A Simplified Model for Normal-Mode Helical Antennas

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Abstract: Normal-mode helical antennas are widely used for RFID and mobile communications applications due to their relatively small size and omnidirectional radiation pattern. However, their highly curved geometry can make the design and analysis of helical antennas that are part of larger complex structures quite difficult. A simplified model is proposed that replaces the curved helix with straight wires and lumped elements. The simplified model can replace the helix in the analysis of larger structures that include a helical antenna reducing the computational effort required.

Keywords: Helical antenna, RFID, FEKO

1. Introduction

Helical antennas are widely used in applications where antenna size is critical. Helical antennas operating in "normal mode" have radiation characteristics comparable to a resonant dipole, but are relatively short. Although helical antennas have been around for a long time, there is lack of reliable formulas for their design [1]. Therefore, numerical techniques are important tools for helical antenna design and analysis.

Although, helical antennas have a relatively simple structure, they are mainly composed of curved surfaces. When modeling these antennas using general purpose numerical modeling tools, mesh elements must be generated to fit the helical wire surfaces. This requires a large density of mesh elements and requires a great deal of computational resources. When modeling large structures that include a helical antenna, a significant portion of the computational effort may be devoted solely to the analysis of the helix, even when the helix is a small part of the total structure volume.

In this paper, a simplified model is proposed to speed up the analysis of large structures containing helical antennas. In the simplified model, turns of the helix are approximated by short straight wire segments connected by lumped elements representing the inductance and capacitance of the helical turns. Eight different helix configurations are evaluated using this approach. The resonant frequency and input impedance of each configuration are examined.

2. Methodology

The geometry of a normal-mode helical antenna is illustrated in Fig. 1. The helical antenna is fed at the midpoint of the coil winding. An accurate full-wave analysis of this structure using a general purpose numerical modeling code requires each turn of the helix to be modeled by a large number of short wire segments.

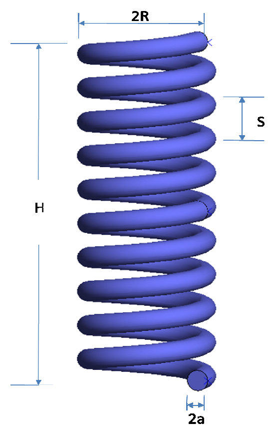


Fig. 1. Helical antenna.

The proposed simplified model consists of one straight wire segment per turn. Each segment is oriented vertically and has a length equal to the vertical height of a single turn in the helix. The segments are connected by parallel inductor-capacitor lumped elements. The lumped elements do not increase the size of the mesh and do not significantly add to the computational complexity of the numerical analysis. Therefore, the simplified model requires considerably less computational resources to analyze than the original full-structure analysis.

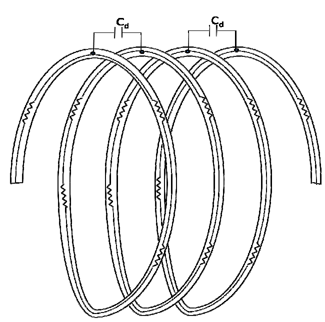


Fig. 2. Distributed capacitance and series resistance in a coil.

A helical antenna is basically a conducting wire wound into a coil form. The coil inductance causes a minute voltage drop between windings, which gives rise to a parasitic capacitance. The distributed capacitance of a helix can be modeled by a shunt capacitance connected between the terminals of the windings as indicated in Fig. 2 [2]. Methods to predict the distributed capacitance of single- or multilayer coils have been proposed in the literature. Applying Massarini's method [3], the turn-to-turn capacitance is given by,

$$C_{to} = 2\varepsilon_0 al \int_0^{\theta_{max}} \frac{1}{S-2acos\theta} d\theta. \tag{1}$$

where l is the turn length given by,

$$l = \sqrt{S^2 + (2\pi R)^2}\ . \tag{2}$$

For typical helical antenna geometries with a pitch much greater than the wire diameter, this shunt capacitance can be neglected.

The inductance of a helix turn is strongly dependent on the pitch angle α, which is defined as

$$\alpha = atan\left(\frac{S}{2\pi R}\right). \tag{3}$$

The inductance of a single turn can be approximated using the equation for the inductance of a circular loop with the same loop radius, R, and wire radius, a, as the helix,

$$L = R\left[ln\left(\frac{8R}{a}\right) - 2\right]. \tag{4}$$

However, this approximation assumes the loop has a planar structure and ignores the mutual inductance between adjacent turns of the helix. For these reasons, Eq. (4) is not an accurate formula for the lumped inductance required by the simplified model. However, it can serve as a general guide for the initial value of this inductance. In this paper, we determine the lumped inductance for the simplified model by comparing an analysis of the entire structure to an analysis of the simplified structure and setting the inductance in the simplified model to the value necessary to get good agreement. The authors are continuing to work on the development of a closed-form expression for determining the appropriate inductance without requiring a full-wave, full-structure analysis of the helix.

