A Design of Very Small Normal Mode Helical Antenna for wireless communication systems

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***Abstract* — The normal mode helical antenna becomes an efficient radiator in the condition of the self resonance. When the antenna size is less than 0.03 wavelengths, the antenna input resistance becomes very small such as about 1 ohm. Therefore, the impedance matching structure is inevitable and its usefulness is required as well.**

Keywords: normal mode helical antenna, impedance matching.

I. INTRODUCTION

A very small normal mode helical antenna (NMHA) was conveniently used for the Radio Frequency Identification (RFID) [1] and the Tire Pressure Monitoring System (TPMS) [2], [3] applications. In the reference [1], it is used NMHA size 0.04 wavelengths at 953 MHz. Antenna has maximum gain approximately -0.5 dBd and reaches information distance about 15 m. In the TPMS, the original system employed a small loop antenna at the transmitter mounted in a car tire. In the next generation system, it is intended to increase the antenna gain in order to save the battery power of the transmitter. A NMHA is considered as a promising candidate by taking into account the circumstances surrounded by metallic objects. In the reference [3], it is used NMHA size approximately 0.01 wavelengths at frequency 315 MHz. When the antennas were placed in tire (with carcass and rubber), maximum gain reached approximately -15 dBd. Antenna used in wireless communication devices require a very small size. With this size, the antenna input impedance becomes very small of about 1 Ω. Therefore, the impedance matching structure is required.

In this paper, a very small NMHA with under 0.03 wavelength size is studied in the following manner. First, self resonance condition of the antenna is explained. Second, the calculated result and measured result of input impedance is compared. Third, in order to achieve impedance matching to a radio unit, a simple tap structure is developed. After that, it is a tap result test through tap length and width change. It is a verification of antenna radiation particularity and a comparison between calculated result and measured result. Because of antenna's long tap, usefulness verification has a need of curving tap to antenna axis.

II. SELF RESONANCE CONDITION OF NMHA

The normal mode helical antenna (NMHA) is commonly expressed by the combination of a small dipole (electric current source) and small loop (magnetic current source) antennas as shown in Figure 1. In designing NMHA, cancellation of the capacitive reactance ($-jX_d$) of a small dipole by the reactive reactance (jX_L) of small loops becomes the fundamental condition. This condition is called the self resonance condition.

This condition is determined by structural parameters of antenna length (H), antenna diameter (D) and number of turns (N). Relations of H/λ, D/λ and N can be found through electromagnetic simulations of antenna input impedances. In this study, the wire diameter 0.55 mm is used. The simulation is performed by using a commercial electromagnetic simulator (FEKO) and employing the method of moment (MoM) approach.

