Spiral Antenna Array Configurations on Spherical Surface

Slavko Rupčić
Laboratory for HF Measurement
J. J. Strossmayer University of Osijek,
Faculty of Electrical Engineering,
Osijek, Croatia
slavko.rupcic@etfos.hr

Vanja Mandrić
Laboratory for HF Measurement
J. J. Strossmayer University of Osijek,
Faculty of Electrical Engineering,
Osijek, Croatia
vanja.mandric@etfos.hr

Abstract – *Array antennas on the spherical surface offer a wide range of opportunities in the variation of their radiation patterns through antennas distribution and phase control. Elementary antennas could be distributed on the spherical surfaces in many different ways and in this paper one of them is chosen – spiral configuration with three subtypes: Archimedean, Fermat and Logarithmic spiral distributions of elementary antennas mounted on spherical surfaces. The paper studies different spiral configuration pattern influence on the radiation pattern of a spherical antennas array. Analysis was made using a developed moment method program with spectral-domain approach.*

Keywords — spiral configuration, conformal antennas, spherical array, method of moment, radiation pattern

I. INTRODUCTION

This paper, as do several papers before [1], [3], [4], [5], deals with circular microstrip elementary antennas mounted on a spherical surface – one of many possible types of conformal antenna arrays. All conformal antennas have a few good common characteristics: the ability to mold to curved shaped surfaces; the ability to produce the desired radiation pattern and finally, the capability of providing electronic scan coverage over the whole sphere. Such antennas could satisfy requirements for many applications.

Earlier investigations [1], [2] showed that spiral type of antenna gives very good results in radiation pattern context. That means that it is possible to achieve narrow main lobe and low level side lobes.

Radiation pattern was calculated using the method of moment and the spectral-domain approach.

Part IV analyzes and compares Archimedean, Fermat and Logarithmic spiral distributions of elementary antennas mounted on spherical surfaces.

II. FAR FIELD CALCULATION

Elementary antennas are mounted on a grounded conducting spherical shaped plane. Because of the spherical radiating structure, radiation problems will be solved using the spherical coordinate system. Spherical array of spiral distribution of microstrip antennas is analyzed using the method of moment in a spectral-domain. The spectral-domain technique transforms a three-dimensional problem into a spectrum of one-dimensional problem, which is easier to solve [6], [7]. This spectrum is obtained by applying the vector-Legendre transformation to the real current density at the circular microstrip antennas. An electrical field radiated by the current shell on the spherical surface in homogeneous media is:

$$\mathrm{E}(r,\theta,\phi)=\sum_{m=-\infty}^{\infty}\sum_{n=|m|}^{\infty}\overline{\overline{\mathrm{L}}}(n,m,\theta)\tilde{\overline{\overline{\mathrm{G}}}}(n,m,r\,|\,r_s)\tilde{\mathrm{C}}(r,n,m)e^{jm\phi} \quad (1)$$

where m and n are the variables in the spectral domain, $\tilde{\overline{\overline{\mathrm{G}}}}(n,m,r\,|\,r_s)$ is a spectral domain dyadic Green's function for a grounded spherical surface, $\overline{\overline{\mathrm{L}}}(n,m,\theta)$ is the kernel of the vector-Legendre transformation and $\tilde{\mathrm{C}}(r,n,m)$ is a spectral domain current placed at each antenna element.

G1DMULT is an algorithm used for calculating spectral-domain Green's function of a multilayer spherical structure [7].

The radiation pattern of the array is obtained as a superposition of fields excited by each antenna.

$$\mathrm{E}(\theta,\phi)=\sum_{n,m}E_{\alpha_n\beta_{nm}}(\theta,\phi) \quad (2)$$

III. THE SPIRAL DISTRIBUTION OF ANTENNA ELEMENTS ON THE SPHERE

Antennas could be placed by several rules (nonuniform) on a spherical surface [1], [2]. One of them is spiral, and that type of configuration has the possibility to satisfy requirements on communications demands like achieving optimum signal reception in any spherical space direction without altering the radiated pattern. This is antenna configuration which appears for a large N, where N is the number of elements in a radiating system [2].

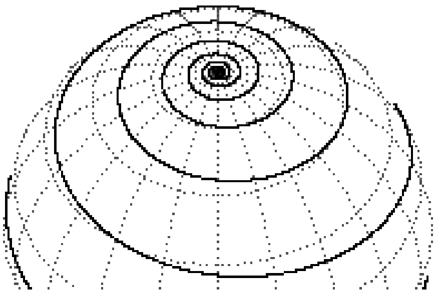

Figure 1. Loxodromic curves which spiral towards the North pole.

