Topology Optimization of Tag Structures for Chipless RFID

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***Abstract*—This paper presents shape optimization of chipless RFID tags. In the present optimization, chipless RFID tag characteristics are analyzed by the finite-difference time-domain method. The shapes of chipless RFID tag are optimized by using the micro genetic algorithm and on-off method with moving average filter in order to maximize an amplitude and a quality factor of backscattering wave reflected by the chipless RFID tag. The optimized chipless RFID tag has higher amplitude and quality factor of backscattering wave.**

Keywords*—*Chipless RFID, FDTD method, μ-GA, topology optimization.

I. Introduction

A chipless radio frequency identification (RFID) has been intensively studied because it has promising applications in remote environmental sensing, retail item management and so on [1]-[3]. The chipless RFID systems are composed of a RFID reader and several chipless RFID tags. The chipless RFID tag provides an advantage on reducing costs because it does not require an IC chip. The RFID reader sends electromagnetic waves at multi frequencies. By reflecting them, the chipless RFID tag sends a data to the RFID reader.

It is important for big data and long range communication between the RFID reader and chipless RFID tag to maximize a quality factor Q and an amplitude of backscattering wave from chipless RFID tag. For this purpose, the chipless RFID tags have been designed [4]-[6]. Although the shapes of chipless RFID tag have been optimized, an enough performance has not been obtained because the conventional parameter optimization has insufficient degrees of freedom (DoFs).

In this work, this characteristics of chipless RFID tag are analyzed by the finite-difference time-domain (FDTD) method. The shapes of chipless RFID tag are topologically optimized by micro genetic algorithm (μ-GA) [7] and the on-off method [8]. The topology optimization has much more DoFs in comparison with parameter optimization. To obtain optimized chipless RFID tags which are good workability, we introduce moving average filter [9] into the optimization processes.

This paper will be organized as follows: in Section II, the optimization settings will be described, and in Section III, numerical results will be presented which shows effectiveness of the present optimization method.

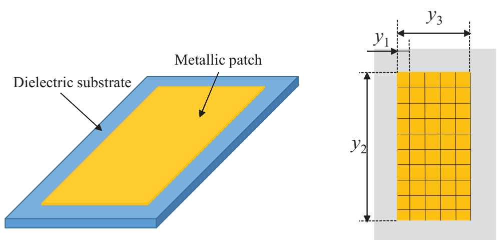
II. Optimization Problem

A. Design of chipless RFID tag

In this work, a structure of chipless RFID tag is optimized. The chipless RFID tag is composed of a metal patch and dielectric substrate as shown in Fig. 1 (a). In this work, the shape of the patch is represented by the on-off method, in which the conductor is set at the cell whose state is "on" as shown in Fig. 1 (b). Moreover, the moving average filter is adapted in the optimization processes for smoothing. The moving average filter used in this work determines the value N_5 shown in Fig. 2 as followings:

$$N_5 = \left[0.5 + \frac{1}{9} \sum_{i=1}^{9} N_i \right] \quad (1)$$

where N_i = {0, 1}. The optimization setting of the chipless



(a) Overview (b) Phenotype

Fig. 1 Overview and phenotype of chipless tag for μ-GA. If the state of the cell shown in (b) is "on", it is covered by small rectangular metal plate.

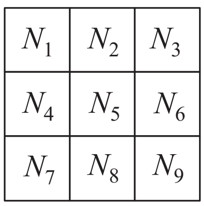


Fig. 2 Moving average filter.

RFID tag is described in the followings, where a phenotype of the chipless RFID tag is shown in Fig. 1 (b).

1. A base patch of the chipless RFID tag is devided into a lattice pattern.
2. Each cell is determined to be conductive or open in the topology optimization.
3. The states of the cells are filtered by the moving average filter.
4. The dielectirc layer is set to the rectangle that is larger than the resulatant patch.

In this work, y_1 is set to 2 mm, y_2 and y_3 are set to 60 and 30 mm. The height of dielectric is set to 1.5 mm. The relative permittivity of substrate is set to 4.2. The shape of chipless RFID tag is represented by 2 bit genes in the μ-GA process.