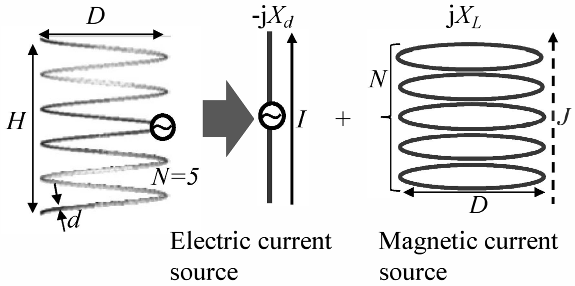

Figure 1. Structure of NMHA

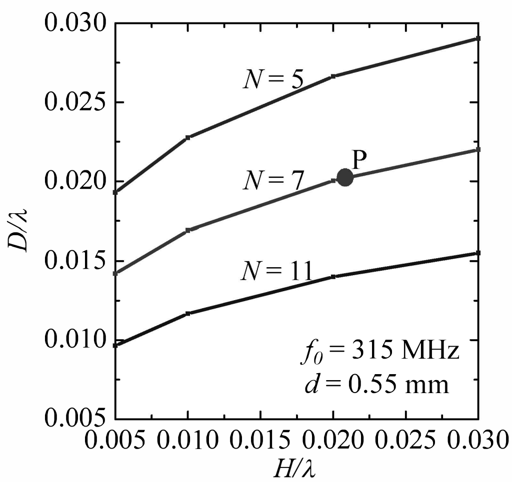

Figure 2. Self resonance condition

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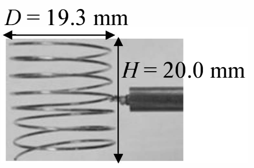
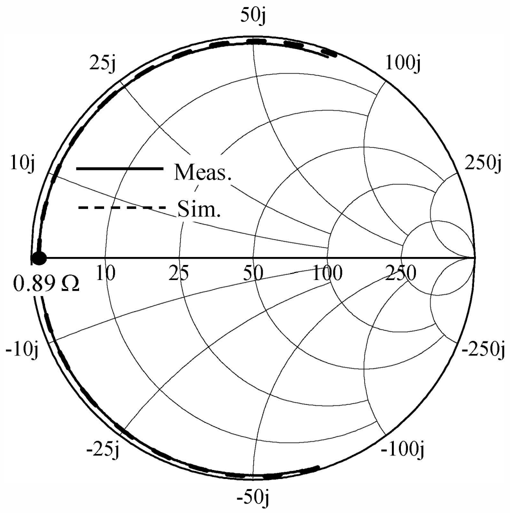
TABLE 1 SIMULATION CONDITIONS (P STRUCTURE)

PC	Intel(R) Core(TM) i3-2350M CPU 2.30GHz, Memory 3.41GB
Simulator	FEKO (MoM)
Frequency	300MHz - 330MHz
Mesh size	1/600 wavelength
Total mesh number	269
Unknown	268
Memory usage	664 kByte
calculation time	1.2 second

The simulation parameters are summarized in Table 1. Structural conditions for self resonances are shown in Figure 2 [4]. When N becomes large, X_L is increased makes X_d must be increased. Accordingly, H/λ is decreased so as to increase X_d. At N = 7, electrical performances are ensured through measurement as shown by black circles. Simulated and measured antenna input impedance of $H/\lambda = 0.021$ (point P in the figure 2) is shown in Figure 3. Figure 3a is the measured structure. The antenna is connected to the 50Ω coaxial cable equipped with a spertopf balun. It is observed that the self resonance condition is satisfied at 315MHz. In the figure 3b, the input impedance is calculated and measured from 300MHz to 330MHz.



(a) NMHA structure (measurement structure, P point)



(b) Input impedance

Figure 3. Measurement structure and input impedance

Moreover, good agreement of measured and simulated results is ensured. In order to estimate antenna gain, values of the radiation resistance (R_r) and the ohmic resistance (R_l) are important. From radiation resistance and ohmic resistance, $R_{in} = R_r + R_l$ is antenna input resistance at the self resonance. In the figure 3b, at the self resonance point (315MHz), the input impedance of 0.89 Ω is ensured. The input impedance is very small and it has a big loss when connected to the 50Ω coaxial cable. In order to achieve impedance matching to the 50Ω coaxial cable, a simple tap structure is considered and will be explained in the next section.

One more important characteristic is antenna efficiency (η) which can be calculated by the $\eta = R_r/R_{in}$ equation. In the simulation, the case of infinite conductivity ($\sigma = \infty$) is obtained to obtain R_r. At point P structure, radiation resistance and input resistance are 0.24 Ω and 0.89 Ω, respectively. The antenna efficiency becomes -5.7 dB.

III. DESIGN IMPEDANCE MATCHING STRUCRURE (TAP FEED)

The problem is to achieve impedance matching between the very small resistance value (0.89 Ω) and the feed cable resistance (50 Ω). A convenient tap structure shown in Figure 4 is employed. The tap feed is connected to the 50 Ω coaxial cable equipped with a spertopf balun. The tap width and length are denoted by a and L, respectively.

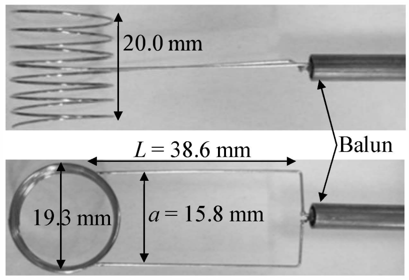
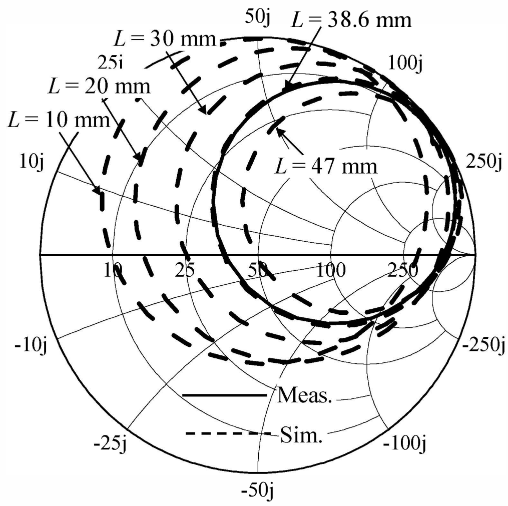
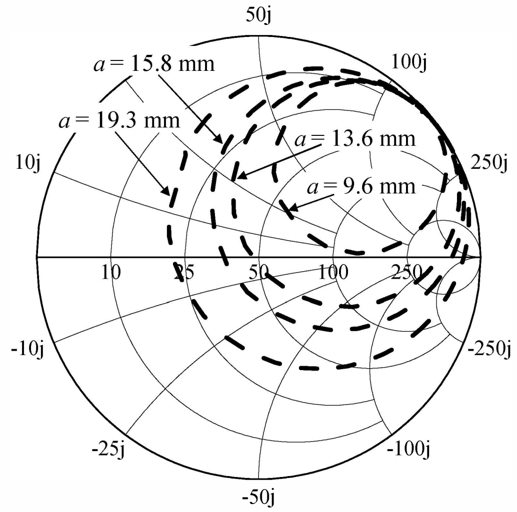