Some investigations on spiral type of spherical antenna are made in [1], [2], [5], so it is decided to make a step further in evaluating and improving radiating pattern characteristics. This paper analyzes and compares three different types of spiral configurations: Archimedean, Fermat and Logarithmic spirals. Their optimization will be left for future investigations.

It is well known that constellations with antennas which are grouped around angles of maximum radiation have narrow main lobe and low level side lobes. To achieve radiation patterns with narrow main lobe and low level side lobes, we decided to analyze these three types of spiral configurations.

A. Archimedean Spiral Distribution

Generally, spiral is given by the equation:

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

where a is a real number and assumed $a > 0$.

Figure 1. shows general shape of a spiral curve. A special case, when $n = 1$ is an Archimedean spiral [8]. 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. In polar coordinates, Archimedean spiral could be described by the equation:

$$\rho = a\varphi. \tag{2}$$

Archimedean spiral is presented in Figure 2.

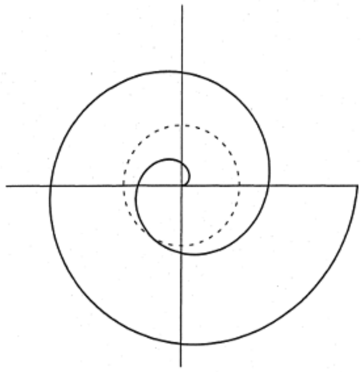

Figure 2. The Archimedean spiral $\rho = a\varphi$ [8].

B. Fermat Spiral Distribution

Let n from (1) become 1/2, and we get another special case - Fermat spiral shape (Figure 3.).

$$r = a\sqrt{\theta} \tag{3}$$

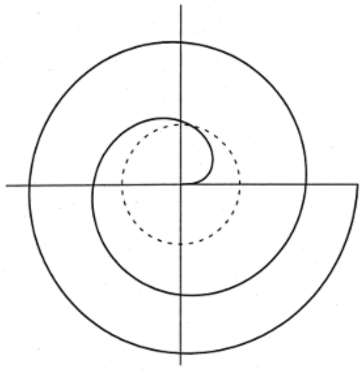

Figure 3. The Fermat spiral $r = a\theta^{1/2}$ [8].

This spiral is also known as the parabolic spiral.

C. Logarithmic Spiral Distribution

Logarithmic (exponential) spiral is the latest configuration described in this paper and is given with:

$$r = ab^{\theta}, \tag{4}$$

where a is a real number and assumed $a > 0$, $b > 1$. Special case of a logarithmic spiral is the golden spiral where $b = \tau^{2/\pi}$ and $\tau = \frac{1+\sqrt{5}}{2}$ - golden section (Figure 4.).

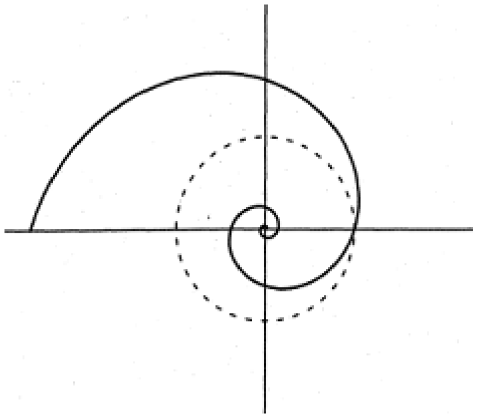

Figure 4. The Logarithmic spiral – special case - Golden spiral $r = \tau^{2\theta/\pi}$ [8].

IV. RESULTS

The goal of this paper is to investigate the influence of different spiral configuration patterns on the radiation pattern of a spherical antennas array. In Figs. 5-13 we have plotted the normalized value of electric field amplitude for Archimedean, Fermat and Logarithmic spiral distributions of elementary antennas mounted on spherical surfaces. Normalized radiation patterns were calculated at the frequency f = 1.70 GHz for E and H plane. Radius of the spherical surface is r=5λ, and the distance between antenna elements was limited to: $d \leq \lambda/2$. Radiation cone angle is 40 degrees.

It is observed that the radiation pattern changes significantly with respect to the change of the spiral constant a for every distribution type. Also, greater constant leads to low density distribution and to the increase of the side lobe levels.