3. Model Results

Fig. 3 (a) shows the structure of a simplified model for a 4-turn helical antenna. Each segment models one turn of the helix with a short straight wire and a lumped inductance and capacitance. Typical helical antennas may have as many as 30 – 100 turns.

Numerical modeling of the helixes and simplified structures in this paper was done using FEKO [5]. FEKO employs a boundary element method that requires 1 unknown per straight wire segment. No additional unknowns are required to model the lumped elements. In FEKO, the lumped elements are applied to ports which are defined at the junctions between wire segments. In the 3D display shown in Fig. 3(b), each port is represented by a red cylinder on the positive side and a blue cylinder on the negative side. As shown in Fig. 4(a), FEKO allows users to specify port positions along a wire as a percentage of the total wire length. In the simplified model, all the ports are uniformly distributed along the straight wire making the definition of ports relatively easy for helical antennas with a large number of turns.

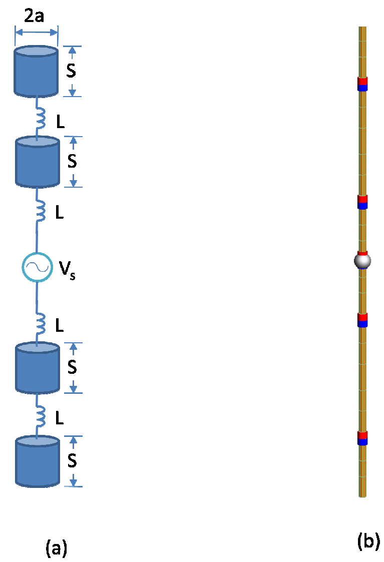
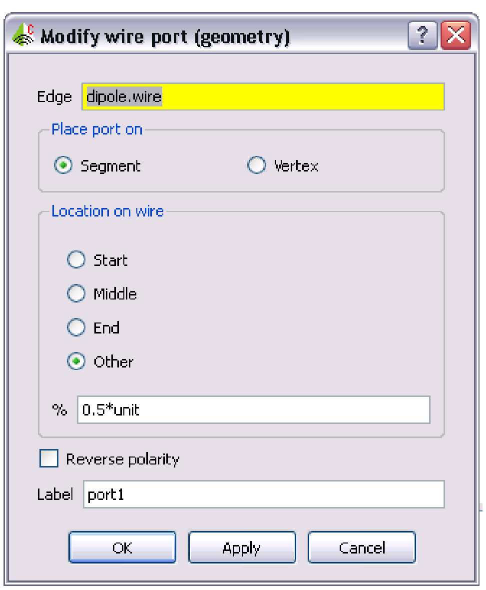


Fig. 3. (a) Sketch of the simplified model. (b) FEKO model.

After the ports are defined, a load consisting of an inductor and capacitor connected in parallel is applied to each of the ports. Assigning a parallel circuit to ports could be a time-consuming task especially for helical antennas with many turns. However, since all circuits are exactly the same except for the port to which the source is applied, EDITFEKO can be used to add a new parallel circuit by copying the LP cards of existing parallel circuits. Cards are pasted and port labels edited directly in the editor window shown in Fig. 4(b). This procedure is repeated until all ports are assigned a parallel circuit.

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** PREFEKO input file generated by CADFEKO version 4.0.107594

