

On a Transmission Efficiency of Tape-wound Spiral Antenna for Coupled Resonant Wireless Power Transfer

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Abstract - Tape-wound dielectric-loaded spiral antenna for coupled resonant wireless power transfer to realize low-frequency high-efficiency power transmission is proposed. This antenna is fabricated by lap winding of a copper tape and a dielectric tape. Because of tape structure and dielectric loading effect, self-resonant frequency decreased by 30.8 %, which enables us to decrease loss in an RF power source. Additionally, transmission distance over 80% efficiency increased by 40 % because the tape structure decreases conductive loss.

Index Terms — Wireless Power Transfer, Coupled Resonant, Spiral Antenna, kQ product

1. Introduction

Coupled-resonant wireless power transfer (WPT) technology [1] is expected to realize mid-distance cable-less power transfer for electric vehicles and portable devices. For practical use, it is necessary to improve transmission efficiency. In order to increase efficiency in an RF power supply and a rectifier, decreasing transmission frequency is effective. Additionally, increasing efficiency between transmission antennas is also important. For this aim, low-frequency high-efficiency antenna is expected.

In the WPT, two types of antenna are used. One is a LC resonant antenna which resonates by a coupling coil and resonant capacitor. Another is the self-resonant antenna that resonates by the inductance and the capacitance of the antenna itself. We have been investigated self-resonant antenna because of its low-loss property. We have proposed a tape wound spiral antenna [2]. By using a conductor tape instead of a wire, self-resonant frequency decreases because of increasing self-capacitance. Furthermore, transmission efficiency is improved because of decreasing conductive loss.

In a previous study, we proposed a dielectric loaded tape-wound spiral antenna [3]. In this report, we evaluate transmission characteristics based on kQ product.

2. Consideration Model

Consideration model is shown in Fig.1. Conventional wire-wound spiral antenna is shown in Fig. 1(a). By using tape structure (Fig. 1(b)), self-capacitance increases to decrease self-resonant frequency. Additionally, decreasing conductive loss is expected. The dielectric loading tape-wound spiral antenna (Fig. 1(c)) is manufactured by lap winding of a copper

tape and a dielectric tape. Self-resonant frequency is further decrease by applying this structure. Furthermore, by using this structure, it is expected to improve mechanical robustness.

For all models, inner diameter, outer diameter, number of turns are identical. Copper (conductivity $\sigma = 58.13 \times 10^6 \text{S/m}$) is used as a material of the conductor of the antenna. Teflon (relative permittivity $\epsilon_r = 2.08$, $\tan \delta = 0.0004$) is used as a material for the dielectric. These models are contra-directional arrangement model [4].

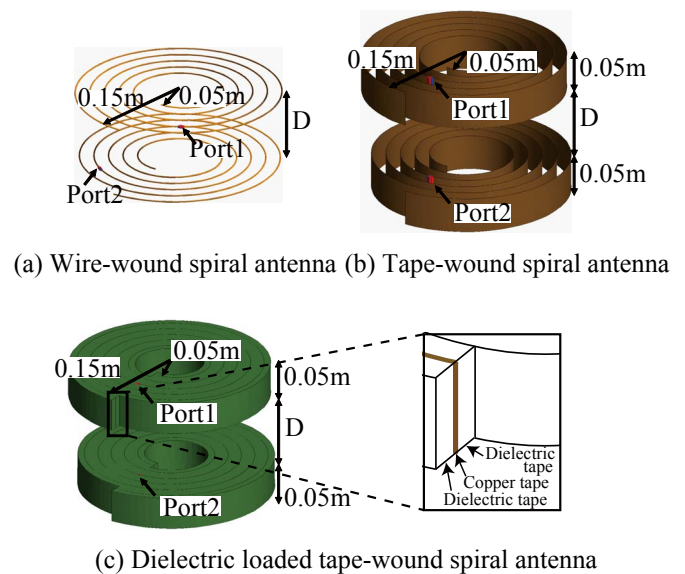


Fig.1 Consideration model

3. Results

(1) Self-Resonant Frequency and Q Factor

Self-resonant frequency is calculated from the input impedance. Table 1 shows self-resonant frequencies of the consideration models. Compared to the wire-wound spiral antenna, resonant frequency of the tape and the dielectric loaded antennas decreased by 14.7 % and 30.8 %, respectively.

Next, Q factor of the self-resonant antennas is calculated from the 3dB bandwidth of the input impedance. Table 1 also shows Q factor of the consideration models. By modifying spiral antenna to tape antenna, Q factor increased from 1321 to 5083. However, by dielectric loading, Q factor decreased to 2474 because of the dielectric loss.

