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Enhancing the Gain of Helical Antennas by Shaping the Ground Conductor

Antonije R. Djordjević, Alenka G. Zajić, *Student Member, IEEE*, and Milan M. Ilić, *Member, IEEE*

***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. By shaping the ground conductor, we have increased the gain of a helical antenna for as much as 4 dB. Theoretical results are verified by measurements.**

***Index Terms*—Antenna gain, axial mode, helical antennas.**

I. INTRODUCTION

AXIAL-MODE helical antennas have been known for a long time [1]. However, some frequently used formulae for antenna design [1], [2] are in discrepancy with experimental results [3] and computed results [4]. Furthermore, the experimental results [3] show substantially higher gain (about 2 dB for longer antennas) than data computed using program NEC [4]. Therefore, the first objective of this letter is to investigate the causes of these discrepancies.

We have also 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 [3] has higher gain then the antenna above an infinite ground plane. 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. Hence, the second objective is to optimize helical antenna gain by shaping the ground conductor.

II. HELICAL ANTENNA ABOVE VARIOUS TYPES OF GROUND CONDUCTORS

A. *Antenna above infinite ground plane*

First, the helical antenna located above an infinite ground plane [Fig. 1(a)] is analyzed. As an example, we considered a helical antenna 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 $\alpha = 13.5^{\circ}$. The number of turns is, consequently, $N = 16.2$. The antenna is designed for the frequency range from 1200 MHz to 2200 MHz, with the central frequency of 1700 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 and Awas [6], [7], which are based on the Method of Moments, and they are practically identical to the results in [4].

B. *Antenna above square ground conductor*

Thereafter, the same helical antenna is analyzed above a finite ground plane. In [2], it is recommended to take a finite-size ground plane in the form of a circle or square plate [Fig. 1(b)]. The circle diameter or square side are recommended to be 0.5–0.75 λ, where λ is the wavelength at the central frequency of the antenna operating band. However, our computations showed (Fig. 2) that this size is too small because the antenna gain is very narrowband, although the peak gain (14.4 dBi) is higher than for the infinite ground plane.

For the considered helical antenna, we optimized the size of the square ground conductor with the goal to maximize the average antenna gain in the considered frequency range. We found the optimal side of the square to be $b = 1.5\ \lambda$. In this case, the peak gain is 14.3 dBi (Fig. 2).

C. *Antenna above cylindrical cup*

In [3], the ground conductor is chosen to have a cylindrical cup shape [Fig. 1(c)]. The optimal diameter of the cup is

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A. R. Djordjević (e-mail: edjordja@etf.bg.ac.yu) and M. M. Ilić (phone: +381-11-3370101; fax: +381-11-3248681; email: milanilic@ieee.org) are with the School of Electrical Engineering, University of Belgrade, King Alexander's Boulevard 73, P.O. Box 35-54, 11120 Belgrade, Serbia and Montenegro.

A.G. Zajić (e-mail: alenka@ece.gatech.edu) is with the Georgia Institute of Technology, 777 Atlantic Drive, Atlanta GA 30332, USA.

$D = 1\ \lambda$, and the height is $h = 0.25\ \lambda$. For our helical antenna, computations verified that these dimensions are close to the optimum. The cup increases the antenna gain for 1.4 dB compared to the infinite ground plane (Fig. 2). This explains the major part of discrepancies in the peak gain between [3] and [4]. The peak gain is 1 dB higher than with the optimal square plate.

However, we have found that the enhancement of gain in [3], obtained using the cylindrical cup as the ground conductor, depends on the antenna length. For the pitch angle considered ($\alpha = 13.5^{o}$), the enhancement of gain is negligibly small for shorter antennas (about one wavelength long), and it increases with increasing the antenna length. The increase depends on the helix pitch, and there seems to be an optimal pitch for which the advantage of using the cup is maximized.

These results motivated us to further investigate the influence of the ground plane on enhancing the gain of helical antennas.

D. Antenna above truncated cone

For the given helical antenna, we modified the shape of the ground conductor. Instead of a cylindrical cup, we took the ground conductor to have the form of a truncated cone [(Fig. 1(d)]. We varied the dimensions of the cone: the upper (larger) diameter (D_1), the lower (smaller) diameter (D_2), and the height (h), and computed the antenna gain. We have found the optimal dimensions of the cone to be $D_1 = 0.75\ \lambda$, $D_2 = 2.5\ \lambda$, and $h = 0.5\ \lambda$. 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 and about 3 dB higher than with the optimal square plate (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.

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.

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 favourably 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.

III. EXPERIMENTAL VERIFICATION AND CONCLUSION

The computed results presented above were verified experimentally. Fig. 3 shows the enhancement of the antenna gain with the optimal cup and the truncated cone, with respect to the gain for the optimal square plate. 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 enhance the gain of the helical antenna.

