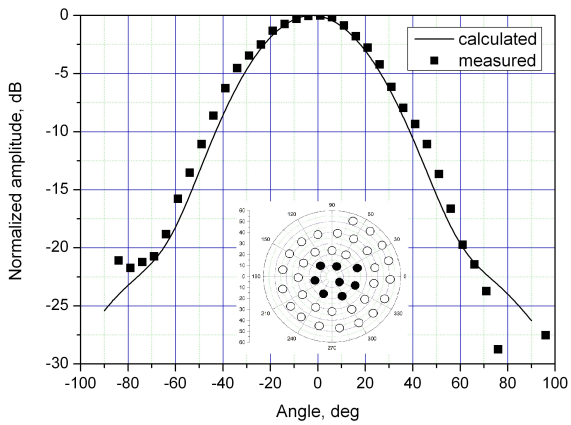
TABLE III. ANTENNA POSITIONS ON THE SPHERICAL SURFACE

a)

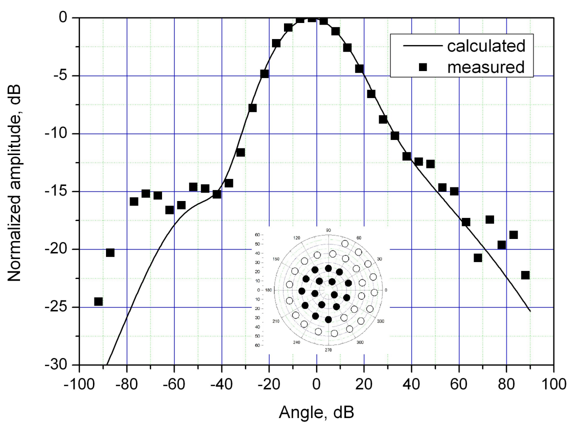
Number of antennas	Theoretical values BW_{-3dB} , deg	Measured values BW_{-3dB} , deg	Differences (%)
***E*-plane** 8 elements in subarray	44.41	47.55	+7.07
***H*-plane** 8 elements in subarray	39.50	40.16	+1.67
***E*-plane** 16 elements in subarray	33.13	32.81	-0.97
***H*-plane** 16 elements in subarray	34.51	33.39	-3.25
***E*-plane** 16 elements in subarray PHASED	31.21	33.07	+5.96
***H*-plane** 16 elements in subarray PHASED	33.92	31.29	-7.75
***E*-plane** 24 elements in subarray	31.53	31.89	+1.14
***H*-plane** 24 elements in subarray	29.43	27.49	-6.59

Values are given for theoretical (calculated) and measured (numerical) radiation pattern results for 8, 16 and 24 elements in a certain subarray, and for *E* and *H* planes respectively. It is important to note that the measurements were made for non-phase controlled antenna arrays. The only phase-controlled result is derived for an array of 16 elements and is labeled as PHASED! Increasing the number of subarray elements reduces the width of the main beam (Table III) as well as the side lobe level (SLL) of the radiation pattern diagram (Figures 6 to 8).

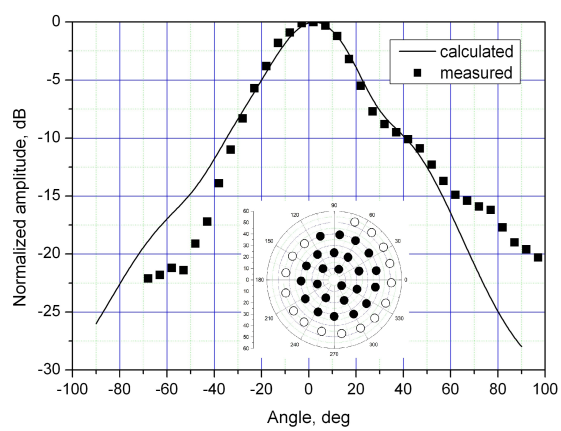
The phased controlled antenna array of 16 antenna elements has a lower (about 2 dB) or equal width of the main lattice and SLL which is 3 to 4 dB lower than the SLL without phase control. The measurements performed in the chamber with EM echo give excellent results in the area of the main beam where the signal level is high. But, outside the main beam, where the signal level is significantly lower and the reflected waves have significantly greater influence on the overall radiation diagram, the deviations are significant. Deviation of the beam width (BW_{-3dB}) of all the measured radiation patterns does not exceed 7.75%.



