Analysis of UHF-band Passive RFID Antennas Loaded by Dickson Charge Pump

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1 Introduction

The UHF-band passive radio frequency identification (RFID) systems consist of a reader-writer and several RFID tags. They attain considerable attentions due to their two practical advantages that the RFID tag does not need battery and communicate distance between reader-writer and RFID tag is a few meters [1]. The RFID tag is composed of a tag antenna receiving electromagnetic waves from reader-writer and IC chip which rectifies and amplifies the received voltage. Previous studies of UHF-band passive RFID have presumed a linear equivalent circuit of IC chip [2, 3]. However, the IC chip is non-linear circuit including often FET and diode in real situations. In [4], the authors have described non-linear analysis of the meander line antennas loaded by the Cockcroft-Walton (CW) circuit, where the performance of RFID tag is computed by hybridization of finite-difference time-domain (FDTD) and modified nodal analysis (MNA). However, it would be difficult to realize the CW circuit in integrated circuits. This study assumes that the antenna is loaded by the Dickson charge pump (DCP) which can be realized in integrated circuits. To consider the non-linearity of DCP, the V-I characteristics of FET is represented by the Akima interpolation [5]. The planer lattice antenna (PLA) composed of line antenna is assumed to be the tag antenna.

2 Hybridization of FDTD method and MNA

The coupling of the FDTD method and MNA will briefly be described in this section. The Maxwell equations are given by

$$\nabla \times \boldsymbol{E} = -\mu \frac{\partial \boldsymbol{H}}{\partial t} \tag{1}$$

$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \varepsilon \frac{\partial \boldsymbol{E}}{\partial t} . \tag{2}$$

where $\boldsymbol{J}=\sigma\boldsymbol{E}$ is conductive current. In the FDTD method, (1) and (2) are approximated by spatial and time central difference and calculated in explicit time domain as follows:

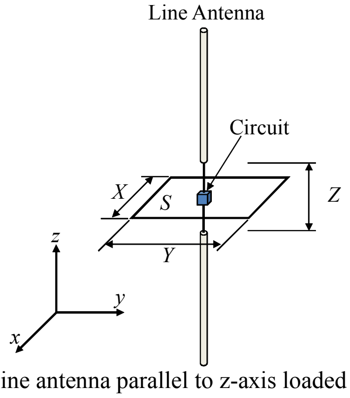

Fig. 1 Line antenna parallel to z-axis loaded by non-linear circuit.

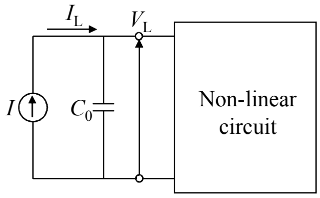

Fig. 2 Equivalent circuit

$$\boldsymbol{E}^{n} = \frac{1-\sigma\Delta t/2\varepsilon}{1+\sigma\Delta t/2\varepsilon}\boldsymbol{E}^{n-1} + \frac{\Delta t/\varepsilon}{1+\sigma\Delta t/2\varepsilon}\nabla\times\boldsymbol{H}^{n-1/2} \tag{3}$$

$$\boldsymbol{H}^{n+1/2} = \boldsymbol{H}^{n-1/2} + \frac{\Delta t}{\mu}\nabla\times\boldsymbol{E}^{n} . \tag{3}$$

Let us consider the line antenna loaded by non-linear circuit, shown in Fig. 1, parallel to z-axis. It is assumed that the spatial size of non-linear circuit is sufficiently smaller than that of the antenna. ΔX, ΔY and ΔZ are cell size of the FDTD method. By integrating (2) on the surface S of FDTD cell, we obtain

$$C_0 \frac{\partial V_{\mathrm{L}}}{\partial t} + I_{\mathrm{L}}\left(V_{\mathrm{L}}\right) = I \tag{4}$$

where $V_{\mathrm{L}} = E_z \Delta Z$ is voltage imposed to the non-linear circuit, $C_0 = \Delta X \Delta Y \, / \, \Delta Z$ is spatial capacitance of the FDTD cell, I_{L} is current flowing into the non-linear circuit and I is the total current given by

$$I = \int_{\partial S} \boldsymbol{H} \cdot \mathrm{d}\boldsymbol{s} . \tag{5}$$

The equivalent circuit corresponding to (4) is composed of parallel circuit of current source I obtained by (5), capacitance C_0 and non-linear circuit shown in Fig. 2. The node voltages of equivalent circuit shown in Fig. 2 are analyzed by MNA.

The followings are procedures in coupling analysis of the FDTD method and MNA.

1) The magnetic field $\boldsymbol{H}^{n-1/2}$ is computed in the FDTD process, where n denotes the time step.
2) The total current I is calculated from $\boldsymbol{H}^{n-1/2}$ by (5) in the MNA process.
3) The electric field in non-linear circuit is calculated by $E_z = V_{\mathrm{L}}/\Delta Z$, and other electric field $\boldsymbol{E}^{n}$ is computed in the FDTD process.
4) Steps 1) to 7) are repeated until the steady state solutions are obtained.

3 RFID tag

3.1 Tag antenna

In this work, the PLA shown in Figure 3 is considered, which contains the floating lines and loops. The structure will be optimized to maximize the output voltage of DCP.

