Design Equation for Self Resonant Structures of Very Small Normal - Mode Helical Antennas

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1. Introduction

Recently, normal-mode helical antennas (NMHA) are employed as very small antennas for metal plate proximity uses [1] ~ [3]. In order to obtain efficient radiation, the self resonant condition of a NMHA should be satisfied. In this condition, the inductive reactance and the capacitive reactance of a NMHA are cancelled. As for the inductance, Wheeler presented an equation employing structural parameters [4]. As for capacitance, any useful expression was not found. Therefore, the design equation based on structural parameters is not clarified. How to establish the design equation of self resonance is left questionable.

In this paper, authors pay attention to calculated results of the total wire lengths of antennas at self resonances. First, resonant wire lengths are obtained through electromagnetic simulations. Next, an approximate equation for resonant length data are obtained. By utilizing the approximate equation the design equation for self resonances are established. Comparisons of the design equation and simulation results are compared. Moreover, electromagnetic field distributions around the resonance are obtained. Interesting electric field distributions are clarified.

2. Simulation results of self resonances

A configuration of the NMHA is shown in Fig.1 (a). A current distribution is also shown. The current vanishes at the antenna ends and becomes the maximum (I_M) at the center. This situation is easily understood by utilizing the expression of Fig.1 (b). The antenna wire is unbended to a straight wire. The length of the straight wire (L_0) is express by the next equation.

$$\frac{L_0}{\lambda} = \sqrt{\left(\frac{H}{\lambda}\right)^2 + \left(\pi N \frac{D}{\lambda}\right)^2} \qquad (1)$$

The current distribution of Fig.1 (b) seems the same as that of Fig.1 (a). So, the resonance phenomena of NMHA may be recognized through the resonance length of a straight wire.

The self resonance structures of NMHA can be easily obtained through electromagnetic simulations [2]. In Fig.2, resonant structures at 315 MHz are shown by solid lines. On the resonant lines, wire lengths (L_0/λ) are also indicated. At N=5, L_0/λ changes from 0.35 to 0.56 in accordance with the increase of H/λ. As the increase of N number, L_0/λ values also increase. It is concluded that resonant lengths spread rather widely around the half wavelength.

One more feature of the resonance is current strengths. The currents (I_M) at the antenna center are shown in Fig.3. It is remarkable that very sharp peaks are formed around resonant structures. Between the neighbouring peaks, very deep and wide valleys are formed.

3. Design equation of resonant antenna length

In Eq. (1), L_0/λ are given by numeric values shown in Fig.2. When L_0/λ are expressed by an approximate equation, we can obtain the design equation. In Fig.4, numeric values of L_0/λ in Fig.2 are shown in solid lines. The main feature of curves are expressed by the relation $(L_0/\lambda)^2 = f(N,H/\lambda)$. When $f(N,H/\lambda)$ is approximated by polynomial functions, the next equation for L_0/λ is obtained.

$$\frac{L_0}{\lambda} = 0.14 + \sqrt{\sqrt{N}\left\{2.5\frac{H}{\lambda} - 33.4\left(\frac{H}{\lambda}\right)^2 + 166\left(\frac{H}{\lambda}\right)^3\right\}} \qquad (2)$$

Results of Eq. (2) are shown by broken lines in Fig.4. At large N values such as N=15, the Eq. (2) curve comes below the numeric data curve. On the other hand, Eq. (2) curve comes upper the numeric data curve at N=5. From this tendency, the limit of Eq. (2) on N change is understood.

As a conclusion, the design equation can be obtained by equalizing Eq. (1) and Eq. (2). Self resonant structures obtained through simulations and the design equation are shown in Fig.5. Solid and broken lines agree rather well at all N values. The usefulness of the design equation is ensured.

4. Electromagnetic fields at the resonance

The empirical design equation is shown in the preceding chapter. The next question is what are happening about electromagnetic distributions. Authors tried to calculate electric and magnetic fields around the resonant points A, B, C shown in Fig.3. Calculated results are shown in Fig.6 and Fig.7. Surprisingly, stable electric and magnetic fields exist simultaneously. First, features of electric fields of Fig.6 are investigated. Electric fields of on resonance (A) and two of off resonances B and C are shown in Fig.6 (a), (b) and (c), respectively. The structures A corresponds to the resonance. The structure B corresponds to the slope position and the structure C corresponds to the bottom position. In all positions, electric field distributions do not change. However, at the both end of the antenna, extraordinal electric field distributions are observed. At the upper end, electric fields seem diverge from the area shown by the broken line. From the Maxwell' equation, the positive charge of (+Q) is contained in this area. In the lower end, -Q charge is contained in the area shown by the broken line. The electric performance seems similar to the capacitor-plate antenna [5].

Next, magnetic fields at structures A, B and C are shown in Fig.7 (a), (b) and (c), respectively. In all cases, ordinal magnetic field distributions of a coil structure are observed. So, the self inductance of this coil can be easily estimated with the flux in the coil and the current intensity. As a result, electromagnetic field distributions around the resonance present the same distribution. The only deference is the current magnitude.