a)



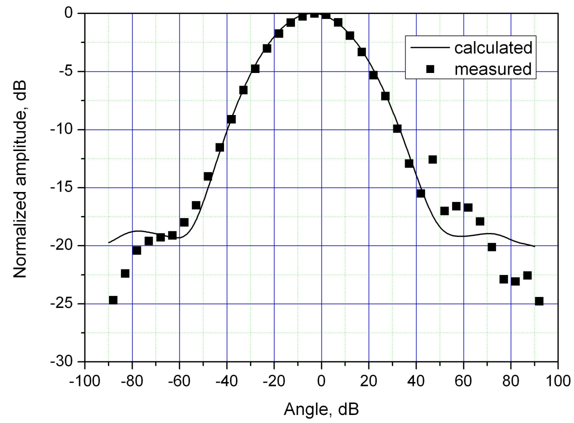
b)



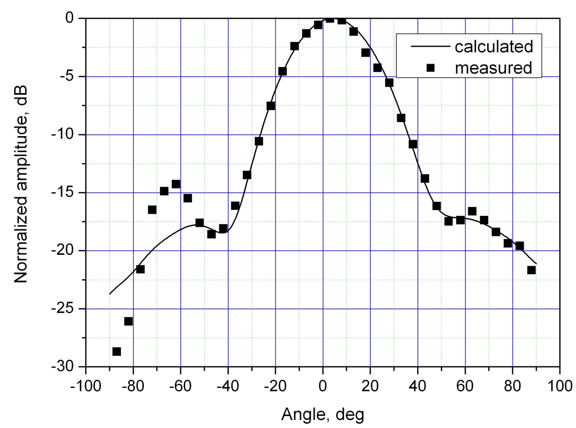
c)

Fig. 6. Radiation pattern of the spherical antenna arrays based on Archimedean spiral in *E*- plane for subarray consisting of: a) 8 antennas; b) 16 antennas and c) 24 antenans.

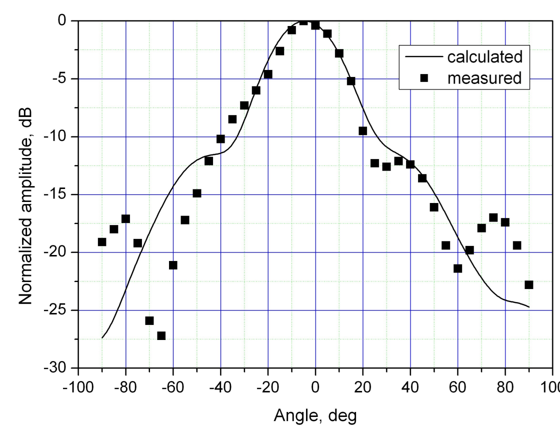
Since the antenna array does not have an element in the position of the north pole, it is shown in Figures 6 and 7 that the peak value of the radiation diagrams is not at 0 degree position.



a)



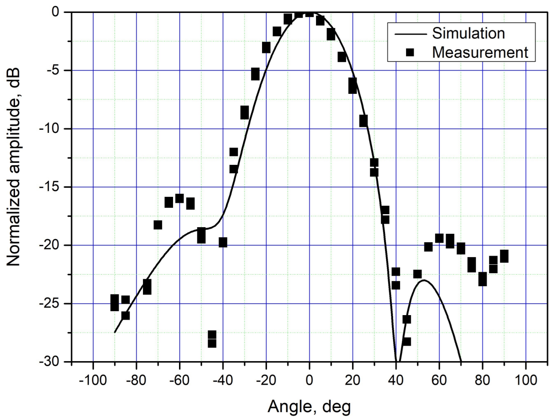
b)