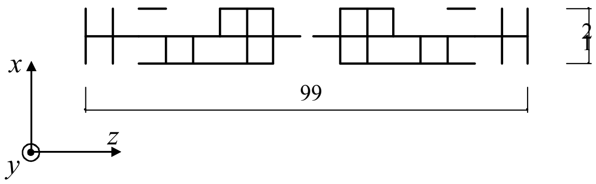

Fig. 3 Planer lattice antenna

3.2 Dickson charge pump

In this study, the DCP circuit shown in Fig. 4 is considered. The DCP circuit rectifies and amplifies the input voltage received by the tag antenna. Although the DCP circuit is composed of diodes and capacitances in general, the diode is represented by using FET. The V-I characteristics of FET is shown in Fig. 5, where V_{GS} is voltage between gate and source terminal, V_{DS} is voltage between drain and source terminal. The drain current I_D is interpolated by Akima interpolation. The Akima interpolation is carried out twice because I_D depends on V_{GS} and V_{DS}.

4 Numerical Results

The UHF-band passive RFID model shown in Fig. 6 is analyzed by hybridization analysis of the FDTD method and MNA. The incident electromagnetic wave from reader-writer is assumed to be plane wave. In FDTD process, the size of FDTD cell, where $\Delta X=\Delta Y=\Delta Z$, is set to 3 mm. The number of FDTD cell, where $NX=NY=NZ$, is set to 100. The frequency of incident wave is set to 1 GHz. The amplitude of incoming electric field is assumed to be 20 V/m. The perfect match layer is employed to enforce the free space conditions on the domain boundary. The time evolution of resultant output voltage V_{out} of PLA shown in Fig. 3 loaded by the DCP circuit is shown in Fig. 7. It can be observed in Fig. 7 that V_{out} tends to increase almost monotonously and reach at the steady value although it includes small ripples. If the ripple amplitude becomes too large, the digital circuit, to which V_{out} is supplied, would have malfunctions in its operation. It is found from computations that the ripple can be reduced by increasing C in Fig. 4, whereas the rise time becomes longer with C.

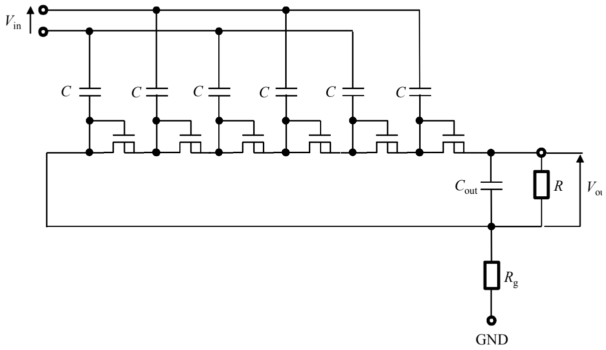

Fig. 4 Dickson charge pump circuit

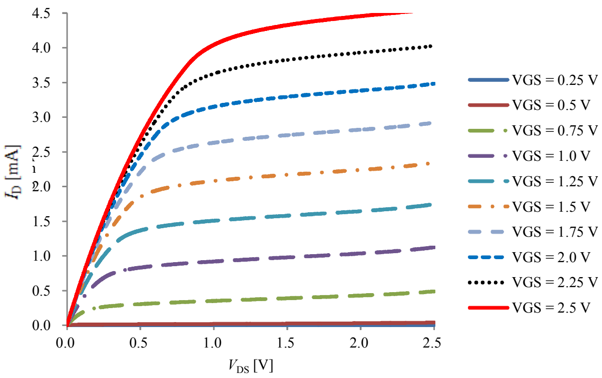

Fig. 5 Drain current of FET

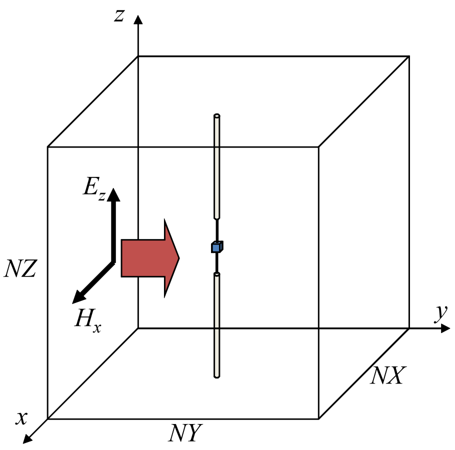

Fig. 6 Analysis model

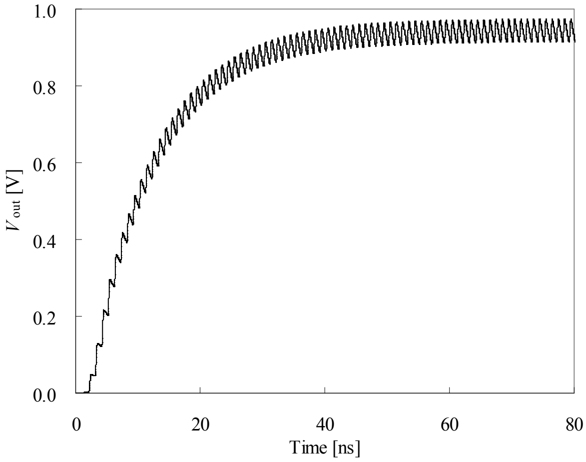

Fig. 7 Output voltage of DCP circuit

5 Conclusions

The characteristics of RFID tags composed of PLA and DCP circuit is computed by hybridization of the FDTD method and MNA. The sinusoidal input voltage received by PLA is successfully rectified and amplified by the DCP.

In extended paper, we will discuss optimization of PLA shape in order to maximize the output voltage of DCP circuit.

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