Printed Antenna with Circular Polarization and a Tunable Elevation Angle

Ivana Radnović, Aleksandar Nešić and Dušan Nešić[1]

Abstract—**Circularly polarized antenna with a possibility of tuning the elevation angle i.e. obtaining maximum radiation in either broadside or directions declined from the zenith is presented in the paper. The antenna consists of a pair of printed crossed dipoles, feed line and gear mechanism for adjusting the height of the antenna in regard to vehicle roof, thus enabling maximums in radiation patterns at lower elevation angles. This feature is particularly interesting in communications between mobile objects and satellites. All simulations and optimizations have been carried out using program package WIPL-D and analysis of obtained results proves the validity of presented concept. Simulated gain is between 4.3 dBi and 7.3 dBi, depending on the antenna position; axial ratio (AR) is less than 3 dB in the operational range of frequencies (2%); reflection coefficient S_{11} is less than -19 dB. Antenna is designed for INMARSAT frequency range.**

Keywords—**Printed antennas; circular polarization; conical radiation pattern.**

I. Introduction

Varying of elevation angle of the antenna radiation often arises as a problem in communications between mobile objects and satellites, Fig. 1. In situations when relatively high angles of elevation are required, antennas with wide radiation patterns in broadside direction are used. However, when there is a need for lower elevation angles [1-3], antennas having conical radiation pattern are much suitable [4-6].

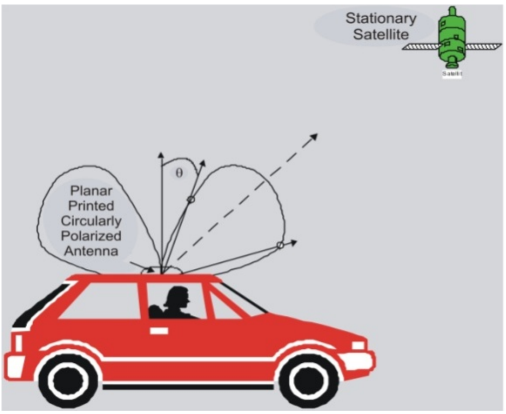

Fig. 1. Application of the antenna with conical radiation pattern: targeting a geostationary satellite

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The paper proposes a possible solution to elevation angle variation problem while keeping the circular polarization in a wide range of angles in elevation plane. Presented antenna is circularly polarized and has the possibility of tuning the elevation angle. The antenna operates in L band, but the solution is appliable in other frequency ranges used for communications between mobile objects and satellites. The example given in the paper is intended for INMARSAT frequency range.

II. Concept and Design

The antenna consists of two paralelly fed crossed dipoles with equal real parts of impedances and the phase difference of 90° between them in order to obtain circular polarization without the use of a phase shifter [7]. Dipoles are printed on a thin dielectric substrate (ε_r=2.17, h=0.127 mm) and optimized, using WIPL-D program package [8], at the distance of 0.25λ from the reflector plate so to obtain complex-conjugated impedances: Z_1=(50-j50) Ω (capacitive dipole) and Z_2=(50+j50) Ω (inductive dipole) at the central frequency of the range f=1.542 GHz. In this way the impedance at the antenna feed point theoretically equals (50+j0) Ω as the two crossed dipoles are connected in parallel. Radiation pattern in this case is conventional (maximum gain is in zenith direction – θ=0°). Layout of crossed dipoles with complex-conjugated impedances is given in Fig. 2.

Proposed solution enables variation of maximum gain elevation angles between θ=0° and θ=±68°. Thus, by continually increasing the distance *d* between the radiating structure and a reflector plate (vehicle roof) we can obtain radiation patterns in which maximum gain direction in elevation plane is obtained at angles declined from θ=0°. This deviation increases (toward lower elevation angles) with increase of the distance *d*, however significant minimum at θ=0° arises not until *d* reaches value 0.45λ.

Certainly, along with the distance *d* change, in order to obtain radiation beam at lower θ-plane angles, degradation of main antenna parameters (VSWR and axial ratio) occurs. This was expected because the radiating elements – crossed dipoles with complex-conjugated impedances – were optimized at the distance *d*=0.25λ from the reflector plate (lesser deviation of the antenna paramaters due to the increase of the antenna height has been obtained than in the case when the antenna was optimized at higher positions and moved downwards).

