Magnetic Resonator Design in a VHF Range using a Systematic Design Approach

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In this study, we propose an unprecedented conductive structure of a metallic magnetic resonator using the phase field design method that is a 2-D design approach to harvest magnetic energy for the wireless communication in very high frequency range. The phase field design method using the reaction diffusion equation combined with a modified interpolation scheme was performed for design of the magnetic resonator. The derived optimal structure is reformed by employing the post-processing scheme only once that determines the clear boundary to improve the performance and manufacturing feasibility of the final model. The performance of the proposed magnetic resonator is verified via numerical simulations.

***Index Terms*—Magnetic resonator, phase field design method, topological design, VHF range**

I. INTRODUCTION

IN modern society, electromagnetic (EM) devices such as the mobile and handheld equipment have been advanced. Following this trend, wireless communication technique has required to enhance its performance of signal transmission and operation efficiency at the target frequency. Magnetic resonator has been repeatedly undertaken for the wireless energy transfer using various approaches such as electrical circuit method and simple theoretical analysis [1]. However, the conventional design technics represent low efficiency and non-effective to lead the performance of the wireless energy transfer of the derived structure in very high frequency (VHF) ranges. The electromagnetic field is sensitively influenced by a structural layout of conductive material. Therefore, a systematic design approach such as the phase field design method is required to obtain an effective and innovative magnetic resonator composed of conductive material.

In this study, we introduce a systematic design approach based on the phase field design method [2] to design the metallic magnetic resonator. We focused on generating magnetic resonance at measuring domain that leads to a smooth wireless energy transfer. The finite element analysis (FEA) and design process were implemented using Matlab programming associated with the commercial package COMSOL Multiphysics 3.5a [3]. Performance of the magnetic resonator was confirmed through numerical simulations.

II. NUMERICAL SIMULATION

Fig. 1 shows the schematic diagram of a numerical simulation model. The total analysis domain is surrounded by the perfect matched layer (PML) region which is set to eliminate the reflection from the boundary [4]. The design domain is composed of two square shaped regions situated above and below the measuring domain which is located by the center of the total analysis domain. The incident plane wave of 1 A/m is excited from left to right of the total analysis domain at the target frequency of 115 MHz. The tangential magnetic field was calculated from solving the wave equation based on the Helmholtz equation for transverse magnetic mode as the following equation:

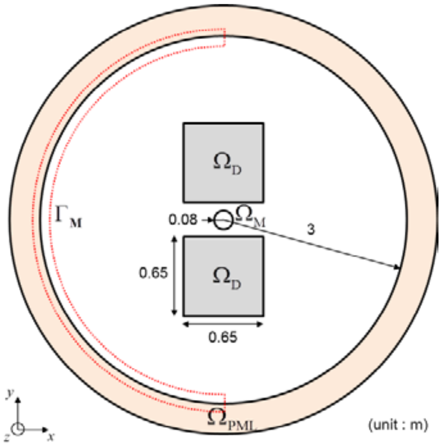

Fig. 1. Schematic diagram for analysis and design of the magnetic resonator.

$$\nabla \cdot \left(\frac{1}{\varepsilon_r} \nabla H_z \right) = -\left(\frac{\omega}{c} \right)^2 H_z , \tag{1}$$

where H_z is tangenitial magnetic field and ε_r is the relative permittivity. ω and c are the angular frequency and the speed of light in the vacuum, respectively.

