Design of a Double-Layer Spiral Resonator for Wireless Power Transfer

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Abstract

This presentation describes a design of double-layer spiral resonator for wireless power transfer. The double layer structure can increase self-capacitance efficiently to reduce the self-resonance frequency of the resonator. The fabricated resonator operates at 14.07 MHz and is smaller than conventional resonators.

Keywords : wireless power transmission, spiral resonator

1. Introduction

Magnetically coupled resonators which are wire structures such as helical or spiral coils for wireless power transfer have been investigated [1-3]. The resonators can be represented in terms of lumped circuit elements (that represent inductance L, capacitance C and resistance R). If we assume a lossless structure, self-resonance frequency f_0 is determined by L and C. Increasing L can be accomplished by increasing total wire length W and thus increasing the number of turns (increasing flux linkage). However, increasing C is not easy because charges accumulate at two line tips that are separated far when pitch and number of turns increase. Therefore, to decrease f_0, W must be increased. Conventional resonators operate at < 20 MHz and do not apply any miniaturization techniques, so they are too large to incorporate in small devices even though these resonators are designed to power portable electronic devices.

In this presentation, we describe a design of a double-layer spiral resonator (DSR) that operates at 14.07 MHz and is smaller than conventional resonators at the same f_0. We also compare results with those of conventional resonators.

2. Structure of Double-Layer Spiral Resonator

The DSR consists of copper wire (diameter 1.5 mm) configured into two spirals (one above the other), joined by one turn of a helix (Fig. 1). The two spirals have the same length and number of turns, but are in opposite directions to keep their winding directions the same in the DSR; one

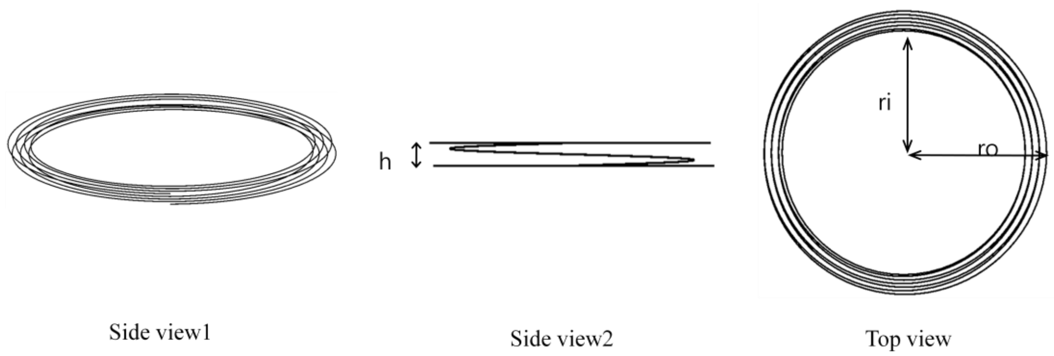


Figure 1: The geometry of DSR. *ri*: inner radius; *ro*: outer radius; *h*: height of helix.

starts from the outer radius into inner radius and the other starts from inner radius to outer radius. Because the line current forms a half-wave sine curve at f_0, this configuration allows the direction of current to be same when the DSR is excited at f_0. A constant radius, one-turn helix connects the two spirals.

At resonance, the current is the strongest at the helix (center of the wire) and is zero at two spirals' tips; conversely, the charge is zero at the center of the helix and strongest at spirals' tips, but the tips are induced by charges of opposite polarity. Therefore, an electric field is formed from one spiral to the other. This means electric energy is stored between two spirals, so its energy contributes self-capacitance which can be controlled by changing the height h of the helix. Because capacitance is in inverse ratio to distance, decreasing h yields increasing capacitance. This indicates that the DSR can increase capacitance efficiently compared to conventional resonators.

The f_0 of the DSR can be reduced by increasing the self-capacitance rather than by increasing W which results in increasing self-inductance and it has a spatial advantage. f_0 is inversely related to the square root of the product of C and L;

$$f_0 = \frac{1}{2\pi\sqrt{LC}}. \quad (1)$$

If C increases and f_0 is constant, L must decrease; W decreases. Also, because the DSR uses a double layer structure, the wire shrinks more than in conventional resonators when h is small. This means that the DSR is a little larger than a single-layer spiral resonator (SSR) but W is two times larger than in the SSR. Therefore, the spatial configuration of the DSR is more efficient than that of a conventional resonator.

