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DESIGN OF OPTIMAL GROUND CONDUCTOR FOR THE HELICAL ANTENNA

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Abstract – *We have observed that the size and shape of the ground conductor of axial mode helical antennas have significant impact on the antenna gain. Of all the shapes considered, the ground conductors in the shape of truncated cone yield the highest increase in the antenna gain when compared to the antennas above the infinite ground plane. We have designed the optimal ground conductor for the specific helical antenna by optimizing the geometrical parameters of the truncated cone with the goal to maximize the antenna gain. The results are compared with the results and measurements reported in our previous work.*

1. INTRODUCTION

Axial-mode helical antennas have been known for a long time [1]. They were made inspired by helices used in traveling-wave tubes. Helical antennas consist of a spiral conductor (helix) placed above a conducting ground, which can take various shapes (Fig. 1). The radiation pattern of a helical antenna is concentrated about the antenna axis, and the field polarization in the axial direction is almost perfectly circular. The polarization sense (right-hand circular or left-hand circular) corresponds to the sense of spiral winding (right-hand, viz. left-hand spiral). The gain of the antenna with flat ground conductor is typically between 10 and 17 dBi. Helical antennas are moderately broadband. Their operating bandwidth is below one octave. They are used in terrestrial and satellite communication systems in the frequency range between approximately 0.1 GHz and 10 GHz.

In our previous research, we have observed and verified computationally that the shape of the ground conductor has impact on the helical antenna performance. For example, the helical antenna above a cylindrical ground conductor (cup) in [2] has higher gain then the antenna above an infinite ground plane. We have reported in [3] that the cup of diameter $D = 1\ \lambda$ and height $h = 0.25\ \lambda$ [Fig. 1(c)] increases the gain of the considered antenna for 1.4 dB compared to the infinite ground plane [Fig. 1(a)] and for 1 dB compared to the square plate of side $b = 1.5\ \lambda$ [Fig. 1(b)], where λ is the wavelength at the central frequency of the antenna operating band. This conclusion explains the major part of discrepancies in peak gain between the experimental results [2] and computed results [4] where the experimental results show substantially higher gain (about 2 dB for longer antennas) than data computed using program NEC [4]. Furthermore, the helical antenna above a conical ground conductor in [5] has lower axial ratio and sidelobe levels than the antenna above an infinite ground plane. Following this conclusion, we have verified and reported in [3] that the ground conductor in the shape of a truncated cone of diameters $D_1 = 0.75\ \lambda$, $D_2 = 2.5\ \lambda$, and height $h = 0.5\ \lambda$ [Fig. 1(d)] can increase the peak gain by 3.4 dB compared with the conductor in the form of an infinite ground plane, and about 3 dB compared with the conductor in the form of a square plate.

Of all the investigated ground conductor shapes, the conical ground conductor has the highest impact on the antenna gain. Hence, the objective of this paper is to optimize the geometrical parameters of the conical ground conductor with the goal to maximize the antenna gain. The second objective is to verify that the geometry of the truncated cone used in [3] was indeed very close to optimal.