III. DESIGN PROCESS

The design objective is set to maximize the integration of the magnetic energy Ψ in the measuring domain as

$$\begin{aligned} &\text{Maximize} \quad F(\phi, H_z) = \Psi\big|_{\text{at the measuring domain}} \\ &\text{Subject to} \quad 0 \le \phi \le 1, \end{aligned} \tag{2}$$

where the F is the design objective function with respect to the design variable ϕ. We perform the design process using the systematic design approach based on the phase field design method. The proposed method separates two phases of the solid and void material distributing the design variable which is updated using the reaction-diffusion equation with double well potential (DWP) functions [5].

$$\frac{\partial\phi(\mathbf{x},t)}{\partial t}=\tau\nabla^2\phi(\mathbf{x},t)-aw(\phi)-g(\phi)\frac{\partial\bar{F}(\phi,H_z)}{\partial\phi},\tag{3}$$

where τ is a diffusion coefficient and a is a symmetry factor. $w(\phi)=\phi^2(1-\phi^2)$, $g(\phi)=\phi^3(6\phi^2-15\phi^2+10)$ are respectively a smooth Dirac delta function and a smooth Heaviside function in the range of $0\le\phi\le1$. $\partial\bar{F}/\partial\phi$ is the gradient of the agmented Lagrangian. Distribution of the conductive material gives rise to unstable convergence from the sharp fluctuation of the design sensitivity. Therefore, the interpolation scheme based on the sigmoid function [6] is proposed to achieve the stabilization of the design sensitivity as following:

$$\varepsilon_r(\phi)=\varepsilon_{air}+(\varepsilon_{a-PEC}-\varepsilon_{air})\left(1+\frac{1-\phi}{1-\kappa_m}\right)(\phi)^{\frac{\kappa_m}{1-\kappa_m}}\tag{4}$$

$$\text{with}\quad 0\le\kappa_m<1\quad\text{and}\quad 0\le\phi\le1,$$

where ε_{air} and $\varepsilon_{a\text{-}PEC}$ are the relative permittivity of the air and the good conductive material, respectively. κ_m is the controllable coefficient to handle the slope of the function. In this study, the post-processing scheme is proposed to determine the clear shape of the final model with the improved performance and manufacturing feasibility. The adaptive mesh generation with a parametric study based on the phase field parameter level was performed only once with respect to the derived optimal model.

IV. Numerical Result

The proposed design process was carried out during the 2000 design iterations. Table I represents the optimal model which is derived from the initial model set to the symmetric circular shaped model. The final model using the post-processing from the derived optimal model has the clear boundaries of the conductive structures. The final model is composed of the differently shaped structures in the upper and the lower design domains. The performance of the final model shows nearly twenty times higher performance than the initial model. Fig. 2 shows good confinement of the magnetic energy density at the measuring domain of the final model.

V. Conclusion

In this study, we derived an unprecedented 2D conductive structure of the magnetic resonator using the phase field design method. We verified the performance of the proposed structure by using numerical simulations. The proposed method can be scaled to higher frequency band such as ultra high frequency (UHF) band and super high frequency (SHF) band for further applications.

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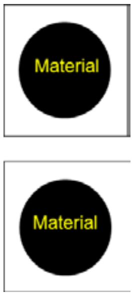
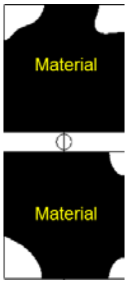
TABLE I
Comparison Results From The Initial Model, The Optimal Model, And The Post-Processing Model

	Initial model	Optimal model	Final model
Objective function [N]	2.21e-7	4.06e-6	4.25e-6
Normalized objective function [a.u.]	1	18.37	19.23
Shape of the model			

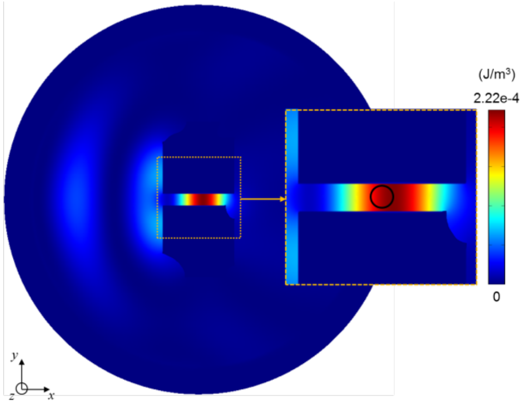


Fig. 2. Contour of the magnetic energy distribution from the final model.

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