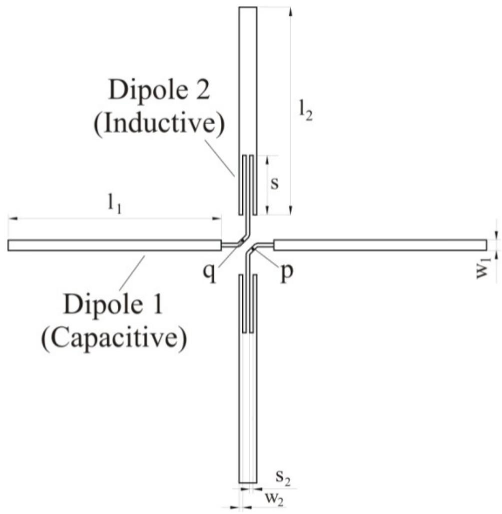

Fig. 2. Layout of crossed dipoles forming the antenna with indicated dimensions optimized to obtain circular polarization

Radiating structure is designed on one side of the dielectric substrate and placed in polyurethane cylinder with a mettalic tube penetrating its bottom. Feed line realized on the dielectric substrate (ε_r=2.17, h=0.127 mm) as a symmetrical (balanced) microstrip line passes through the tube and is terminated with a *bal-un* [9,10] and a coaxial SMA connector, Fig. 3.

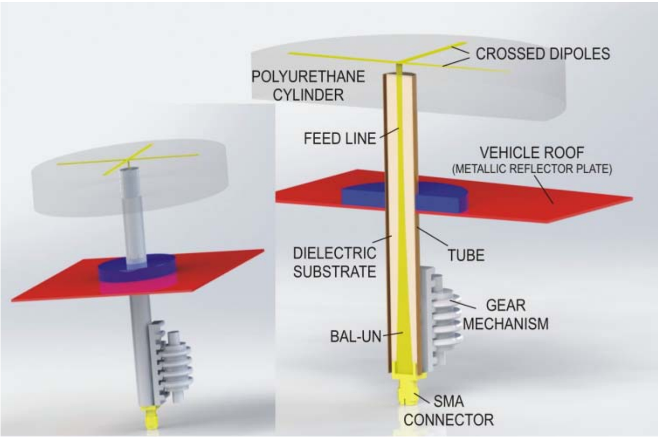

Fig. 3. Sketch and longitudinal section of the antenna structure with crossed dipoles, *bal-un*, SMA connector and mechanism for adjusting the antenna height

The lower part of the tube passes through the vehicle roof (or the roof of a immovable object). The tube that holds the antenna structure is moving along vertical axis by use of the gear mechanism. Step size of the tube is equal to the difference between maximum and minumum antenna distance from the reflector plate (vehicle roof).

III. Simulated Results

During the research and the analysis of the proposed concept it has been noticed that relatively wide radiation pattern could be obtained by optimization of the crossed dipoles' dimensions in the case when d=0.25λ. Simulated 3 dB beamwidth is nearly 92° (±46°), while gain of the antenna in the broadside direction is 7.34 dBi. Axial ratio is less than 2 dB in the whole frequency range at all angles (φ) in horizontal plane at θ=0°, and less than 3 dB up to θ=±30°, Fig. 4. Simulated gain of the antenna is shown in Fig. 5. For the reason of easier comparison of further results both axial ratio and gain diagrams are given for two typical φ-angles where the best and the worst AR is obtained in the case of conical radiation pattern.

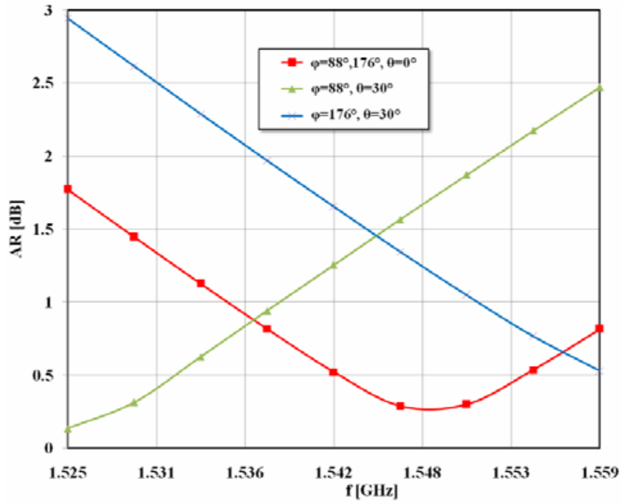

Fig. 4. Simulated axial ratio (AR) of the antenna at the distance 0.25λ from the reflector plate at two elevation angles (θ=0° and θ=30°) and two azimuthal angles (φ=88° and φ=176°)