Figure 4. NMHA with tap feed (P structure, $H = 0.021\lambda$)



(a) Fixed a = 15.8 mm, change L



(b) fixed L = 38.6 mm, change a

Figure 5. Input impedance

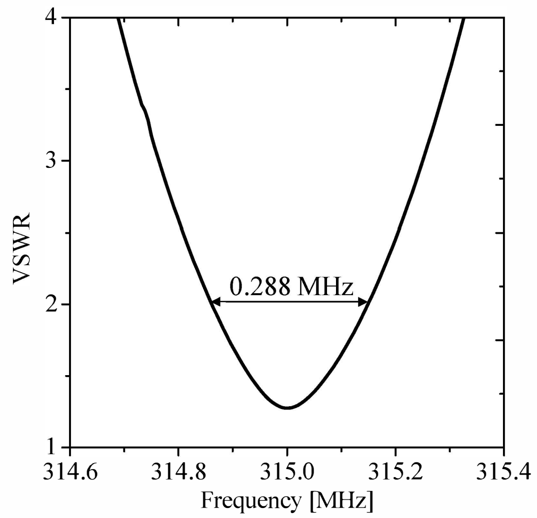


Figure 6. VSWR characteristics

The simulated of input impedances are shown in Figure 5. Firstly, tap width is fixed (a = 15.8 mm), result in figure 5a shows that increasing tap length rises antenna input impedance. With the tap length 47 mm, antenna input impedance reaches 50 Ω. Like this, antenna can has combination impedance with coaxial cable without circuit of impedance matching.

Second, tap length is fixed (L = 38.6 mm) and tap width is changed. Simulated result of antenna input impedance value is shown in figure 5b. The result in figure 5b shows that decreasing tap width creates increasing antenna input impedance at resonance point.

With above result, choices in tap width a and length L for antenna reaches 50 Ω and minimum tap structure simultaneously.

In case of L = 38.6 mm (L = 2D), measurement with structure as in figure 4 comes to result is solid line in Figure 5a. This result shown simulated result and measured result are the same. Consequently, simulated results are verified.

With the antenna structure as shown in Figure 4, measured VSWR characteristic of antenna is presented in Figure 6. This result shows that a very small antenna has narrow bandwidth. With the antenna length at 0.021 λ, its appropriate bandwidth VSWR<2 is 0.288MHz equal to about 0.1% only. Despite the narrow bandwidth, this antenna which is used for TPMS has just been studied at one frequency position. In the process of antenna design, only small change in antenna length can adjust antenna input impedance; shift it to resonance position at working frequency. Hence, narrow bandwidth antenna can be applied in TPMS system well.

With the antenna structure with tap in figure 4, antenna radiation pattern is measured. Measured and simulated radiation characteristics are shown in Figure 7. Dashed line shows simulated results, solid line shows measured results. In this case, the electrical current source component is E_θ and the magnetic current source component is E_φ. Measured and simulated results agree very well. Accordingly, achievement of simulated gain is ensured through measurements. Calculated total gain (G_{total}) is -3.9 dBi. With this result, the total gain which is calculated by formula: $G=D\times\ \eta$ (D is directive property, D = 1.5) is experimented. This result indicates the same antenna efficiency with and without tap. In conclusion, tap of antenna has no affect to antenna gain but increases antenna input impedance for impedance matching with transceiver.