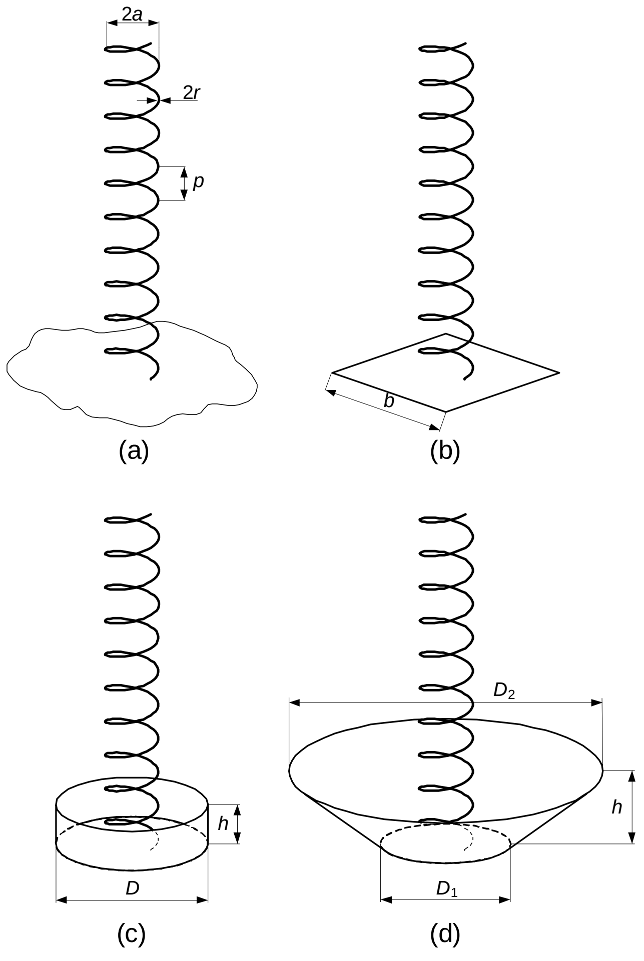

Fig.1. *Helical antenna above (a) infinite ground plane, (b) square conductor, (c) cylindrical cup, and (d) truncated cone.*

2. HELICAL ANTENNA ABOVE TRUNCATED CONE

We first considered a helical antenna above an infinite ground plane with the following data: axial length $L = 684$ mm, diameter $2a = 56$ mm, and wire diameter $2r = 0.6$ mm. With the given data, the antenna pitch angle is optimized to maximize the frequency range (bandwidth) for the prescribed gain variation of 4 dB. The optimal pitch angle is found to be $\alpha = 13.5^{o}$. The number of turns is, consequently, $N = 16.2$. The antenna is designed for the frequency range from 1200 MHz to 2200 MHz. Fig. 2 shows the antenna gain as a function of frequency. The peak gain is 13.9 dBi. The results for the antenna gain in the axial direction are obtained using programs WIPL-D and Awas [6], [7], which are based on the Method of Moments, and they are practically identical to the results in [4].

For the given helical antenna we designed the ground conductor in the form of a truncated cone [(Fig. 1(d)]. The dimensions of the cone are: the lower (smaller) diameter ($D_1 = 0.75\ \lambda$), the upper (larger) diameter ($D_2 = 2.5\ \lambda$), and the height ($h = 0.5\ \lambda$), and computed the antenna gain. For these dimensions, the peak gain is as high as 17.3 dB. This is 3.4 dB higher than with the infinite ground plane (Fig. 2). We have also observed that, for the fixed pitch angle, the enhancement of gain obtained using the conical ground conductor practically does not depend on the antenna length.

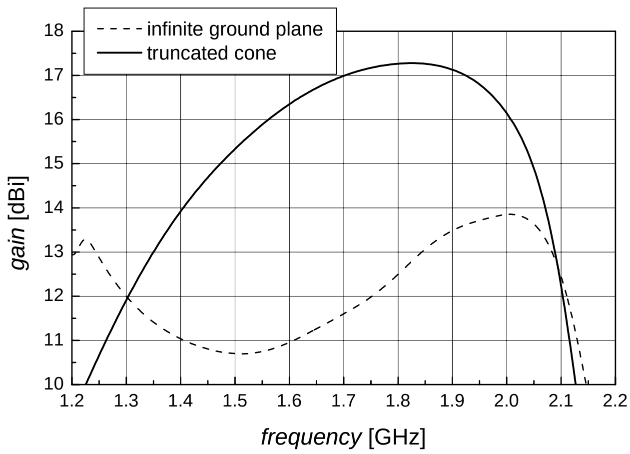

Fig.2. *Computed gain of helical antenna above infinite ground plane and truncated cone.*

We verified both computationally and experimentally the gain enhancement of the helical antenna with the truncated cone ground conductor with respect to the gain of the antenna with the square plate. Fig. 3 shows the enhancement of the antenna gain with the truncated cone with respect to the gain for the square plate of side $b = 1.5\ \lambda$. The gain enhancement is presented as a function of frequency. The agreement between the computed and measured results is very good and confirms that the adequate selection of the size and shape of ground conductor can significantly enhance the gain of the helical antenna.