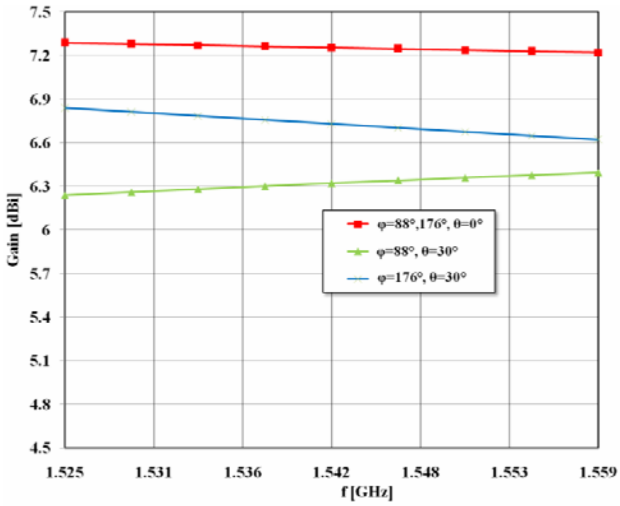

Fig. 5. Simulated gain of the antenna at the distance 0.25λ from the reflector plate at two elevation angles (θ=0° and θ=30°) and two azimuthal angles (φ=88° and φ=176°)

By gradually increasing the height of the antenna to d=0.45λ in regard to the reflector plate, its radiation pattern is being considerably deviated into conical shape having the maximum gain at elevation angle θ around ±50°. Similar results are obtained for distances d=0.46λ, 0.47λ and 0.5λ with more or less emphasized minimum at θ=0°, depending on the distance d value. The following results are given for the distance d=0.47λ where achieved difference between the maximum gain (at θ=±50°) and the minimum at θ=0° is around 12 dB. Simulated radiation patterns at two characteristic angles in horizontal plane (at which the lowest and the highest axial ratio is obtained) are presented in Fig. 6 and Fig. 7, respectively. In these cases antenna gain is around 6.14 dBi in the direction of maximum radiation. Around θ=±68° gain drops to 4.34 dBi (minimal required level). This means that range of elevation angles is additionaly broadened from Δθ=92°(θ=±46°) to Δθ=136° (θ=±68°).

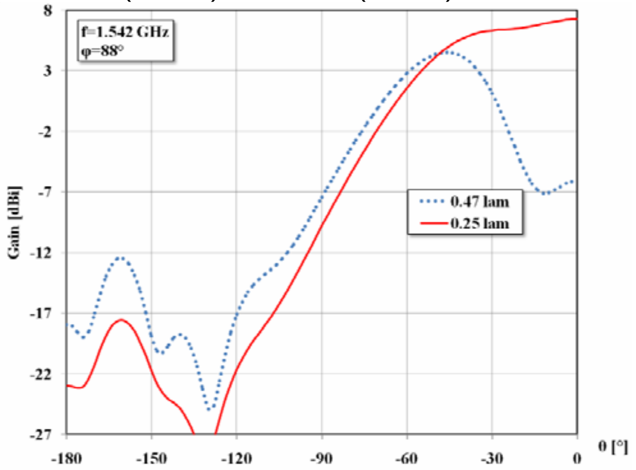

Fig. 6. Simulated radiation pattern in θ-plane for two positions of the antenna (d=0.25λ and d=0.47λ) at the azimuthal angle φ=88°