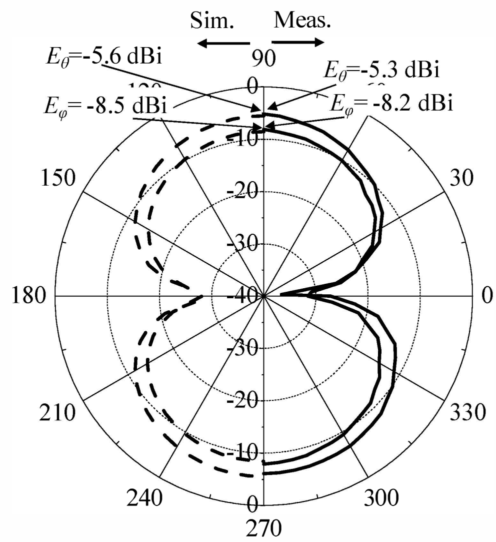


Figure 7. Radiation pattern

IV. USEFULNESS OF THE IMPEDANCE MATCHING STRUCTURE

Using antenna with tap structure in figure 4, impedance can be combined with coaxial cable or transceiver. It is observed in figure 4 that small antenna structure with long tap increases antenna with tap structure very much. To make good, folded tap structure is advanced as figure 8. Distance between antenna to folded point is L_1, remain part of tap is L_2 ($L = L_1 + L_2$).

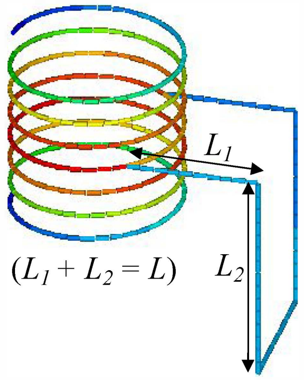


Figure 8. Abilities of a bended Tap Feed structure

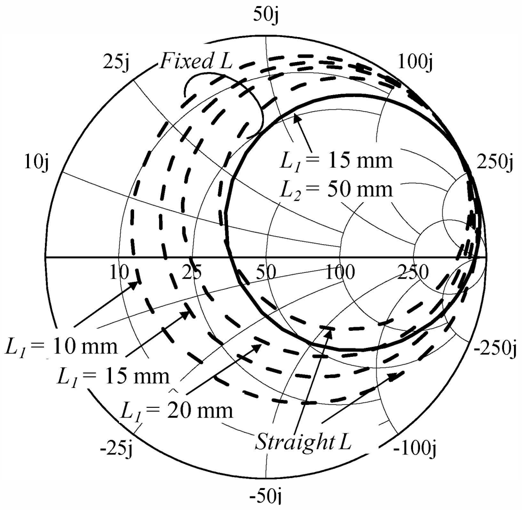


Figure 9. Input impedance (change L_1)

First, fixed tap synthesized length is L (L = 38.6 mm) and width (a = 15.8 mm). L_1 is changed to 10 mm, 15 mm, and 20 mm, respectively. The result of input impedance is shown in figure 9. Calculated result in figure 9 shows, the nearer of tap folded position is, the smaller of antenna input impedance is (the smaller step up is). According to [5], it proves that the nearer tap folded position with antenna makes increasing mutual coupling between antenna and tap and decreasing the step up of antenna.

In the case of L_1 = 15mm, in return for decreasing step up by folded tap structure, antenna synthesized length is increased (mean rise L_2). With the situation of antenna and tap in figure 4, if antenna step up is unchanged, antenna synthesized length will be increased from 38.6 mm to 65 mm (appropriated with increase L_2 from 23.6 mm to 50 mm). Increasing L_2 is appropriate with synthesis mutual coupling between antenna and tap. In that way, it increases step up for antenna. Increasing L_2 length makes antenna synthesized length in accordance with axis increased. In applications such as TPMS, antenna placed in tire which is narrow width but long in other sides is feasible.

Thus, antenna with folded tap will make its structure in perpendicular dimension axis smaller to suitable with applications such as placed antenna in TPMS system.

V. CONCLUSIONS

A very small NMHA under 0.03 wavelength size is designed for wireless communication systems and electrical characteristics are verified through measurements.

- The self resonance conditions for the very small NMHA are shown.

- The input impedance of NMHA is very small about 1 Ω.

- The Impedance matching structure using tap feed is employed.

- Antenna gain of −3.9 dBi is ensured. In this case, electrical current source component (E_θ) is -5.3 dBi, and the magnetic current source component (E_φ) is -8.2 dBi.

- Usefulness of the impedance matching structure is employed by abilities of a bended Tap Feed structure.

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