TABLE 1 Self-resonant frequency & Q-factor

	Wire	Tape	Dielectric
Self-resonant frequency	36.7MHz	31.3MHz	25.4MHz
Q-factor	1320	5082	2474

(2) Transmission Characteristics

First, conductor loss and radiated loss normalized by the incident power are shown in Fig. 2. By using the tape antenna, conductor loss is decreased by 10dB. On the other hand, conductor loss of the dielectric-loaded antenna is decreased only by 3dB. This is due to the dielectric loss. Radiated loss is same between the tape antenna and the dielectric-loaded antenna.

Next, distance property of maximum available efficiency η_{max} is calculated. The η_{max} is obtained from Z parameters[5]:

$$\eta_{max} = 1 + \frac{2}{|z_{21}|^2} \left\{ |\mathbf{R}| - \sqrt{(|\mathbf{R}| + |z_{21}|^2)|\mathbf{R}|} \right\} \quad (1)$$

where \mathbf{R} is the real part of the Z parameter matrix. Calculation result of η_{max} is shown in Fig. 3.

By using the tape antenna, transmission distance over 80% efficiency is extended by 100 % compared to the spiral antenna. On the other hand, transmission distance over 80% efficiency of the dielectric-loaded antenna is extended only 40 % compared to the spiral antenna. This is due to the Q factor, which is degraded by dielectric loss.

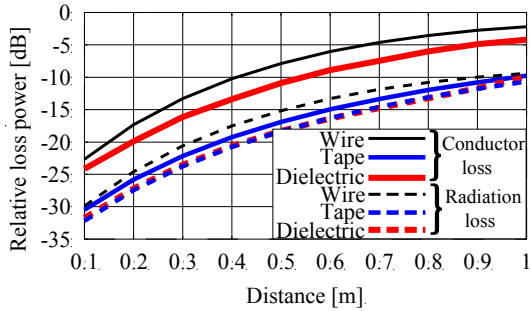


Fig. 2. Distance property of conductor and radiation loss

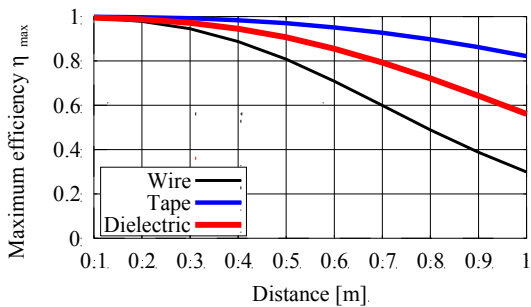


Fig. 3. Efficiency vs distance

4. kQ Product

Comparison of kQ product calculated through different procedures is shown in Fig 4. The solid line shows kQ product that obtained from the Z parameters:

$$kQ = \frac{|z_{21}|}{\sqrt{|\mathbf{R}|}} \quad (2)$$

The broken lines in Fig.4 show kQ product that obtained by multiplying the Q-factor shown in Table 1 to the coupling coefficient calculated from equivalent circuit [6][7].

In all of the models, kQ product obtained through the Eq. (2) and obtained through the equivalent circuit has close value. The tape model has larger kQ product than the dielectric and the spiral model. As a result, the tape model has the best available efficiency among these models.

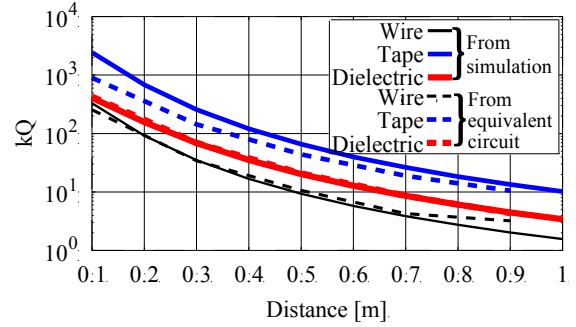


Fig. 4. kQ vs distance

5. Conclusion

We discussed the tape-wound spiral antenna and the dielectric-loaded tape-wound spiral antenna. The dielectric-loaded antenna has 30.8% lower resonant frequency than the wire spiral antenna. The tape antenna has 100 % greater η_{max} than the wire spiral antenna. By using tape structure, Q value was increased. In addition, it was confirmed the best kQ product of the tape-wound antenna in the two types of calculation procedures.

Experimental validation is further challenge.

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