Nonuniformly-Wound Helical Antennas

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Abstract— **We investigate nonuniformly-wound helical antennas without ground plane (antenna counterbalance is a wire pigtail), with aim to maximize RHCP gain. By optimizing radii and pitches of these antennas, we obtain antennas with the gain that is very close to the gain of the optimal uniformly-wound helical antennas with infinite ground plane, while the obtained nonuniform antennas are smaller and handier.**

I. INTRODUCTION

Helical antennas have been known for a long time [1], but the literature is overwhelmed with controversial information about their performance. In [2], these discrepancies were pointed out and optimized design data for helical antennas located above an infinite ground plane were presented. In [3], it was observed that the shape of the ground conductor has an important influence on performance of helical antennas. The aim of this paper is to present results of optimization for nonuniformly-wound helical antennas with a wire pigtail counterbalance. The optimization goal is to maximize the RHCP gain. The antenna optimizations are carried out using Particle Swarm Optimization algorithm [4]. For modelling and simulating the helical antennas, the electromagnetic solver AWAS is used [5]. The obtained results are crosschecked using the electromagnetic solver WIPL-D [6], [7].

II. OPTIMAL NONUNIFORMLY-WOUND HELICAL ANTENNAS

Fig. 1 shows a nonuniformly-wound helical antenna without ground plane. The antenna counterbalance is a wire pigtail. We consider three families of helical antennas. Each family has constant wire radius, $r/\lambda=10^{-2}$, 10^{-3} and 10^{-4}. For each family, nine antenna lengths are considered: L/λ = 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5 and 5.

We approximate the radius and the pitch of the helix, as functions of the z-coordinate along the antenna axis, by segmented lines, i.e., we have independent piecewise-linear (PWL) approximations for pitch and radius. A PWL function is defined by its values at the segment endpoints. In this particular case we define the helix antenna using 6 points. Therefore, at 6 points along the antenna axis (z=0, z=0.1 λ, z=0.2 λ. z=L/2, z=L-0.05 λ, L) we optimize the radii (R) and pitches (P) of the helical antenna. We take more flexibility for radii and pitches close to the antenna ends, because we expect these areas to be critical. The optimization parameters were varied in the ranges $0.05<R<0.3$, $0.05<P<0.5$.The antenna optimizations are carried out using a Particle Swarm Optimizer based on [4]. For modeling and simulating the helical antennas, the electromagnetic solver AWAS is used [5]. Each optimization is carried out ten times, with a random starting set of solutions, to maximize the possibility of finding the best solution. Best-found results are shown in Table I. Note that the wire radius has negligible influence on the optimal gain for all helix lengths.

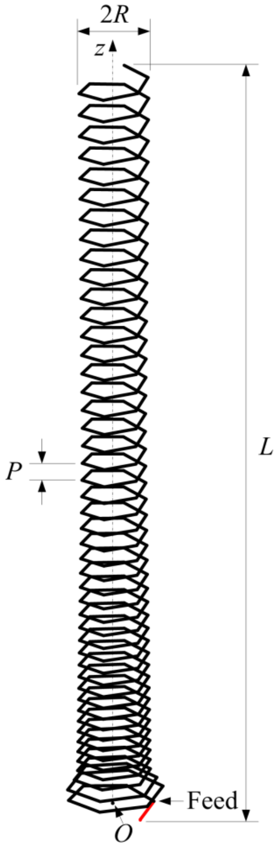

Fig. 1 Nonuniformly-wound helical antenna with wire pigtail counterbalance (red)

For uniformly wound helical antenna with infinite ground plane, the maximal gain for narrowband applications was established in [2]. These results are repeated in Table I. The optimal results for the uniformly-wound antennas with infinite ground plane are close to our results for the nonuniformly-wound antennas. Fig. 2 shows the results from the Table I. For nonuniformly-wound helices we used the average value of the gain of the three familes. For longer helices we obtain slightly higher gain than for the optimal uniformly-wound helices. The obtained nonuniformly-wound antennas are smaller and handier. Hence, these antennas seem to present a very good engineering solution.

TABLE I
GAIN OF HELICAL ANTENNAS

L/λ	Gain[dBi] $r=10^{-2}\lambda$	Gain[dBi] $r=10^{-3}\lambda$	Gain[dBi] $r=10^{-4}\lambda$	Gain[dBi] Ref [2]
1.0	11.67	11.88	11.77	12.6
1.5	13.27	13.11	13.03	13.5
2.0	14.10	14.03	13.96	14.2
2.5	14.99	14.68	14.76	14.8
3.0	15.53	15.55	15.35	15.3
3.5	16.05	16.10	16.01	15.7
4.0	16.54	16.44	16.47	16.1
4.5	16.88	16.83	16.89	16.5
5.0	17.29	17.26	17.25	16.8

Input impedance, gain, and radiation pattern of the obtained optimal helix for $L=4\lambda$ and $r=10^{-3}\lambda$, are shown in Figs. 3-5, respectively. For comparison, the results are obtained using electromagnetic solvers AWAS [5] and WIPL-D [6], [7]. The excellent agreement between the two sets of results makes us confident about the validity of the theoretical results.