** Work in mm
SF: 1 :   :   :   :   : 0.001

** Import mesh model
IN   8 31  "SimpModel.cfm"

** End of geometry
EG: 1 : 0 : 0 : : : : 1 : 1 :   : 0 : 0 : 0 : 0

** Loads
LP: dipole.Wire6.port1 : : : : : 0 : 1e-08 : 0 : : : : :  ** Load1

LP: dipole.Wire6.Port2 : : : : : 0 : 1e-08 : 0 : : : : :  ** Load2

LP: dipole.Wire6.Port3 : : : : : 0 : 1e-08 : 0 : : : : :  ** Load3

LP: dipole.Wire6.Port4 : : : : : 0 : 1e-08 : 0 : : : : :  ** Load4

** Set frequency
FR: 200 : 2 :   :   :   : 335000000 :   : 355000000

** Sources

A2: 0 : dipole.Wire6.feedport : 1 : 1 :   : 1 : 0 ** VoltageSource1

** Total source power
** use defaults

** Requested output
DA: : : : 2
OS: 0 ** Currents1

** End of file
EN

** CADFEKO Checksum: 4472f7547073fbe772a8203ad35494bc
```

(a) (b)

Fig. 4. (a) Create wire port dialog. (b) EDITFEKO.

4. Simulation Results

The appropriate value of the lumped inductance is determined by comparing the analysis of the simplified model to the analysis of a full-structure helix model. Two parameters, the resonant frequency and the real part of the input impedance at resonance, are monitored. The error in the real part of the input impedance is defined as the ratio of the resistance difference over the resistance, Re_0, of the helical antenna at its resonant frequency f_0. The error in the resonant frequency of the helical antenna is difference between the resonant frequency of the simplified antenna, f, and the full helix, f_0, divided by f_0. Expressed as a percentage, the equations for these errors is indicated below,

$$error(Re) = \frac{|Re_0 - R_e|}{Re_0} \times 100\% \tag{5}$$

$$error(f) = \frac{|f_0 - f|}{f_0} \times 100\%. \tag{6}$$

Simplified models were developed for eight helical antenna configurations. In all cases, the wire radius was 0.1 mm and the material was a perfect electric conductor. The geometries and resonant frequencies are listed in Table 1.

Table 1: Simulation configurations

No	Geometry	Resonant frequency
1	$N = 70, R = 1.0\ mm, S = 2.28\ mm, \alpha = 20^\circ$	546 MHz
2	$N = 70, R = 2.0\ mm, S = 4.57\ mm, \alpha = 20^\circ$	258 MHz
3	$N = 70, R = 1.0\ mm, S = 10.9\ mm, \alpha = 60^\circ$	179 MHz
4	$N = 70, R = 2.0\ mm, S = 21.8\ mm, \alpha = 60^\circ$	89 MHz
5	$N = 30, R = 1.0\ mm, S = 2.28\ mm, \alpha = 20^\circ$	1.17 GHz
6	$N = 30, R = 2.0\ mm, S = 4.57\ mm, \alpha = 20^\circ$	556 MHz
7	$N = 30, R = 1.0\ mm, S = 10.9\ mm, \alpha = 60^\circ$	413 MHz
8	$N = 30, R = 2.0\ mm, S = 21.8\ mm, \alpha = 60^\circ$	206 MHz

The simulation results are shown Table 2. For each of the antennas evaluated, it was possible to identify a lumped inductance that would approximate both the resonant frequency and the real part of the input impedance of the corresponding helical antenna accurately.

Table 2: Simulation results

No	Turn N	Pitch angle α	L (nH)	Error (Re) (%)	Error (f) (%)
1	70	20°	5.20	1.07	1.10
2	70	20°	13.4	2.83	0.12
3	70	60°	2.99	0.61	1.68
4	70	60°	7.72	3.17	2.25
5	30	20°	5.20	4.84	1.10
6	30	20°	13.4	6.82	2.86
7	30	60°	2.99	2.37	1.94
8	30	60°	7.72	3.50	2.91

For the configurations evaluated, the simplified model generally yielded results very close to the full-structure helix results within the operating bandwidth of the antenna. The radiation patterns were also similar as illustrated in Fig. 5, which shows the radiation pattern obtained from Configuration 1.

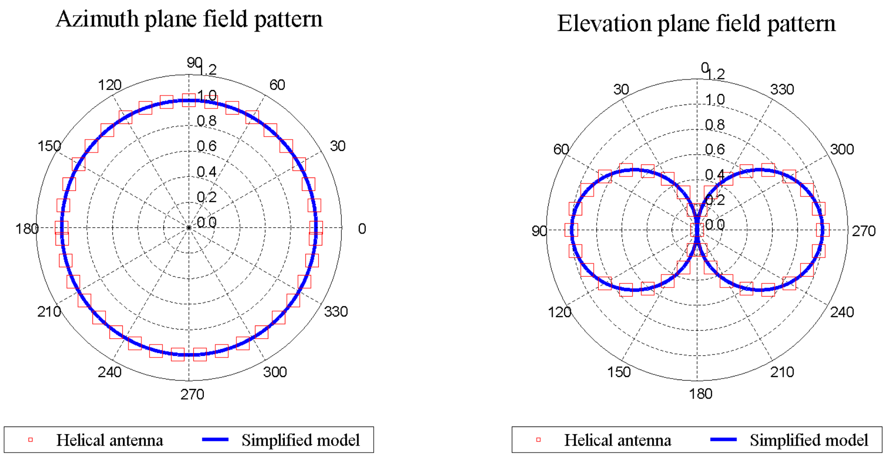

Fig. 5. Normalized radiation patterns from Configuration 1 at 546 MHz.

5. Conclusions

A simplified model for normal-mode helical antennas has been proposed and evaluated using FEKO. Analysis of the simplified model uses considerably less computational resources than analysis of the full helix structure. The simulation results demonstrate that the simplified model exhibits an in-band performance that is very close to that of the full-structure helical antenna.

Although development of the simplified model requires a full-structure analysis of the helical antenna in order to determine the appropriate lumped inductance, this model is useful for analyzing large structures that include a source with a helical antenna. The simplified model allows the detailed analysis of the helix to be separated from the analysis of the larger structure, greatly reducing the computational resources required. Also, once the simplified model is determined, it can replace the full helix in all future large structure simulations employing that antenna.

The authors are continuing to work on the development of a closed-form equation for determining the appropriate lumped inductance without requiring a full-wave analysis of the entire helix.

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