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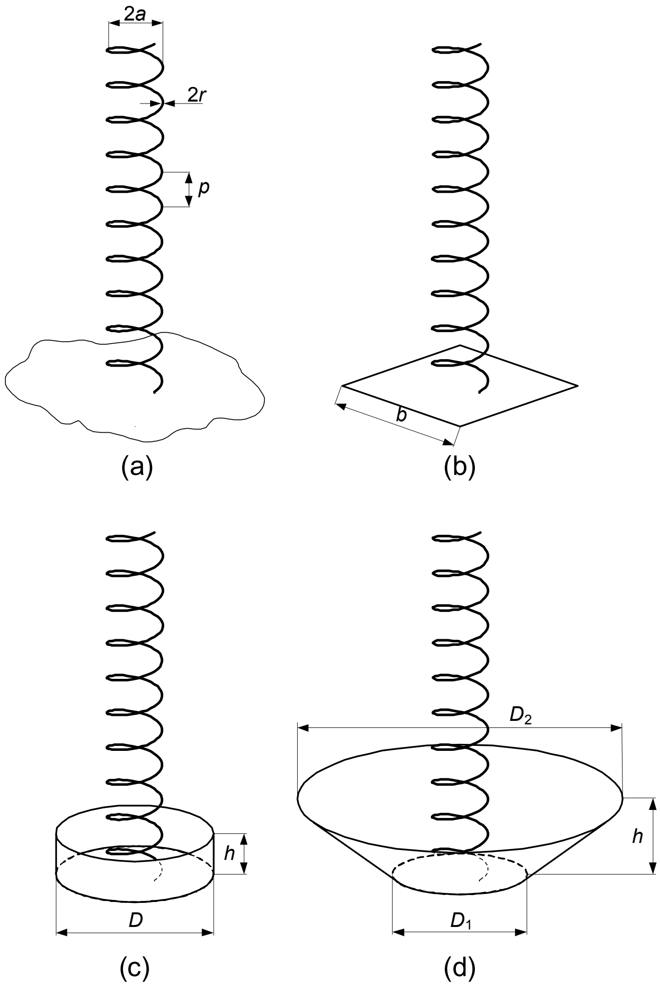

Fig. 1. Helical antenna above (a) infinite ground plane, (b) square conductor, (c) cylindrical cup, and (d) truncated cone.

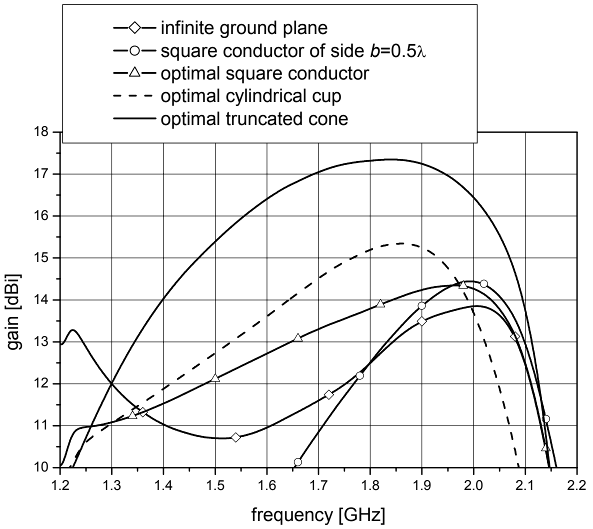

Fig. 2. Computed gain of helical antenna above: infinite ground plane, square conductor of side $b = 0.5\ \lambda$, optimal square conductor, optimal cylindrical cup, and optimal truncated cone.

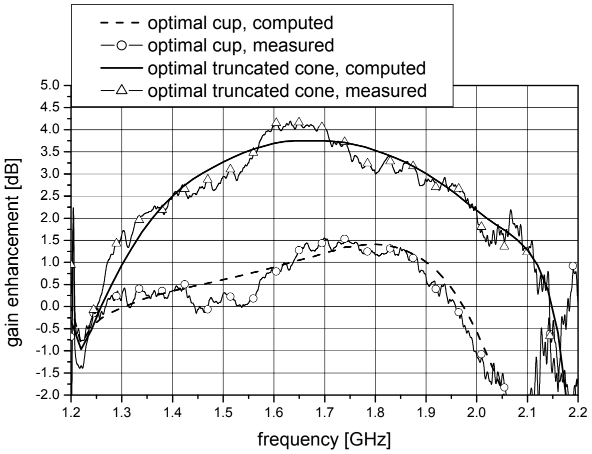

Fig. 3. Computed and measured enhancement of antenna gain (with respect to optimal square conductor) for the antenna above optimal cup and optimal truncated cone.