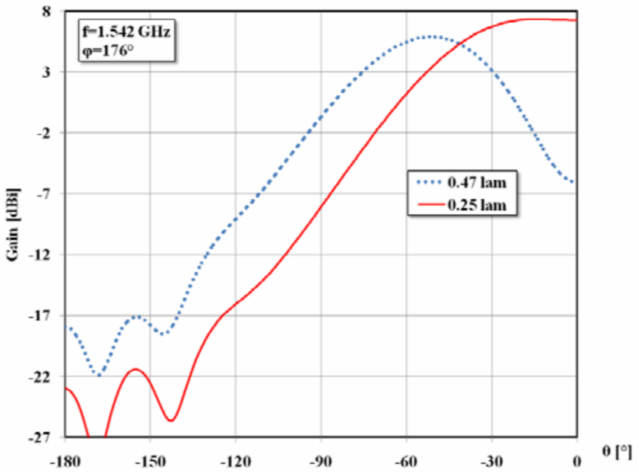

Fig. 7. Simulated radiation pattern in θ-plane for two positions of the antenna (d=0.25λ and d=0.47λ) at the azimuthal angle φ=176°

Axial ratio highly depends on the azimuthal angle φ - for example, at the lowest elevation angle (θ=±68°) AR is around 5 dB at azimuthal angle φ=88°, while it is even much worse at φ=176° (two extreme cases of AR), Fig. 8 and Fig. 9, respectively. Results are given for the central frequency f=1.542 GHz. However, this disadvantage can be easily compensated by rotating the antenna around z-axis. Variations of axial ratio and antenna gain in the whole receiver's frequency range at the angle of maximum radiation (θ=±50°) for two extreme horizontal angle cases: φ=88° and φ=176° are shown in Figs. 10 and 11, and Figs. 12 and 13, respectively.

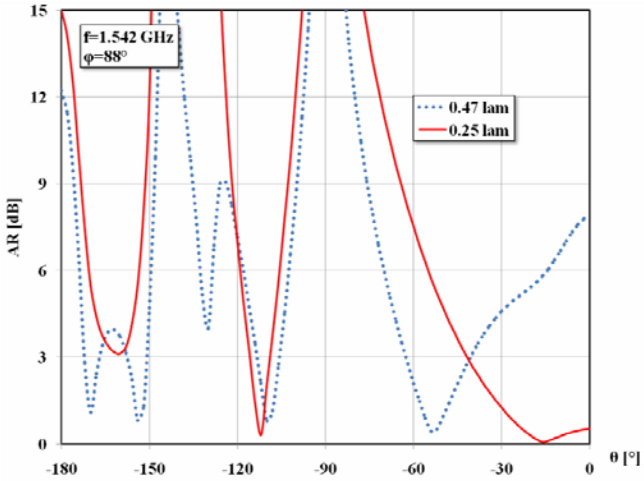

Fig. 8. Simulated axial ratio in θ-plane for two positions of the antenna (d=0.25λ and d=0.47λ) at the azimuthal angle φ=88°

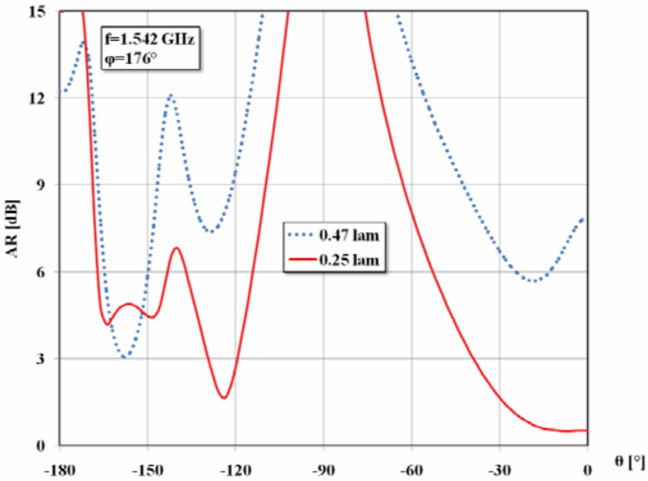

Fig. 9. Simulated axial ratio in θ-plane for two positions of the antenna (d=0.25λ and d=0.47λ) at the azimuthal angle φ=176°