B. Micro genetic algothim

A genetic algorithm (GA) is an optimization method that mimics mechanism of the evolution of animate beings. The μ-GA is one the new version of the GA that has very small population and reinitialization. In the reinitialization, all individuals are replaced by randomly generated individuals if population is judged to have converged to local optimum. In μ-GA the reinitialization actualizes a global search. The preserving elite individual and selection actualize local search. The μ-GA can avoid the excessive fitness evaluation because the number of individual is very limited. The followings are procedures in the μ-GA.

1. The initial population of size N_{pop} is generated randomly.
2. The fitness of each individual is calculated from the FDTD method in this work.
3. The individual having the highest fitness is preserved as elite individual.
4. Two individuals are selected randomly as the parent by preforming tournament selection.
5. A child is produced by applying uniform crossover to parents
6. N_{pop}-1 children are produced by repeating steps 4 and 5.
7. If the population converges, it is reinitialized.
8. Steps 2 to 7 are repeated until the iteration number reaches to maximum.

C. Optimization problem

The shapes of chipless RFID tag are optimized by the μ-GA and on-off method. An aim of optimization is that the quality factor Q_{bs} and amplitude E_{bs} of backscattering wave refleced by the chipless RFID tag are maximized when plane waves are incident on the chipless RFID tag as shown in Fig. 3. The plane waves are incident to the chipless RFID tag, assuming that the RFID reader is sufficiently far from the chipless RFID tag. The optimization problem is defined by

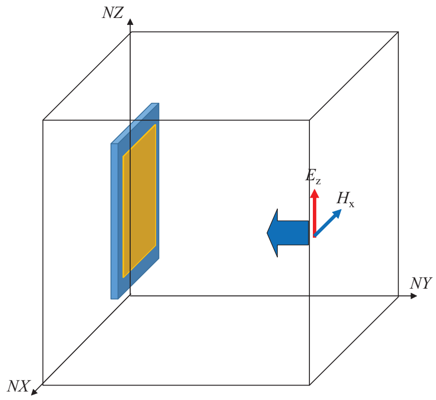


Fig. 3 Overview of computation model.

$$\frac{E_{bs}}{E_{inc}} + wQ_{bs} \rightarrow \max \qquad (2)$$

where E_{inc} is the amplitude of incident plane wave and w is weighting coefficient. E_{bs} / E_{inc} is a reflection coefficient.

The reflection coefficient of chipless RFID tag obtained by the optimization depends on the incident wave angles. The chipless RFID tag such as half-wave dipole antenna having a isotropic reflection coefficient has small reflection coefficient. In this research, the incident wave angle is assumed to be orthogonal so that the long range communication is realized.

III. Numerical Results

A. Topology optimization of chipless tag

The topology optimization of the chipless RFID tag is performed by the μ-GA and FDTD method. The number of FDTD cell, where $NX = NY = NZ$, is set to 200. The size of FDTD cell, where DX = DY = DZ, is set to 1 mm. The incident waves are set to the Gaussian pulse. The perfect matched layer is employed to enforce the free space conditions on the domain boundary. The weighting coefficient w is set to 0.2.

Fig. 4 is the shape of chipless RFID tag optimized by μ-GA with moving average filter. The reflection coefficient of optimized chipless RFID tag is shown in Fig. 5. Note that the quality factor Q and amplitude of scattering waves of metal patch set to 60 mm × 30 mm are 4.7 and 0.26. It can be seen in Fig. 4 and Fig. 5 that the optimized chipless RFID tag obtained by μ-GA with filtering has higher fitness than its metal patch.