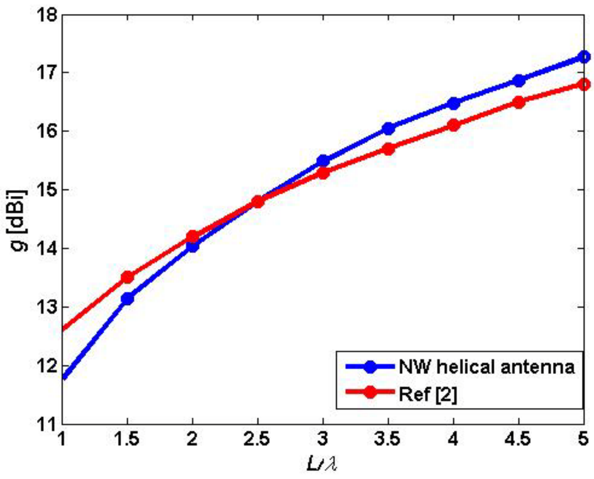

Fig. 2 Antenna gain versus normalized antenna length

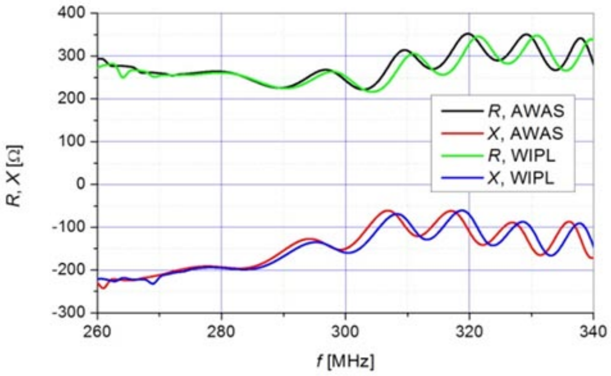

Fig. 3 Input impedance of the antenna

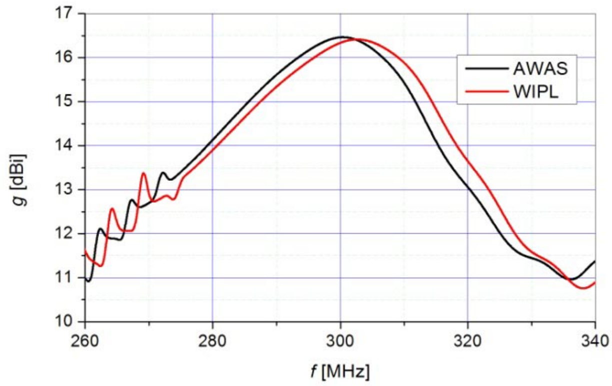

Fig. 4 Antenna gain

In the practical implementation, the antenna is fed using a coaxial cable. It is necessary to prevent leakage of the current along the coaxial cable. Otherwise, it would behave as a part of the antenna and would radiate. A possible solution is to use a coaxial sleeve (a short-circuited quarter-wavelength coaxial-line structure). An alternative is to use a ferrite choke, but it can be inconvenient for high-power applications.

A practically simpler solution is to use a small metallic plate, as shown in Fig. 6. The dimensions of the metallic plate are almost the same as the diameter of the last turns of the helical antenna. This conductive plate does not affect the optimal gain, although it slightly improves gain for the lower frequencies. Hence, the antenna will be more broadband. The plate also prevents current leakage along the coaxial feeder. The input impedance is shown in Fig. 7. It is lower than that of the antenna with wire pigtail counterbalance, which facilitates matching to a 50 Ω coaxial line. The antenna gain is shown in Fig. 8.