The helical antenna above the conical ground plane has been previously analyzed [5]. It has been found that the helical antenna above the conical ground conductor has lower axial ratio and lower sidelobes than antenna above the square ground conductor. This enhancement is due to the conical ground plane, which suppresses sidelobes in directions that are close to horizontal directions and below, thus also suppressing back radiation. However, no gain enhancement is observed in [5]. Furthermore, our results are not comparable with those in [5] because the tested antenna in [5] had tapered feeds and terminations.

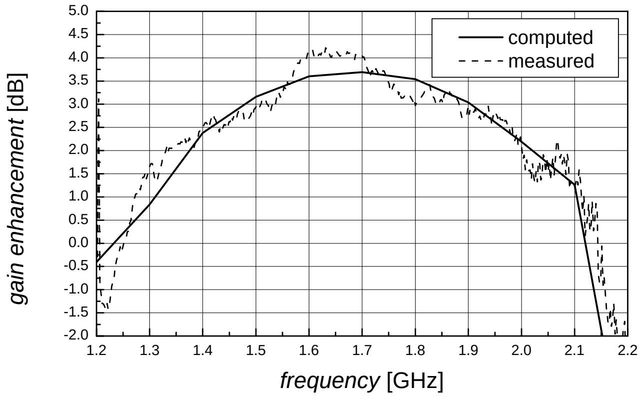

Fig.3. *Computed and measured enhancement of antenna gain (with respect to square conductor) for the antenna above truncated cone.*

Our explanation for the function of the cone is that it acts not only like a reflector (which collects and directs the energy spilled into the sidelobes), but also like a horn antenna that creates its own radiation pattern, which favorably interacts with the pattern of the helical antenna. Results in [8] confirm our claim, since the helicone antenna is obtained if the conical ground conductor is further enlarged.

3. OPTIMIZATION OF THE CONICAL GROUND CONDUCTOR

A. Systematic search

The optimization goal was to maximize the antenna gain in the axial direction at the operating frequency $f = 1.8$ GHz. In the first step, we varied the radii of the truncated cone ground conductor in steps of $\Delta R = 0.05\,\lambda$ within the limits $0.2\,\lambda \le R_{\text{lower}} \le 1.7\,\lambda$ and $0.2\,\lambda \le R_{\text{upper}} \le 1.7\,\lambda$, where $D_1 = 2R_{\text{lower}}$ and $D_2 = 2R_{\text{upper}}$. Hence, the optimization space involved a total of $31 \times 31 = 961$ points. The truncated cone height was kept constant at $h = 0.5\ \lambda$. The obtained cost-function, calculated as $cf = 20 - gain\,[\text{dB}]$, is shown in Fig. 4.

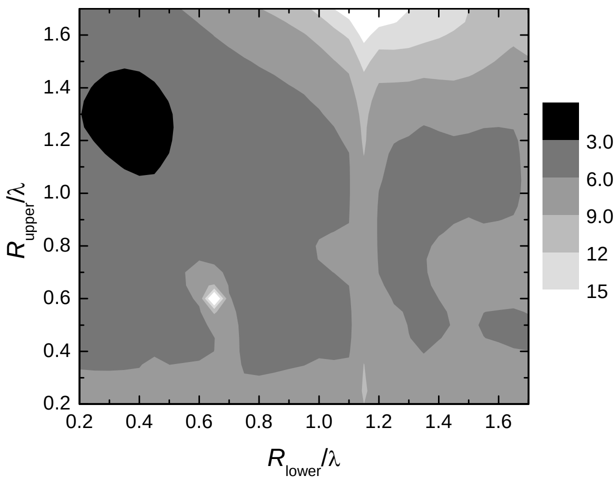

Fig.4. *The cost-function in the optimization space.*

We can conclude from the figure that there exists a single minimum in the optimization space, i.e., there exists a single maximum of the antenna gain for the fixed reflector height. This maximum occurs for $R_{\text{lower}} = 0.4\,\lambda$ and $R_{\text{upper}} = 1.3\,\lambda$.