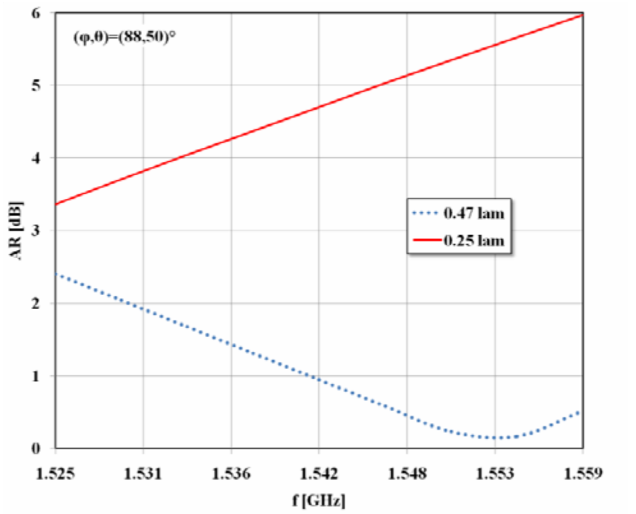

Fig. 10. Simulated axial ratio at θ=50° (maximum radiation angle) and φ=88° for two positions of the antenna (d=0.25λ and d=0.47λ)

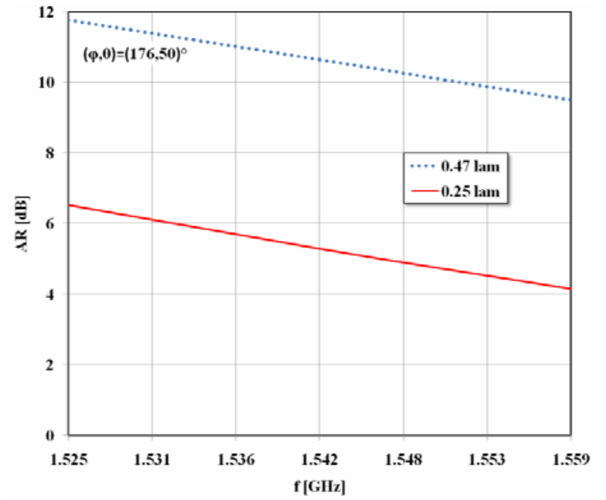

Fig. 11. Simulated axial ratio at θ=50° (maximum radiation angle) and φ=176° for two positions of the antenna (*d*=0.25λ and *d*=0.47λ)

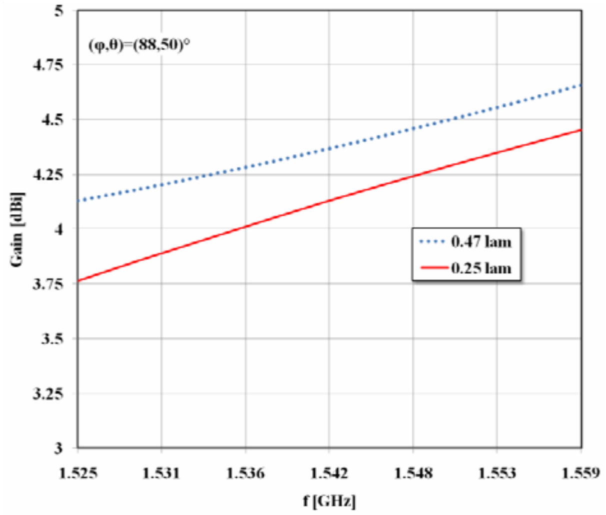

Fig. 12. Simulated gain at θ=50° (maximum radiation angle) and φ=88° for two positions of the antenna (*d*=0.25λ and *d*=0.47λ)

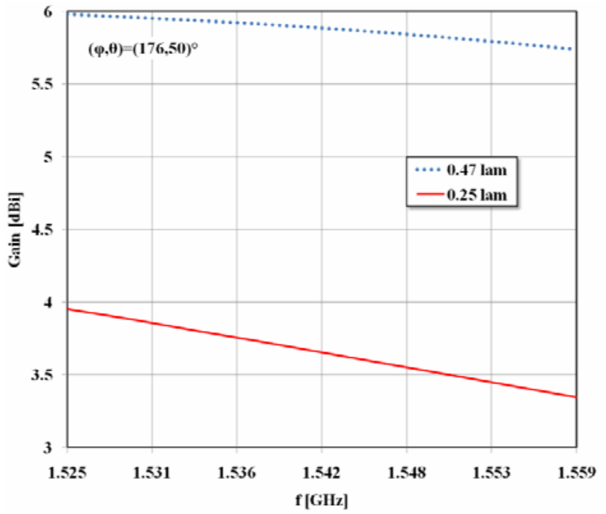

Fig. 13. Simulated gain at θ=50° (maximum radiation angle) and φ=176° for two positions of the antenna (*d*=0.25λ and *d*=0.47λ)

