Accelerated FDTD Computation Applied to Antenna Shape Optimization

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Abstract — This paper presents an accelerated FDTD method which is applied to the optimization of antenna shapes for a passive IC tag which contains the Cockcroft-Walton (CW) circuit. In the present optimization, the characteristic of antenna is analyzed by hybridization of FDTD method and MNA. To accelerate the convergence to the steady state, the unknowns are decomposed into the fast and slowly converging components which are separately determined.

I. INTRODUCTION

The passive UHF-band Radio Frequency Identification (RFID) composed of a reader and an IC tag has been intensively studied because it has promising applications such as a remote sensing, a retail item management system, and so on [1], [2]. The IC tag consists of a tag antenna and an IC chip. The reader sends power and data to the IC tag by the electromagnetic waves. By receiving them, the IC chip stats operating to make a response by reflecting the backscatter waves modulated by a semiconductor switch.

It is important for long range communication of RFID to keep impedance matching condition between the tag antenna and IC chip. For this purpose, the tag antenna has been optimized [3], [4]. The IC chip consists of non-linear circuit such as Cockcroft-Walton (CW) circuit for voltage amplification. Hence the field analysis must be carried out taking coupling effect between electromagnetic waves and non-linear circuits into account. However, it takes considerably long time to optimize shapes of tag antenna because the hybridization of electromagnetic field and nonlinear circuit analysis requires high computational costs.

In this work, considering the nonlinearity, the IC tags are analyzed by the hybridization of FDTD method and modified nodal analysis (MNA). To overcome problem that hybridization FDTD method and MNA has high computational cost, the time-periodic explicit error correction (TP-EEC) method [5] is applied to MNA for accelerating the convergence to steady state. The TP-EEC method has been studied in low frequency problems for motor analysis. However the validity of this method is unclear for high frequency problems, which are discussed in this paper. On the basis of this analysis, the shapes of the tag antenna loaded by the CW circuit are optimized using micro genetic algorithm (μ-GA).

II. ANALYSIS METHOD

A. TP-EEC Method

Let us consider the nonlinear simultaneous equation having periodicity is given by

$$\boldsymbol{f}_i(\boldsymbol{x}_i) + C\frac{\mathrm{d}\boldsymbol{x}_i}{\mathrm{d}t} = \boldsymbol{b}_i(t) \tag{1}$$

$t=n\Delta t$ and the period is set to $N_s\Delta t$. In steady state, the solution $\boldsymbol{x}_i$ is assumed to be

$$\boldsymbol{x}_0 = \boldsymbol{x}_{N_s}\,. \tag{2}$$

To accelerate the convergence to the steady state, the solution $\boldsymbol{X}=[\boldsymbol{x}_0\ \boldsymbol{x}_1 \cdots \boldsymbol{x}_{Ns}]^t$ is decomposed to vale having fast and slow convergence as follows:

$$\boldsymbol{X} = \widetilde{\boldsymbol{X}} + B\boldsymbol{p}\,, \tag{3}$$

where $\boldsymbol{p}$ is correction vector set to dimension N_p and B is matrix expressing slow convergence terms such as the DC (0th order) and 1st order components [5]. The correction vector $\boldsymbol{p}$ is determined by solving

$$B^t\frac{\partial}{\partial \boldsymbol{X}}\left(\boldsymbol{f}(\boldsymbol{X}) + C\frac{\mathrm{d}\boldsymbol{X}}{\mathrm{d}t}\right)B\boldsymbol{p} = B^t\boldsymbol{r}\,, \tag{4}$$

where $\boldsymbol{r}$ is a residual vector.

B. Hybridization of FDTD and MNA

The spatial size of the non-linear circuit is assumed to be sufficiently smaller than that of FDTD cell. Let us consider the line antenna loaded by non-linear circuit parallel to the z-axis. By integrating the Maxwell equation on the surface including non-linear circuit, we obtain

$$C_0\frac{\partial V_L}{\partial t} + I_L(V_L) = I\,, \tag{5}$$

where $V_L=E_Z/\Delta z$ is the voltage imposed to the circuit, $C_0=\varepsilon\Delta x\Delta y/\Delta z$ is the space capacitance, Δx, Δy and Δz are length of FDTD cell, I_L is current flowing into the circuit and I is total current given by $I = \int_{\partial S}\boldsymbol{H}\cdot \mathrm{d}\boldsymbol{s}$.

I is calculated from the magnetic field $\boldsymbol{H}$ computed by FDTD method and substituted to (4). Then (4) is solved by the MNA for V_L. The resultant electric field $E_z=V_L / \Delta z$ is substituted to FDTD process, which is solved for $\boldsymbol{H}$. TP-EEC method is applied to MNA because the time constant of non-linear circuit is long compared to electric field.

