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Design and numerical analysis of a Birdcage resonator without lumped capacitors

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Abstract

To handle the high, continuously transmitted power, a birdcage resonator without lumped capacitors is created. The discussed design consists of eight partially overlapping sheets of copper on polyimide. The resulting structure (polyimide substrate between two copper layers) creates the capacitive part of the resonator, without the need for any added capacity. The fine-tuning of the resonance frequency by the change in the area of the overlapping part is described. Finally, the frequency of the fundamental resonance mode is adjusted to 300 MHz.

1. Introduction

The birdcage resonators were created for use in magnetic resonance imaging (MRI) [1]. The resonator consists of two endrings and an even number of legs, which connect the endrings together. There are two basic designs, based on the position of the capacitors: high-pass and low-pass [2]. Recently, birdcage resonators were also proposed for utilization in plasma sources [3]. However, for plasma processing, one might expect long-term operation, with hundreds of watts of transmitted power. While the power was usually delivered in the pulse regime in the field of MRI, the continuous regime is expected within the plasma source. This condition will create thermal stress on all parts of the birdcage resonator. Following the standard design, the inserted capacitors will be the weak points. The dimensions of the resonator are in the range of units or tens of centimeters, but the capacitors are usually delivered in SMD housing. Heat can be better dissipated in designs that rely on distributed capacity.

There can be found attempts to create the birdcage resonator without using the lumped capacitors [4,5]. However, our design is relying on well-available materials, with special emphasis on easy fabrication. The concept discussed within this paper consists of a polyimide foil with a copper layer, the ordinary substrate for flexible printed circuit boards.

2. Design of the Resonator

The model contains eight sheets of polyimide with etched copper structures (Figure 1). Both the polyimide and the copper layers are 35 µm thick. Half of each sheet overlaps with the adjacent one, creating a copper – polyimide – copper sandwich structure, which produces the capacitance. The eight sheets completed together to the octagon shape create the high-pass type birdcage resonator (Figure 2). We favored the octagonal structure over the circular shape due to significantly reduced computational time and easier fabrication of the future prototype. However, the circularly shaped resonator will bring even better homogeneity of the electric and magnetic fields, which may be important for specific applications.

The resonant frequency can be changed by the area of the overlapping parts. In Figure 3, three resonators with different endring widths are compared. The resonator created of wider endrings possess more inserted capacity, therefore its resonance frequency is shifted to the lower values. The fundamental resonance mode is highlighted by a red dashed line.

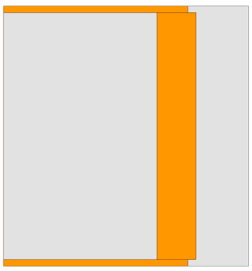

Figure 1: Schematic drawing of one of the segments, that creates the resonator

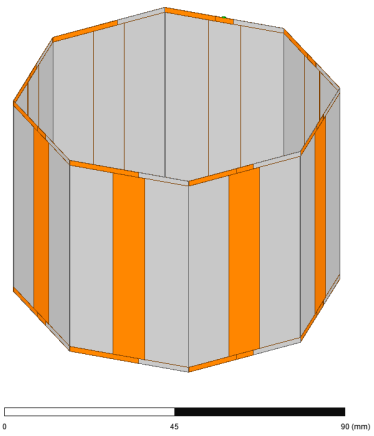

Figure 2: Design of the resonator.

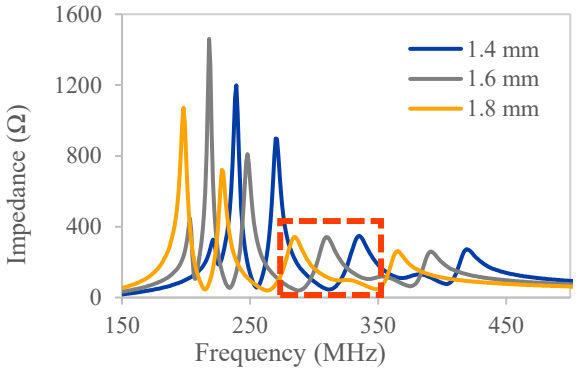

Figure 3: Comparison of the resonators with different width of the endrings

3. Results and discussion

The width of the endrings was used to tune the resonance frequency of the fundamental resonance mode to the value of 300 MHz. The resulting width was 1.52 mm, and the parameters of this resonator are shown in Figure 4. The magnetic field distribution inside the birdcage resonator for the frequency of 300 MHz is shown in Figure 5. The homogeneity of the field shows the correct choice of the resonance mode and the feasibility of the proposed design.

Once the resonator is manufactured, impedance matching will be performed. The impedance peak at the resonance frequency is broader than that for standard resonators. Therefore, the frequency of minimal reflection may be located farther to the maximum impedance peak (in dependence on the chosen impedance matching). The minimal value of S_{11} obtained from the numerical analysis (using Ansys HFSS) is -29.9 dB, at the frequency of 288.3 MHz. If the resonator is matched by a capacitor in series, the operating frequency can be expected to be similar. On the other hand, with inductive-coupled matching, the minimal reflection, therefore, the operating frequency will remain 300 MHz. However, by adjusting the width of the endrings, the operating frequency can be adjusted.

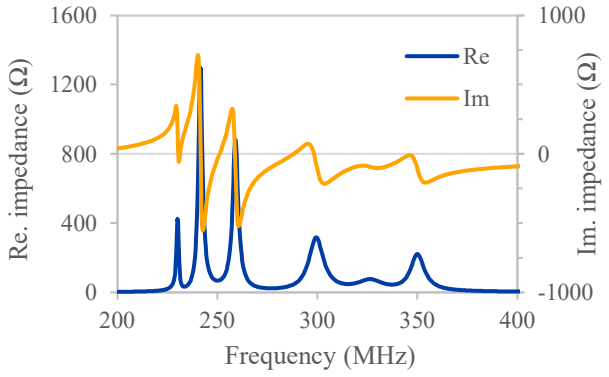

Figure 4: Impedance (real and imaginary part) of the final resonator with 1.52 mm wide endrings

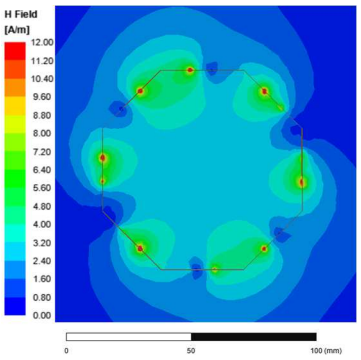

Figure 5: Magnetic field distribution in the half of the width of the resonator (top view)

4. Conclusions

By changes in the endring width, the final resonance frequency of the birdcage resonator was tuned to 300 MHz while the homogeneous magnetic field was created. The low reflected power and the homogeneous field distribution confirms the viability of the described concept.

5. Acknowledgements

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6. References

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