Analysis of obtained simulated results given in Figs. 10, 11, 12 and 13 shows that optimization which was carried out to achieve satisfactory gain and optimal axial ratio of the antenna caused discrepancies in gains of individual dipoles – capacitive and inductive. The consequence of this is deviation of the antenna radiation pattern in φ-plane (at θ=±50°) from ideal circle of about 1.5 dB (Fig. 16) as well as the difference in AR values (Fig. 10 and Fig. 11) which is the most significant at angles φ=88° (AR_{min}) and φ=176° (AR_{max}). Nevertheless, poor values of axial ratio at φ=176° are compensated by a higher gain occuring at the same angle in the horizontal plane, Fig. 13.

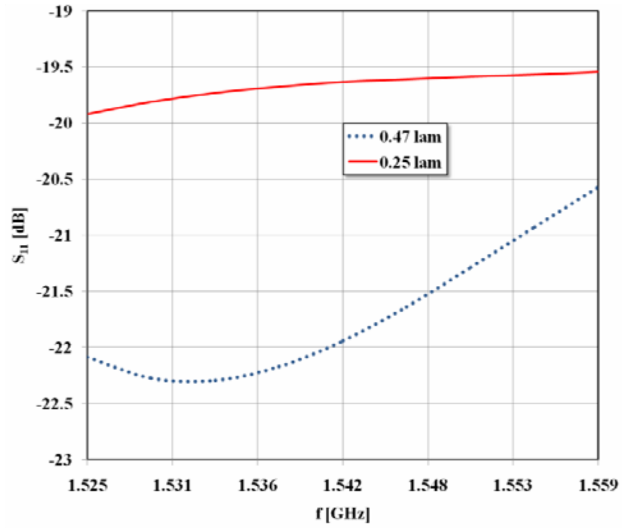

Fig. 14. Simulated reflection coefficient S_{11} for two positions of the antenna (*d*=0.25λ and *d*=0.47λ)

From the diagrams presented in Fig. 14, it can be seen that reflection coefficient S_{11} is better than -19.5 dB (VSWR<1.3) in both antenna positions.

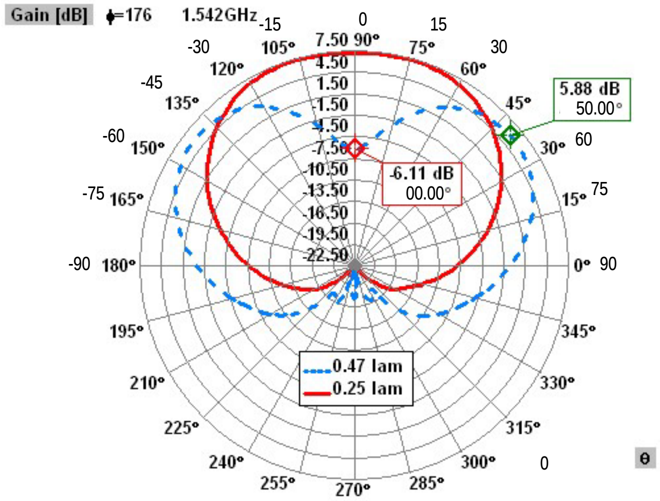

Fig. 15. Simulated radiation pattern in the elevation plane for *d*=0.47λ and *d*=0.25λ at the central frequency

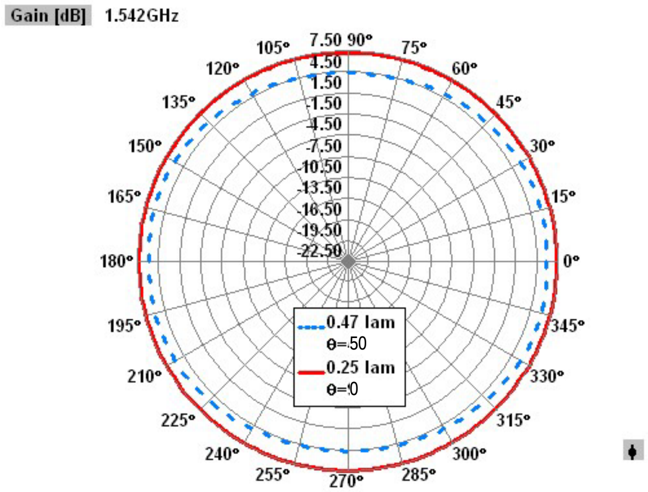

Fig. 16. Simulated radiation patterns in the azimuthal plane for d=0.47λ/ θ=50° and d=0.25λ/ θ=0° at the central frequency