A. Archimedean Spiral Distribution - results

It can be seen from distribution diagrams (fig. 5, 8 and 11) that the spiral distribution in all analyzed types of arrays has “shifts”. The reason for these shifts is the minimal distance between antenna elements: $d \leq \lambda/2$.

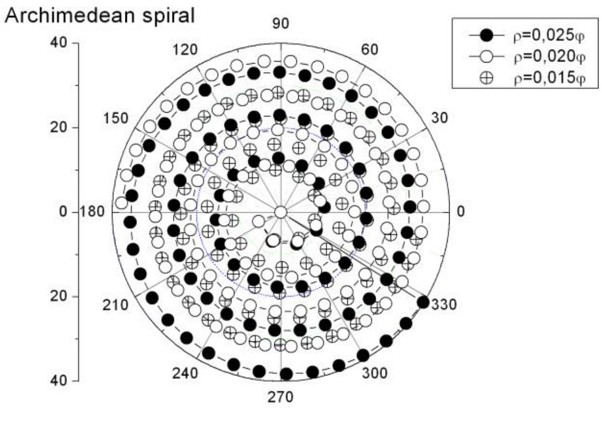

Figure 5. Archimedean spiral distribution of a spherical antenna array

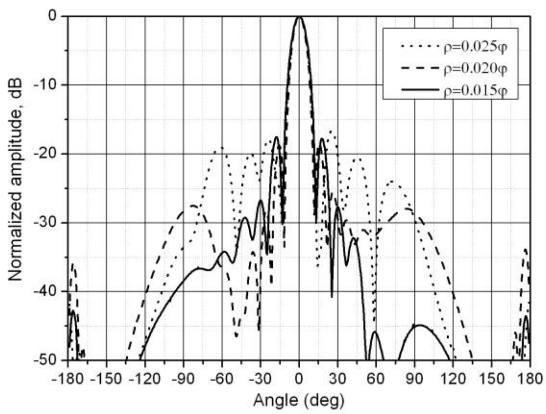

Figure 6. Normalized calculated radiation pattern of Archimedean spiral distribution in E plane.

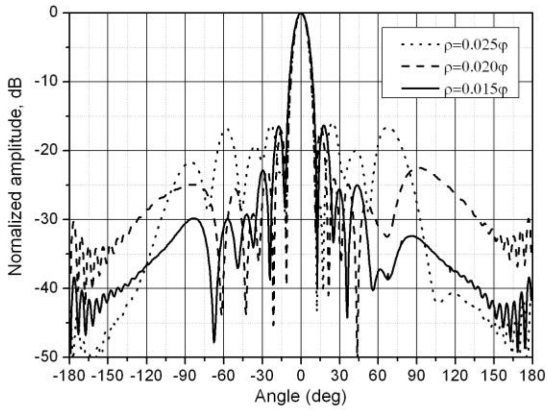

Figure 7. Normalized calculated radiation pattern of Archimedean spiral distribution in H plane.

B. Fermat Spiral Distribution

Fermat spiral distribution has very similar radiation patterns as Archimedean distribution.

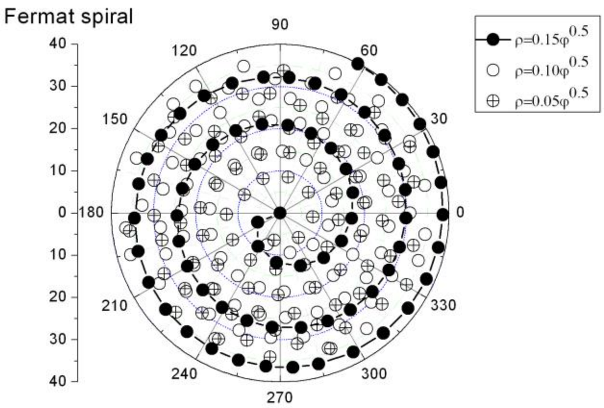

Figure 8. Fermat spiral distribution of a spherical antenna array

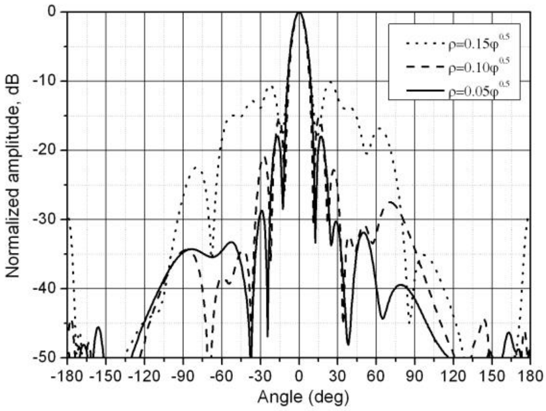

Figure 9. Normalized calculated radiation pattern of Fermat spiral distribution in E plane.