III. NUMERICAL RESULT

A. TP-EEC method

The half-wave dipole antenna loaded by CW circuit shown in Fig. 1 is analyzed by hybridization of FDTD method and MNA to test improvement of convergence to steady state by applying TP-EEC method to MNA. The output voltage V_{out} of CW circuit is computed when the plane wave is incident to the IC tag. The amplitude of incident wave is assumed to be 20V/m. The frequency of

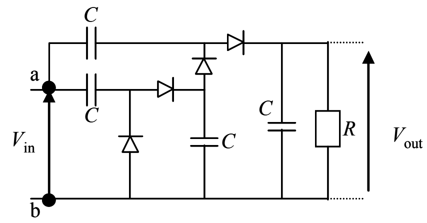

Fig. 1. Cockcroft-Walton circuit.

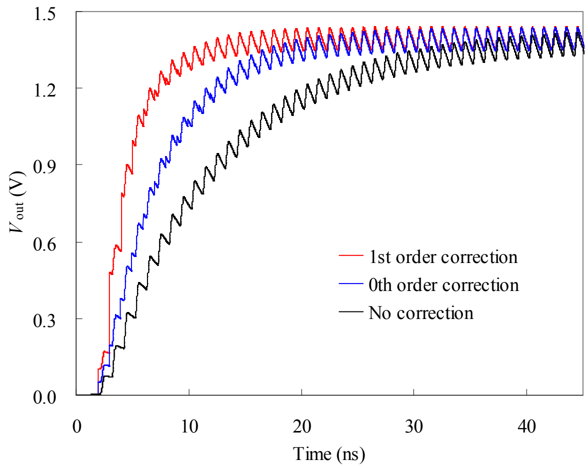

Fig. 2. Output voltage of CW circuit.

incident wave is set to 1GHz. In FDTD process, the number of FDTD cell, where $NX=NY=NZ$, is set to 100. The size of FDTD cell, where $\Delta x=\Delta y=\Delta z$, is set to 3mm. The perfect matched layer is employed to enforce the free space conditions on the domain boundary.

The time evolution of V_{out} for half-wave dipole antenna loaded by the CW circuit is shown in Fig. 2. It can be seen in Fig. 2 that the convergence to steady state is clearly accelerated by the present method.

B. *Optimization Problem*

The tag antenna is assumed to be the patch antenna. The optimization of the patch antenna is performed by μ-GA and hybridization of FDTD method and MNA applied to TP-EEC method. The optimization setting for the patch antenna

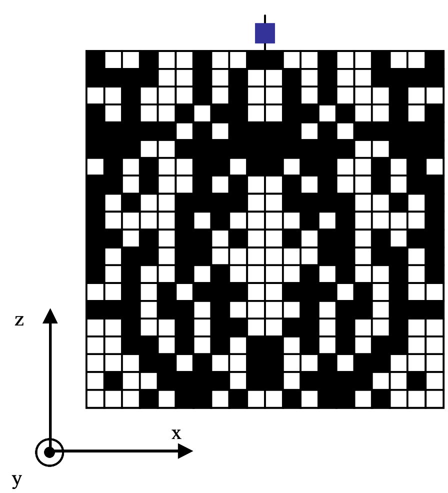

Fig. 3. Shape of patch antenna optimized by μ-GA

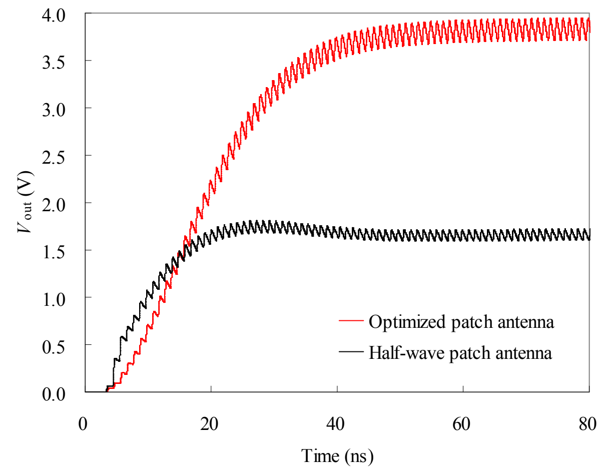

Fig. 4. Output voltage for the optimized patch antenna loaded CW circuit.

is described in the followings.

1. A base area of patch is divided into square cells.
2. Each cell is determined to be open or conductive in the optimization.
3. The other half of the patch is similarly formed, assuming the right-left symmetry.
4. The ground plane is set that is bigger than the resultant patch.

The aim of this optimization is that the output voltage V_{out} for the patch antenna loaded by the CW circuit is maximized. The optimization problem is defined by

$$V_{out} + \left(1 - \frac{N}{N_{\max}}\right) \rightarrow \max \, , \tag{6}$$

where the second term is introduced for stabilization of the optimization, N is number of the conductive area in optimization process and N_{max} is the maximum number of lattice in patch.

The shape of patch antenna obtained by optimization is shown in Fig. 3 and V_{out} for the optimized patch antenna and half-wave patch antenna loaded by the CW circuit are comparatively shown in Fig. 4. It can be observed in Fig. 4 that the steady value of V_{out} for optimized patch antenna is more than two times larger than that for the half-wave patch antenna.

IV. REFERENCES

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