Figures 15 and 16 show simulated radiation pattern φ- and θ-cuts for both distances between the antenna and the reflector plate (vehicle roof). Azimuthal patterns (Fig. 16) are plotted at their maximum radiation elevation angles (d=0.47λ/θ=50° and d=0.25λ/θ=0°). It can be seen that antenna has omnidirectional radiation characteristic in both cases with maximal deviation of about 1.5 dB from ideal circle.

IV. Conclusion

Up to now research in the field of antenna structures with circular polarization and conventional radiation patterns intended for satellite communications has been aimed at broadening the antenna beam in order to cover as wide as possible part od the hemisphere. To our knowledge, maximal obtained coverage was around 90º (θ=±45º). In order to achieve radiation at lower elevation angels (below 45º or 50º) antennas with conical radiation beam have been investigated. Most of them, published after 1998 have cited papers [2,3] dealing with this subject. The main idea of presented investigation is to obtain: (1) conventional radiation pattern with circular polarization and (2) circularly polarized conical radiation pattern, using the same antenna structure (crossed dipoles, *bal-un* and feed line) only by switching the distance from the reflector plate between two positions (0.25λ and 0.47λ).

Results of the analysis show that it is possible to achieve coverage of the hemisphere up to the elevation angle θ=±68°.

The goal of further investigation is to accomplish additional optimizations by which the imbalance between gains of individual dipoles in φ-plane would decrease and so the axial ratio of the antenna. Another objective of the future work is developing a method for electronic tuning of the antenna elevation angle.

Acknowledgment

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References

[1] H. Kawakami, G. Sato, R. Wakabayashi, “Research on Circularly Polarized Conical Beam Antennas*”, IEEE Antennas and Propagation Magazine*, vol. 39, no. 3, June 1997, pp. 27-39.

[2] A. Nesic, V. Brankovic, I. Radnovic, “New Circularly Polarized Planar Printed Antenna with Conical Radiation Pattern”, *IEEE Antennas and Propagation Society International Symposium*, 21-26 June 1998, vol. 3, pp. 1438-1441.

[3] A. Nesic, V. Brankovic, I. Radnovic, “Circularly polarized printed antenna with conical beam”, *Electronics Letters*, vol. 34, no. 12, June 1998, pp. 1165-1167.

[4] Jeen-Sheen Row and Ming-Che Chan, “Reconfigurable Circularly-Polarized Patch Antenna With Conical Beam”, *IEEE Transactions on Antennas and Propagation*, vol. 58, no. 8, August 2010, pp. 2753-2757.

[5] C. Y. D. Sim, T. Y. Han, C. J. Chi, B. Y. Chen, “A 2 x 2 Array Antenna with Circular Polarization and Conical Beam Radiation”, *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 24, no. 2, March 2014, pp. 223-228.

[6] S.-Shan Qi, Wen Wu, and D.-Gang Fang, “Singly-Fed Circularly Polarized Circular Aperture Antenna with Conical Beam”, *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 6, June 2013, pp. 3345-3349.

[7] A. Nesic, I. Radnovic, M. Mikavica, S. Dragas and M. Marjanovic, “New printed antenna with circular polarization”, *26th EuMC*, Prague, Czech Republic, 9-12 Sept. 1996, pp. 569-573.

[8] WIPL-D Pro v.10.0 software package, www.wipl-d.com, WIPL-D d.o.o.: Belgrade, Serbia, 2012.

[9] A. Nesic, S. Dragas, “Frequency Scanning Printed Array Antenna”, *IEEE Symposium on Antennas and Propagation Digest*, Newport Beach, California, USA, June 1995, pp. 950-953.

[10] Sang-Gyu Kim and Kai Chang, “Ultrawide-Band Transitions and New Microwave Components Using Double-Sided Parallel-Strip Lines”, *IEEE Trans. on Microwave Theory and Techniques*, vol. 52, no. 9, Sept. 2004, pp. 2148-2152.