3. Comparison Result

We designed five resonators (Fig. 2) and used a moment method simulator, FEKO (EMSS-SA) to calculate f_0 for each of them (Table 1). Design (a) is a DSR as a reference. Design (b) is an SSR; compared to the DSR, it has the same f_0 and *ro*, but it has 65.2% longer W and cannot be designed with the same pitch. Design (c) is also an SSR; compared to the DSR, it has the same f_0, *ri*

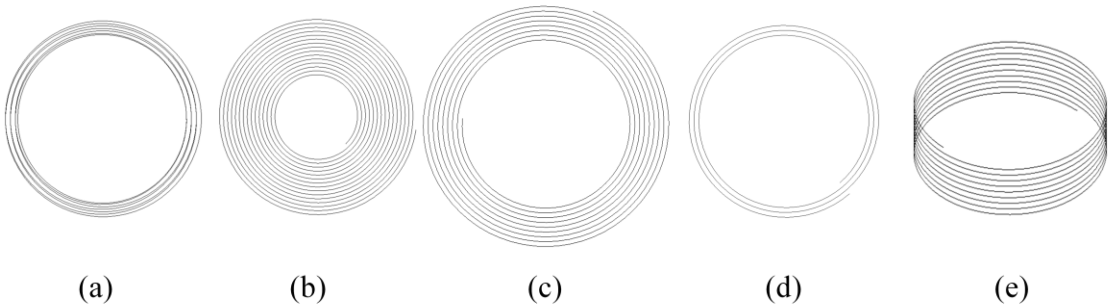
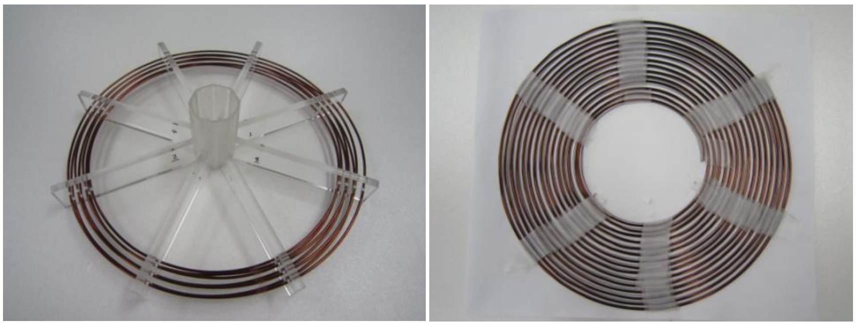


Figure 2: The geometry of five resonators. Characteristics are described in the text.

Table 1: Comparison results. Wire diameter: 1.5 mm.

Case	f_0 (MHz)	*ri* (mm)	*ro* (mm)	# turns	*h* (mm)	Wire length (mm)
(a)	15	85	100	3	5	4,021
(b)	15	40	100	15.1	-	6,642
(c)	15	85	128.5	8.7	-	5,835
(d)	47.7	85	100	3	-	1,743
(e)	15	100	100	9.5	47.5	5,970



(a) (b)

Figure 3: Photographs of resonators a and b (Fig. 2). Wire diameter: 1.5 mm.

and pitch, has 28.5% larger *ro* and 45.1% longer *W*. Design (d) is an SSR and is a component of (a); design (d) operates at 47.7 MHz, which is three times higher than that of (a), but its bulk is not much different from that of the reference. Design (e) is a helix resonator; compared to the DSR, it has the same f_0 and *ro*, but is bulkier and has 48.5% longer *W*.

We fabricated designs (a) and (b) (Fig. 3), then excited them using a small feeding loop and measured their f_0s. Design (a) resonated at 14.07 MHz and design (b) resonated at 14.71 MHz. Thus, these two designs had similar f_0 even though *W* of (b) is 65.2% longer than *W* of (a). However, their f_0s are lower than obtained in the simulations (Table 1). This difference can be caused both by fabrication error and by the proximity of dielectrics. The copper wire was coated with a dielectric, and the supporter was also a dielectric. Because *L* decreases as *W* decreases and f_0 increases as *L* decreases (Eq. 1), the resonators can be tuned to resonate at the desired f_0 by trimming the end of the wire.

4. Conclusion

This study presents designs of a DSR for wireless power transfer. This design has the advantage that its self-capacitance can be easily adjusted. Moreover, the DSR is a double layer structure so it increases spatial efficiency. Compared to conventional resonators, the DSR is smaller and shorter at the same f_0.

References

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Acknowledgments

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