5. Conclusions

The total wire length of a NMHA is considered as the deterministic element of the self resonance. Important technical results are summarized as follows.

(1) Resonant wire lengths spread widely around the half wave length.

(2) An approximate functional expression for resonant wire lengths are obtained.

(3) By equating the approximate expression to the total length expression, a design expression for the self resonance structure is formulated.

(4) Electromagnetic field distributions around the resonant structures are obtained.

(5) In the electrical field distributions, charge concentrations like the capacitor-plate antenna are clarified.

6. References

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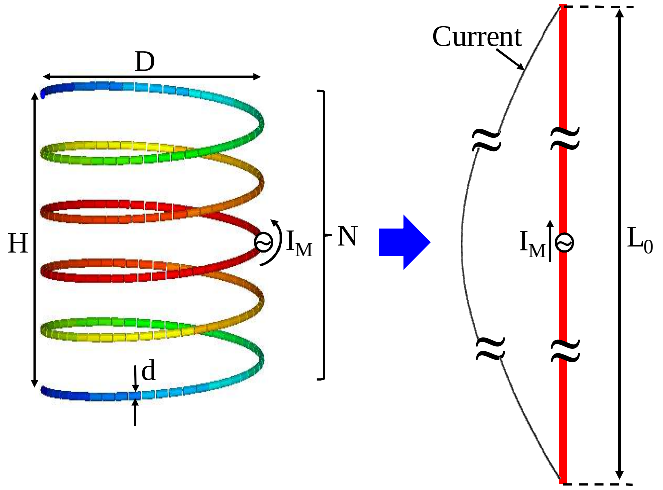


(a) Structural parameters (b) Straight wire configuration of the same wire length