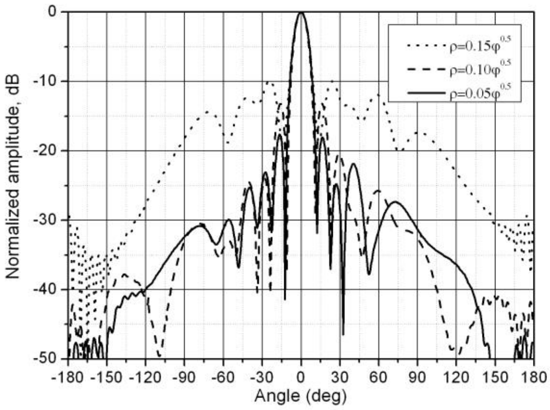

Figure 10. Normalized calculated radiation pattern of Fermat spiral distribution in H plane.

C. Logarithmic Spiral Distribution

Radiation patterns for logarithmic spiral distribution of antenna elements have the highest side lobes and represent radiation patterns "worst case".

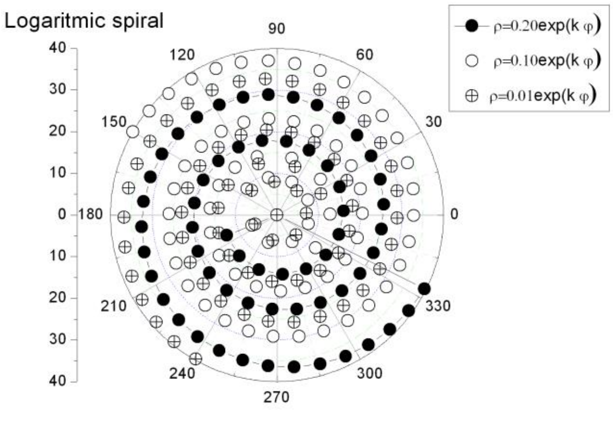

Figure 11. Logarithmic spiral distribution of a spherical antenna array

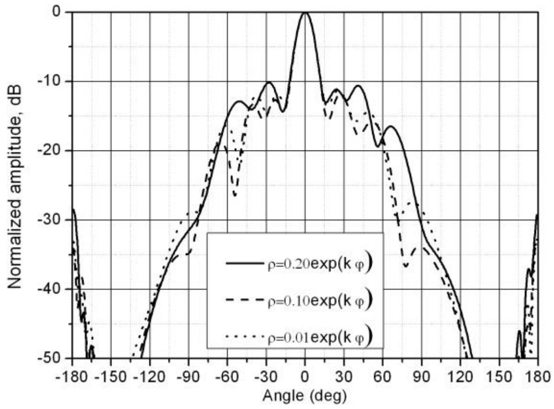

Figure 12. Normalized calculated radiation pattern of Logarithmic spiral distribution in E plane.

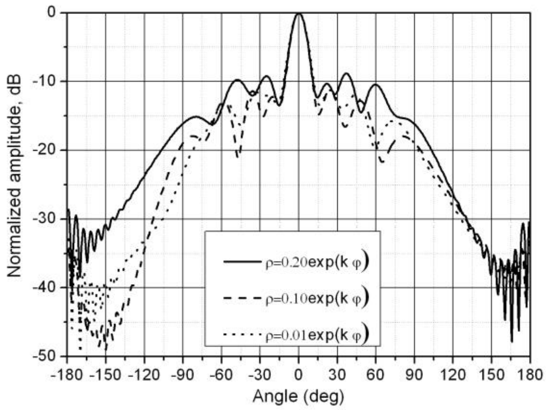

Figure 13. Normalized calculated radiation pattern of Logarithmic spiral distribution in H plane.

D. All Spiral Distribution

As we can see in Figures 15. and 16., it is clear that the influence of changing spiral distribution has very important effect on the array radiation pattern. Figures 14. to 16. show best solution radiation patterns for spiral distributions antenna arrays.