B. Local optimization

In the next step, we fine-tuned the solution obtained in the previous step by locally applying the Nelder-Mead simplex optimization algorithm. We used the approximate solution obtained by the systematic search as the starting point for the local optimization. We found that the maximum gain occurs for $R_{\text{lower}} = 0.391\lambda$ and $R_{\text{upper}} = 1.302\lambda$. Note that the corresponding optimal cone diameters, $D_1 = 0.782\,\lambda$ $D_2 = 2.604\,\lambda$, are indeed very close to the dimensions used in our computations and experiments ($D_1 = 0.75\,\lambda$ and $D_2 = 2.5\,\lambda$). Comparison of the gain of the helical antenna with the optimized conical ground conductor and the gain of the antenna used in [3] is shown in Fig. 5. We can conclude from the figure that the optimized conical ground conductor improves the antenna performance.

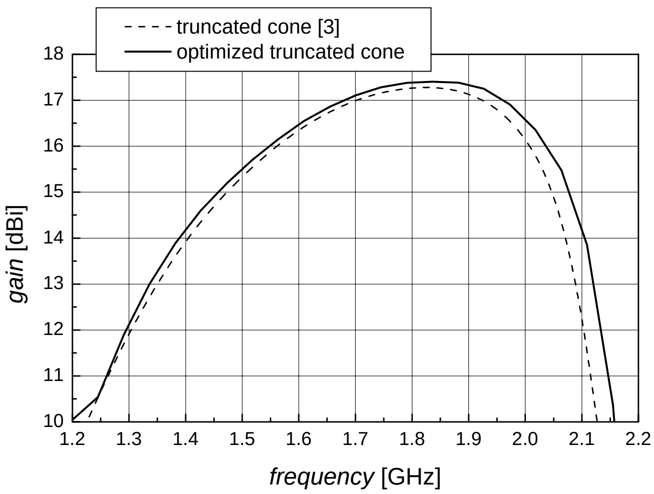

Fig.5. *Antenna gain versus frequency.*

C. Influence of the reflector height

In the final step, we investigated the influence of the reflector height on the antenna gain. For the antenna with the optimal radii of the conical reflector, found in the previous step, we varied the reflector height within the limits $0.1\,\lambda \le h \le 3.1\,\lambda$. The resulting cost function is shown in Fig. 6.

We can conclude based on the figure that there exists a single minimum of the cost function (maximum of the antenna gain) which occurs for $h = 0.6\,\lambda$. The optimal height is very close to the height used in our computations and experiments ($h = 0.5\,\lambda$).

4. CONCLUSION

The shape and the size of the ground conductor can significantly influence the helical antenna performance. The ground conductor in the form of truncated cone has the highest favorable impact on the antenna gain, which was demonstrated both computationally and experimentally. The geometrical parameters of the conical ground conductor were optimized with the goal to maximize the antenna gain. The details of the optimization procedure were outlined. The obtained optimal parameters (cone diameters and height) are in good agreement with those used in our computations and experiments. The performed optimization of the conical ground conductor improves the antenna performance.

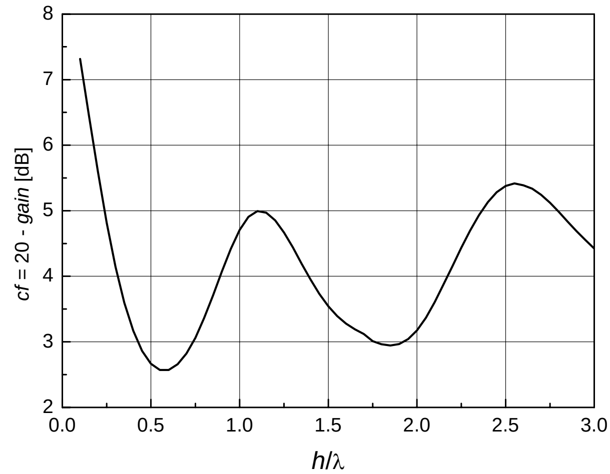

Fig.6. *The optimization cost-function against the reflector height.*

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