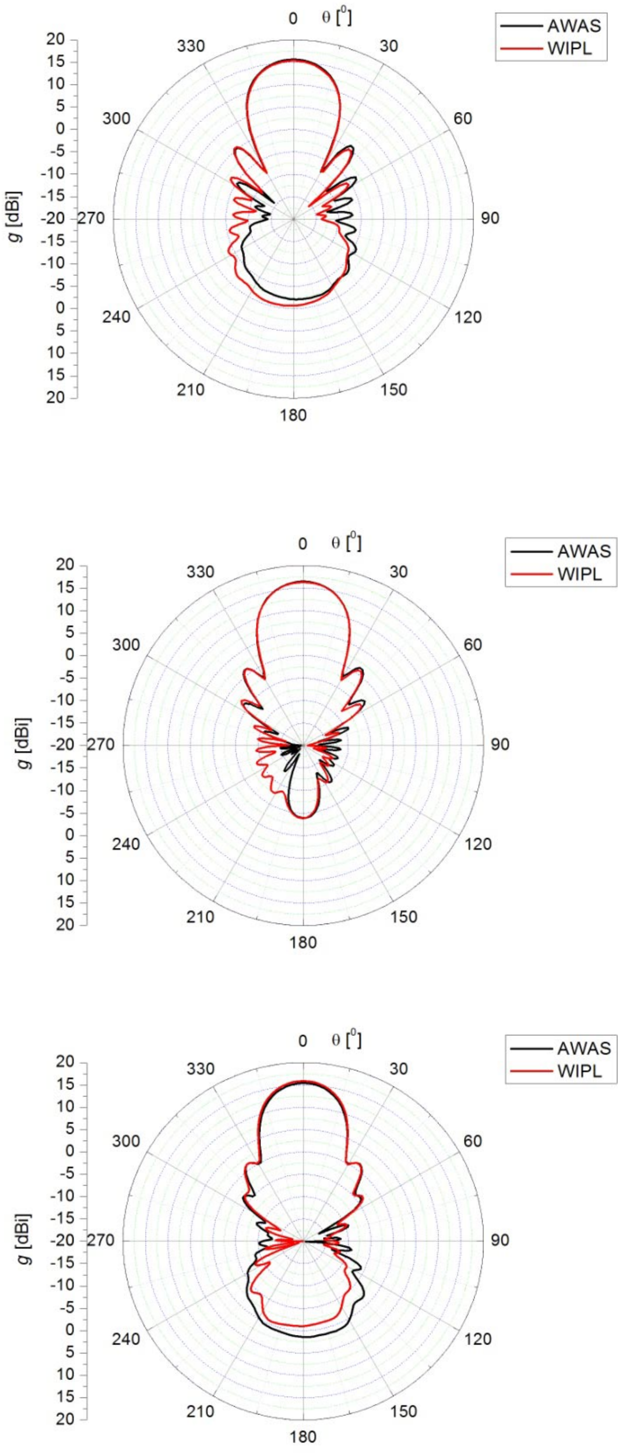

Fig.5 Antenna radiation pattern at
f=290MHZ, f=300MHz and f=310MHz, respectively

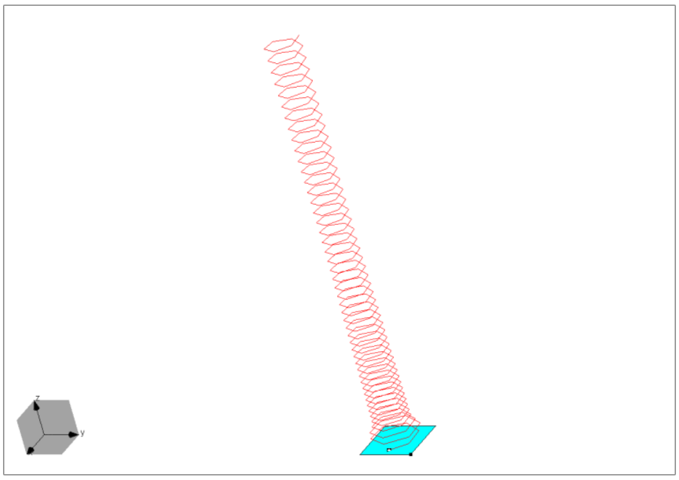

Fig.6 Nonuniformly-wound helical antenna with metallic plate

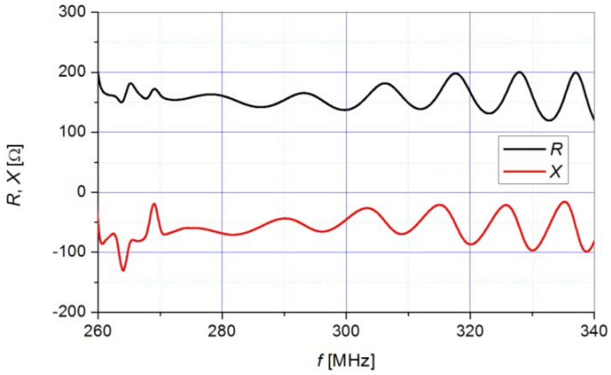

Fig.7 Input impedance of the helix with metallic plate

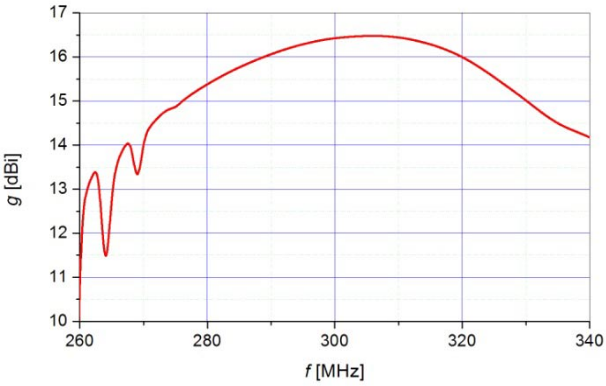

Fig.8 Gain of the helix with metallic plate

III. CONCLUSIONS

We have shown that nonuniformly-wound helical antennas with a wire pigtail counterbalance have gain that is very close to the gain of optimal uniformly-wound helical antennas with infinite ground plane. For the longer antennas, the gain is even slightly improved. The new antennas without the ground plane are smaller and handier and hence provide a very good engineering solution. In practice, the antenna is fed by coaxial cable. To prevent leakage of the current down the coaxial feeder, we propose using a sleeve, a choke, or a small metallic plate. This plate does not affect the maximal gain, while increasing the antenna bandwidth.

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