FDTD Analysis of Unwanted Emissions from a Variable Capacitor with Sinusoidal Motion

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Abstract — In this paper, we investigate the unwanted emission from a variable capacitor with sinusoidal motion. Then, a finite-difference time-domain method with an adaptive local subcell implementation is applied. First, our computational implementation is verified by computing the time course of the charge accumulated on the electrode of the capacitance with those for the electrode with a fixed separation. The primary finding of our numerical result shows that unwanted emission is radiated with its amplitude modulated at the frequency of the motion of the metal.

I. INTRODUCTION

The large-scale integration constructed built on a semiconductor would be relatively easy to realize downsizing. On the contrary, there is some difficulty in miniaturizing passive components such as filters [1]. In order to solve this difficulty, the radio frequency-micro mechanical systems (RF-MEMS) are promising [2]. One of the potential applications of RF-MEMS is variable capacitors with its feature of a wide variable region or radio-frequency switches. The MEMS switches, however, have weakness in relatively low speed. With the improvement of its switching speed, the mechanical motion contains the micro-vibration until its electrode reaches a steady state [3, 4]. During the vibration, unwanted emissions are likely to be radiated from MEMS switches, which may have a potentially detrimental effect on the internal circuit. An accurate knowledge of the electromagnetic field emitted from the moving electrode is of interest.

One of the authors developed over set generation method [5] and a coordinates’ transform technique [6] for the analysis of electromagnetic wave radiation/propagation for two-dimensional moving structures as the feasibility study. In [7], the characteristics of 3-D RF-MEMS switches were analyzed by considering its steady state. Thus, a computational method is verified. The only other fields to consider in the update are the fields in their update. The domain of the Ez equations located in the moving region require no changes. It should be noted that at the edge of the update region the Ez field above the moving plate results in; Ez fields located on the metal have to be zero.

The Ez equations located in the moving region require no changes. It should be noted that at the edge of the update region the Ez field above the moving plate results in; Ez fields located on the metal have to be zero. The domain of the Hx and Hy fields in their update. The domain of the H fields in these areas is the entire length of the cell, however, so this does not present a problem. The Hx and Hy fields in update region simply require the substitution of dz in the update equation with the appropriate length for the cell whose size varies with time.

The only other fields to consider in the update are the fields surrounding the moving region. In these areas Hx and Hy require special update equations. These equations were derived using Ampere’s and Faraday’s law in integral form derivation of the FDTD technique [6]. The H fields in these equations are determined using the equation;

$$\oint_{C_1} E \cdot dl = -\mu \frac{d}{dt} \int H \cdot dS_i. \quad (1)$$

In this equation, S_i represents the cell surface centered on the H field, and dl_i represents the contour surrounding it that contains the E fields.

Using this equation to derive the updated equation for the Hy field above the moving plate results in;
Similarly, $2\Delta z - h(t)$ is used instead of $dz$ for the $Hy$ filed below the moving plate. When the value of $h(t)$ becomes larger than $\Delta z/2$ or smaller than $-\Delta z/2$, the cell, to which eq. (2) is applied, is taken over to the next cell.

B. Variable Capacitor Modeling

Fig.2 illustrates the circuit model with a variable capacitor used in our investigation. A metal plate is located on an $x$-$y$ plane in Fig.2. The dimension of the metal plate, as an electrode of the variable capacitor, is set at $10 \text{mm} \times 10 \text{mm}$. The electrode distance varies sinusoidally with time in the $z$ direction between $1 \text{mm}$ and $2 \text{mm}$. In order to construct the circuit, we connect the metal plates and a source with thin wires. The capacitance is calculated from a surface integral of the bottom plate’s electric field or charge. The cell resolution is $0.1 \text{mm} (x) \times 0.1 \text{mm} (y) \times 0.05 \text{mm} (z)$. The frequency of the source and that of the motion of the electrode are chosen as $5 \text{GHz}$ and $200 \text{MHz}$.

III. Computational Results

A. Time variation of a capacitance when an electrode separation varied

We evaluate the time variation of the capacitance which is fed by source. There was a high-frequency contamination in the early stage of the computation, and thus the time course of electric field takes the ripples or oscillation components. However, it converged to a certain value with time evolution. In order to evaluate the error in computed capacitance for the variable capacitor with that fixed at $1 \text{mm}$, we have introduced a following measure;

$$\alpha = \frac{C_{\text{move}} - C_{\text{fix}}}{C_{\text{fix}}} \times 100 \ [%],$$

where $C_{\text{fix}}$ is the capacitance for the electrode with a separation of $1 \text{mm}$. $C_{\text{move}}$ is the capacitance for the electrode with vibration; in that computation, the capacitance corresponding at the separation of $1 \text{mm}$ is estimated in the time domain. The value of $\alpha$ was $1.9 \%$ in the earlier stage of computation, but converged to $1.2 \%$ with sufficient computational time, suggesting the effectiveness of our computational modeling for moving object in the three dimensional time domain.

B. FDTD analysis of radiated fields from the variable capacitor when the electrode separation with sinusoidal vibration

Fig.3 shows frequency characteristics of radiated fields when the electrode separation varied with sinusoidal vibration. The value of electric fields peaks at $5 \text{GHz}$, corresponding to the frequency of the injection current. When comparing the radiated fields between the fixed and moving electrodes, the value of radiated fields for the moving electrode is larger than that of the fixed electrode at $4.8 \text{GHz}$ and $5.2 \text{GHz}$. This is thought that the radiated fields are an amplitude modulation depending on frequency of vibration because the electrode of the capacitor varies with sinusoidal motion at $200 \text{MHz}$. 

\[ H_{z}^{n+1} \big|_{i,j+1/2,k+1} = H_{z}^{n+1/2} \big|_{i,j+1/2,k+1} + \frac{\Delta t}{\mu} \left( \delta_{i,j+1/2,k+3/2} - 0 \right) h(t) \]

\[ = \frac{E_{z}^{n+1/2} \big|_{i,j+1/2,k+1} - E_{z}^{n+1/2} \big|_{i-1/2,j+1/2,k+1}}{\Delta x} \]
IV. CONCLUSION

In this paper, we developed the numerical technique based on the FDTD method with an adaptive local sub-cell implementation to analyze the 3-D moving object by extending the techniques in [6, 7, 8]. This simulation method is applied to the analysis of a variable capacitor with sinusoidal motion. Focusing unwanted emission from the variable capacitor, we evaluated the frequency characteristics of radiated fields. The radiated fields are found to have amplitude modulated characterized by the frequency of vibration.

Future study is to investigate the unwanted emission from electrode with more realistic motion.

REFERENCES