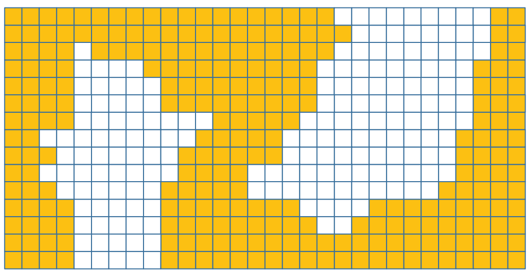


Fig. 4 Shape of chipless tag obtained by optimization

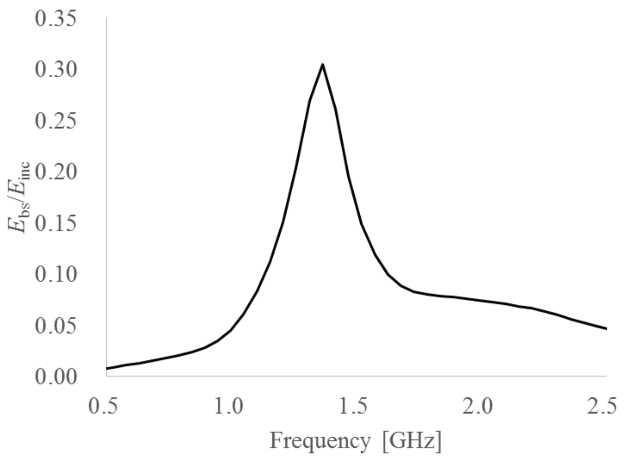


Fig. 5 Amplitude of backscatter waves from chipless tag obtained by optimization

B. *5 bit chipless tag*

The chipless RFID tag is assumed to have 5 bits data. The RFID reader is assumed to send electromagnetic waves at frequencies from 0.5 to 2.5 GHz. Fig. 6 shows a 5 bits chipless tag composed of chipless tags optimized by μ-GA and on-off method with filtering. The maximum number of data is limited by a size of the chipless RFID tag and frequency band of RFID reader antenna. The optimized chipless tags are changed size to shift resonance frequency. The amplitude of backscattering wave of 5 bit chipless tag is shown in Fig. 7. It can be seen in Fig. 7 that the optimized chipless tags have 5 bits data from 1 GHz to 2.2 GHz.

IV. Conclusions

In this paper, the shapes of chipless RFID tag are optimized to maximize the quality factor and amplitude of backscattering waves from chipless RFID tags. The resultant chipless RFID tag has higher quality factor and amplitude of backscattering wave comparison with metal patch set to 60 mm × 30 mm.

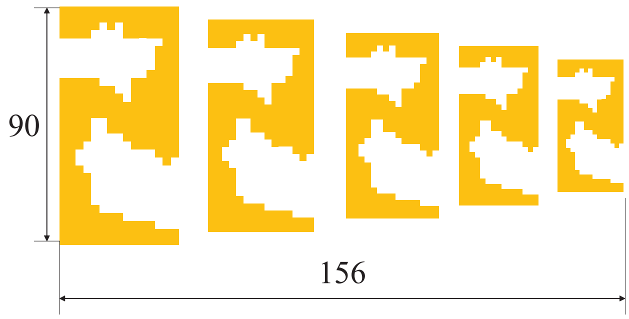


Fig. 6 5 bits chipless tag obtained by optimization

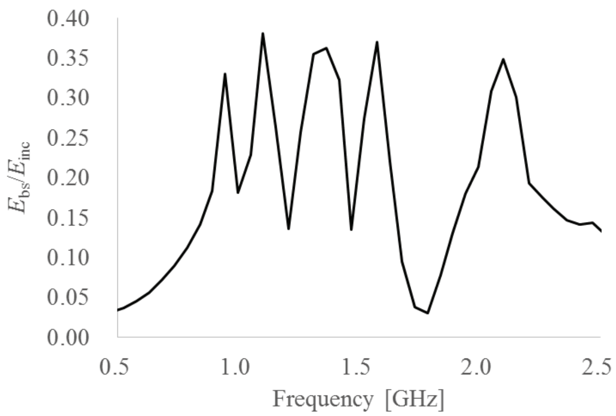


Fig. 7 Amplitude of backscatter wave from 5 bits chipless tag obtained by optimization

Moreover, it has been shown that 5 bits chipless tag composed of optimized tag has five resonance frequencies from 1 GHz to 2 GHz.

V. Acknowledgment

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