Fig.1 NMHA configuration

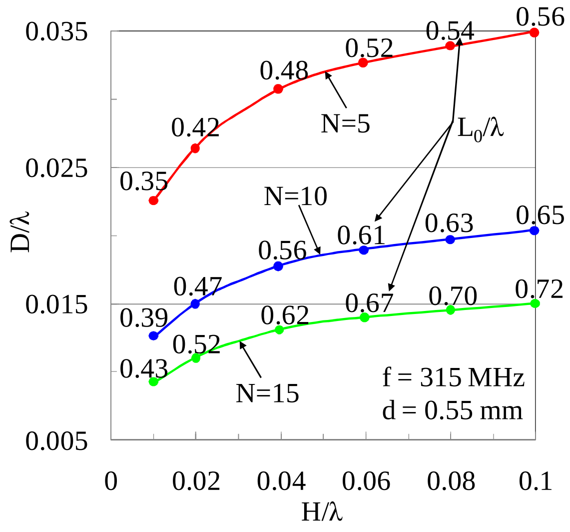


Fig.2 Resonant structures

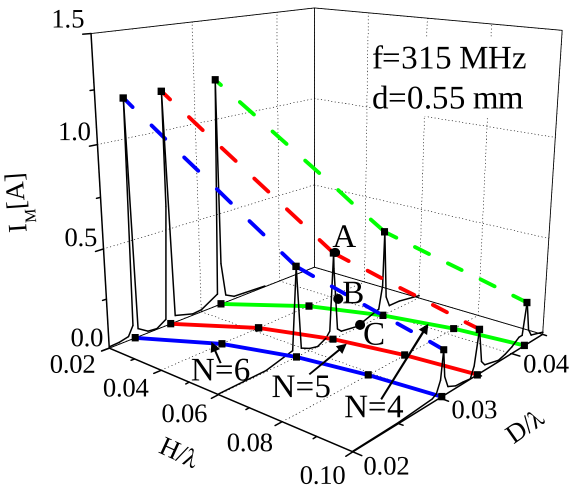


Fig.3 Current near resonances

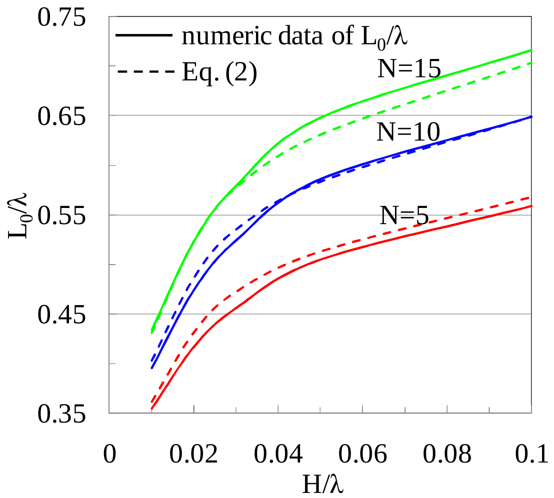


Fig.4 Wire lengths of NMHA

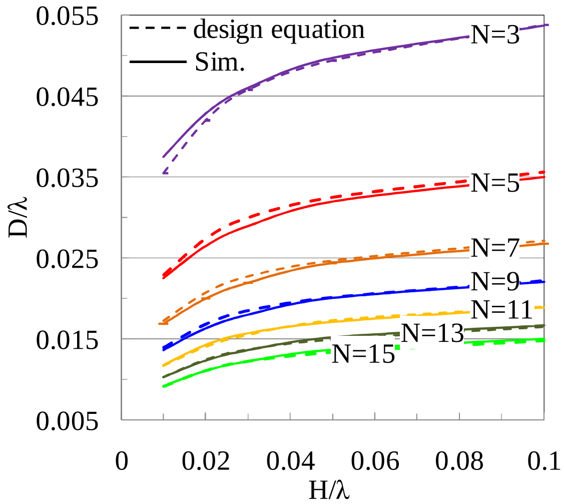
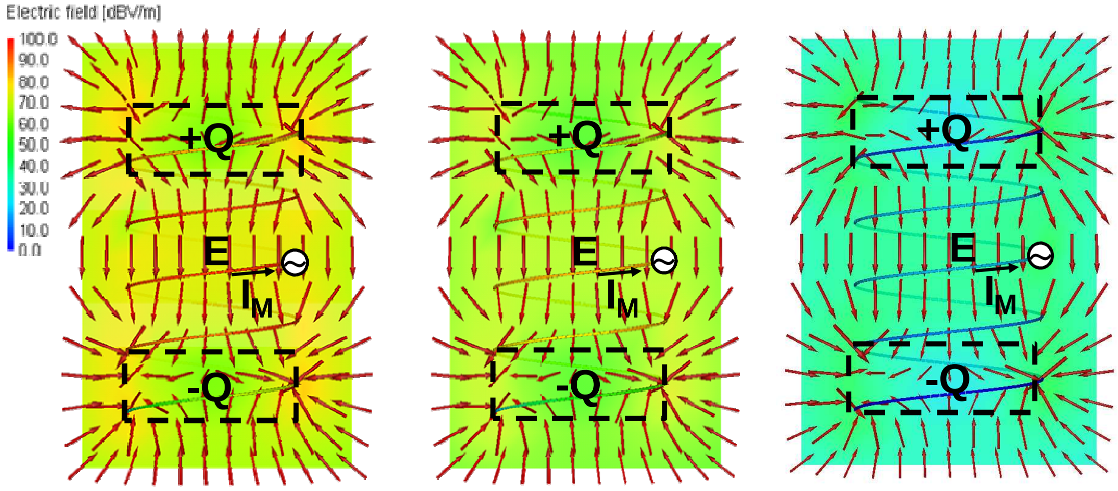


Fig.5 Comparisons of the design equation and simulation results

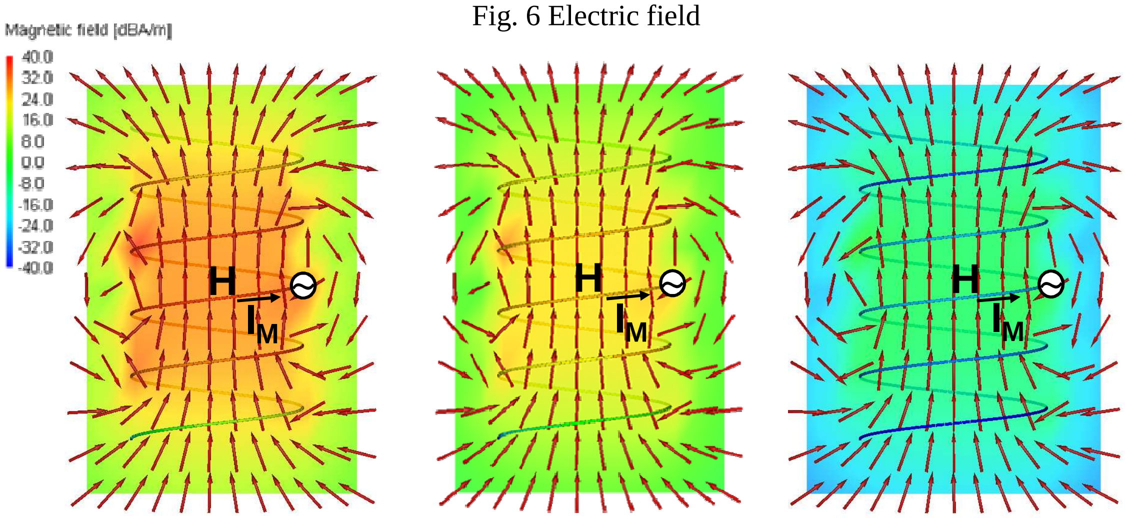


(a) On resonance
(Structure A)

(b) Off resonance
(Structure B)

(c) Off resonance
(Structure C)

Fig. 6 Electric field



(a) On resonance
(Structure A)

(b) Off resonance
(Structure B)

(c) Off resonance
(Structure C)

Fig.7 Magnetic field