Topology Optimization of UHF-band Antennas

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Abstract

This paper presents topology optimization of antenna shapes for a passive IC tag which contains the Cockcroft-Walton (CW) circuit. The characteristics of the antenna loaded by the CW circuit are analyzed by the hybridization of FDTD method and modified nodal analysis. The shape of a planer lattice antenna (PLA) formed on the dielectric substrate is topologically optimized by using the micro genetic algorithm (µ GA) in order to maximize the output voltage of the CW circuit and minimize the antenna size.
Background

It is necessary to increase communication distance of UHF-band RFID. Optimization of the tag antenna and IC tag chip is vital for this purpose.

The IC tag chip has been assumed to consist of linear circuits for simplicity in the conventional optimization.

What is problem?
• IC tag chips usually consist of non-linear circuits, and this nonlinearity has not been considered.
• The conventional parameter optimization has insufficient DoFs.

Goal of this work
• We topologically optimize the shapes of the planer lattice antenna taking the effect of non-linear circuits into consideration.
The UHF-band passive RFID system is composed of the IC tag and an RFID reader.

Communication Processes

1. The reader sends power and data by electromagnetic waves to the IC tag.
2. The tag chip starts operating by receiving the energy and information through the tag antenna.
3. The tag chip modulates the backscatter by changing impedance $Z_c$. 

Fig. 1 UHF-band passive RFID system
IC Chip

• The IC tag chip for the UHF-band passive RFID usually includes a rectifier and amplifier as shown in Fig. 2.
• The Cockcroft-Walton circuit makes voltage multiplication that converts a low voltage AC to a higher voltage DC.

![Fig. 2 Cockcroft-Walton Circuit](image-url)
Hybridization of FDTD and MNA

The equation between FDTD and circuit

\[ C_0 \frac{\partial V_L}{\partial t} + I_L(V_L) = I \]  

(1)

where,

\[ C_0 = \varepsilon \frac{\Delta X \Delta Y}{\Delta Z} \]

\[ I_L = \Delta X \Delta Y J_z(E_z) \]

\[ V_L = E_z \Delta Z \]

\[ I = \int_{\partial S} H \cdot ds \]

Computation Process

1. \( I \) is computed from the magnetic field \( H \) obtained by FDTD.
2. Equation (1) is solved by the circuit simulation.
3. The electric field \( E_z = V_L / \Delta Z \) is used by FDTD
Antenna design:
1. A base area is divided into lattice pattern.
2. Each edge of the lattice is determined to be conductive or open by using topology optimization.
3. The other half of the antenna is similarly formed, assuming the right-left symmetry.

![Diagram of lattice pattern and genotype](image)

Fig. 3 Procedure of PLA modeling
Topology Optimization of PLA

Optimization Problem

\[ V_{\text{out}} + (1 - N / N_{\text{max}}) \rightarrow \max \]

\( N \) and \( N_{\text{max}} \) are number of conductive and maximum edge.

Fig. 5 Optimized antenna shape (unit: mm)
Conclusions

The shape of a PLA loaded by the Cockcroft-Walton circuit is topologically optimized by $\mu$ GA. The resultant PLA, which has relatively small area, has higher output voltage of CW circuit in comparison with the half-wave dipole antenna.