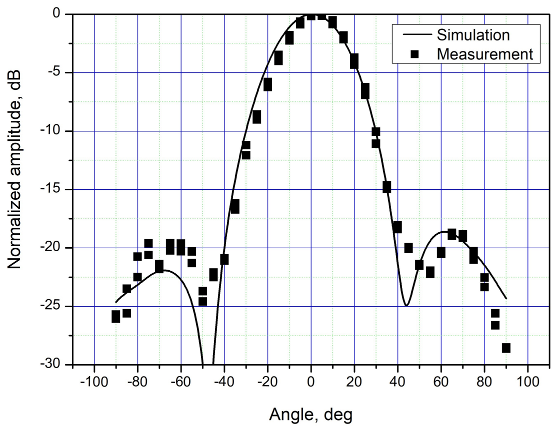
c)

Fig. 7. Radiation pattern of the spherical antenna arrays based on Archimedean spiral in *H* – plane for subarray consisting of: a) 8 antennas; b) 16 antennas; c) 24 antennas

Adjusting the excitation phase to assure the maximum radius in the direction of the north pole, results in a peak value at 0 degrees. Furthermore, this phasing results in narrowing



a)



b)

Fig. 8. Calculated and measured radiation pattern of the sixteen elements spiral antenna array: a) *E*-plane and b) *H*–plane (PHASED).

the main beam and increasing the side lobe level SLL (Figure 8).

The spiral antenna array on the spherical substrate is not spatially uniform and the radiation pattern is not uniform as well. However, given radiation diagrams provide sufficient information about its spatial shape. Measured results confirm the calculated and allow further development of the software as well as the optimization of such elements on the sphere.

V. CONCLUSION

This article is a continuation of previous research which has shown that the spiral constellation of the antenna on the spherical surface is quite suitable for enlarging or narrowing of the main beam and suppressing side lobe radiation, but it was not verified by measurements.

The laboratory model of the spherical antenna array based on Archimedean spiral was made and radiation pattern measurements were performed for several subarrays (8, 16 and 24 array arrays). The radiation pattern was calculated using the method of moment (MoM Method) in a spectral-domain (G1DMULT algorithm). This algorithm (while satisfying the appropriate conditions) transforms a three-dimensional problem into a one-dimensional problem, which is easier to solve. Using the phase shift of the excitation verified the part of the computer routine that involves excitation.

The measured results show excellent matching with calculated results and confirm the expected theoretical results that increasing the number of elementary antenna using a phase shift improves the radiation pattern.

There are deviations in the values of measured results (the measured results differ from calculated), due to real conditions in the measurement process.

Radiation pattern optimization will be explored in future research.

VI. REFERENCES

[1] S. Rupčić, V. Mandrić Radivojević, K. Grgić, “Loxodromic Antenna Arrays Based on Archimedean Spiral”, *International Journal of Electrical and Computer Engineering Systems,* vol. 7, no. 1, pp. 7-13, 2016.

[2] L. Marantis, E.D. Witte, P.V. Brennan, “Comparison of various Spherical Antenna Array Element Distributions”, Antennas and Propagation 2009, EuCAP 2009. 3rd European Conference, pp. 2980-2984, March, 2009.

[3] Mandrić V., Rupčić S., Žagar D., “Optimization of the Spherical Antenna Arrays”,Proceedings of ELMAR 2012, Zadar, Croatia, September, 2012.

[4] Rupčić S., Mandrić V., “Spiral Antenna Array Configurations on Spherical Surfaces”, Proceedings of ICECOM 2013, Dubrovnik, Croatia, September, 2013.

[5] P.-S. Kildal and J. Sanford, “Analysis of conformal antennas by using spectral domain technique for curved structures”, Proceedings of COST 245 – ESA workshop on active antennas, Noordwijk, Netherland, pp. 17-26, 1996.

[6] Z. Sipus, P.-S. Kildal, R. Leijon, and M. Johansson, ”*An algorithm for calculating Green’s functions for planar, circular cylindrical and spherical multilayer substrates*”, Applied Computational Electromagnetics Society Journal, vol. 13, no. 3, pp. 243-254, November, 1998.

[7] D. Dunham, ”Hyperbolic Spirals and Spiral Patterns”, The International Society of Arts, Mathematics and Architecture, Department of Computer Science, University of Minnesota, Duluth, USA, pp. 521 – 528, 2003.