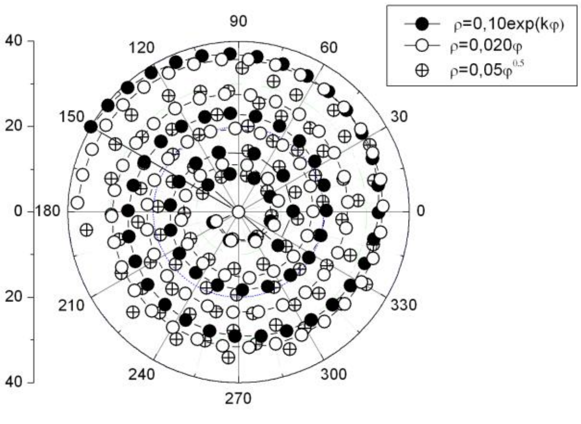

Figure 14. All spiral distribution of a spherical antenna array

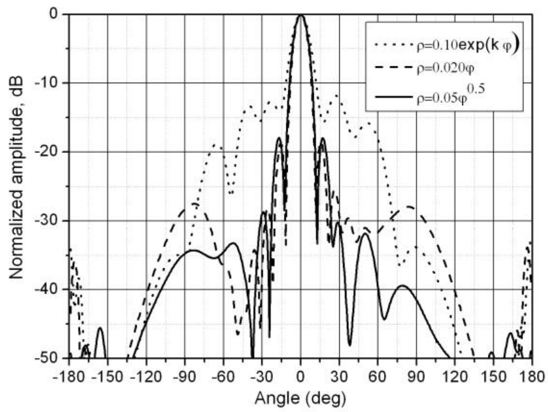

Figure 15. Normalized calculated radiation pattern of spiral distributions in E plane.

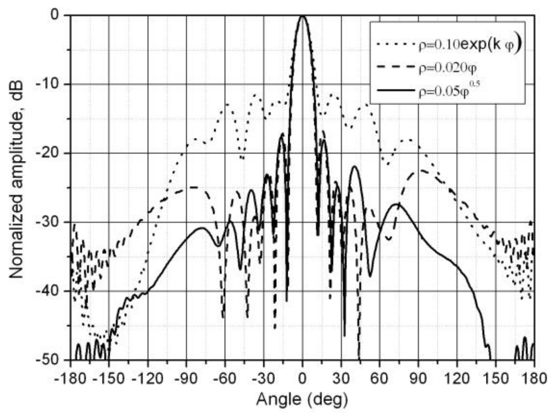

Figure 16. Normalized calculated radiation pattern of spiral distributions in H plane.

Fermat distribution has the best characteristics in regards of narrow main lobe and low side lobes level (-18 dB). Logarithmic distribution has the highest level (-11.5 dB). Necessary step for future work will be the optimization of spiral distribution to obtain a narrow main lobe and low side lobes level.

V. CONCLUSION

The presented numerical computations investigate influences of three different spiral distributions on radiation pattern of spherical antenna arrays: Archimedean, Fermat and Logarithmic spiral distributions. The analysis method is based on the moment method where the elements of the moment method matrix are calculated in the spectral domain.

It is demonstrated that it is possible to obtain a narrow main lobe and low side lobes level (for Archimedean, Fermat distribution) by a proper selection of the spiral distribution, especially if we apply optimization. This paper will not deal with the optimization; these three types of configurations will be compared only in regards to radiation pattern characteristics. Radiation pattern optimization and verification by comparison with measured results will be the future work.

REFERENCES

[1] V. Mandric, "Radiation pattern optimization for antenna arrays on spherical surface", Doctoral dissertation, Faculty of electrical engineering, University of Osijek, Osijek, 2012.

[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] S. Rupčić, " Circular Waveguide Antenna Arrays on Spherical Structures", PhD Thesis, *University of Zagreb, Faculty of Electrical Engineering and Computing*, Zagreb, 2009.

[4] Mandrić V., Rupčić S., Pilski D., Experimental Results of Spherical Arrays of Circular Waveguide and Microstrip Antennas, *Proceedings of ELMAR 2011*, Zadar, September 2011., p.p. 345-351.

[5] Mandrić V., Rupčić S., Žagar D., Optimization of the Spherical Antenna Arrays, *Proceedings of ELMAR 2012*, Zadar, September 2012.

[6] 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, pp. 17-26, 1996.

[7] 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.

[8] D. Dunham, "Hyperbolic Spirals and Spiral Patterns", The International Society of Arts, Mathematics and Architecture, Department of Computer Science, University of Minnestota, Duluth, pp. 521-528, USA.