PRACTICAL METAL LOSS IMPLEMENTATION FOR A MICROSTRIP LINE STRUCTURE USING SIBC IN FDTD SIMULATION

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ABSTRACT

Metal transmission loss of a microstrip line was calculated by FDTD simulation using surface impedance boundary condition (SIBC) technique. Calculated results were compared to measurement results. Proper SIBC implementation in FDTD simulation produced good results, even if coarse grids were used for a microstrip line structure.

INTRODUCTION

Rapid growth of wireless communication market accelerates the development speed of high frequency modules such as millimeter-wave transceiver modules. Full wave simulation tools are indispensable for developing such modules. In that field, FDTD simulation became one of the attractive method for its applicability to various structures. On the other hand, with higher carrier frequency, metal loss due to skin effect increases and loss should be treated accurately in the simulations. Methods to include metal loss have been introduced into the FDTD algorithm [1], [2], but accuracy of the loss calculation for planar transmission structures has not been clear so far. This paper discusses the validity of the implementation of SIBC in FDTD algorithm for such structure. Though the merit of using FDTD method is its applicability to various structures, simple microstrip line structure was adopted to evaluate the transmission loss, which enabled the direct comparison of the results with the measured results and the other reliable simulated data based on quasi-TEM approximation. When coarse grids were used for the structure, the discrepancy between measured data and calculated data by FDTD method was more than 40% at the frequency from 10 GHz to 60 GHz. By adding a proper strip edge condition, the discrepancy decrease to 16% at 37 GHz and within the error bar of the measurement data at 11 GHz, without enlarging the number of grids.

IMPLEMENTATION

The concept of surface impedance was originally derived for incident wave to fairly broad good conductive plane [3], [4]. Consequently, applying the SIBC to the FDTD simulation, the results become more accurate if the number of grids allocated on a metal strip increased. For applying the FDTD algorithm to complex structures, however, small number of grid allocation on the strip is preferable from the computer resource point of view. In this paper, we examine the accuracy of FDTD analysis of metal loss when using coarse Yee grids, and propose a method of improving the accuracy. Maxwell's curl equation in FDTD algorithm reflecting surface impedance boundary connotation is as follows [5];

$$H_y^{n+1/2}(i,j,k+1/2) = \frac{\mu_0\Delta Z-(Rs\Delta t)/2+Ls}{\mu_0\Delta Z+(Rs\Delta t)/2+Ls} H_y^{n-1/2}(i,j,k+1/2) + \frac{\Delta t}{\mu_0\Delta Z+(Rs\Delta t)/2+Ls} E_x^n(i,j,k) + \frac{\Delta Z\Delta t}{\Delta X}\frac{\Delta t}{\mu_0\Delta Z+(Rs\Delta t)/2+Ls} \cdot\left\{E_z^n(i,j,k)-E_z^n(i+1,j,k)\right\} \quad (1)$$

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where Rs and Ls are the terms reflecting surface impedance and defined as follows;

$$Rs = \sqrt{\frac{\varpi\mu}{2\sigma}} \quad , \quad Ls = \sqrt{\frac{\mu}{2\sigma\varpi}} \tag{2}$$

Even though the surface impedance boundary condition itself neglects the variation in tangential direction, the last term in equation (1) assures field propagation in that direction.

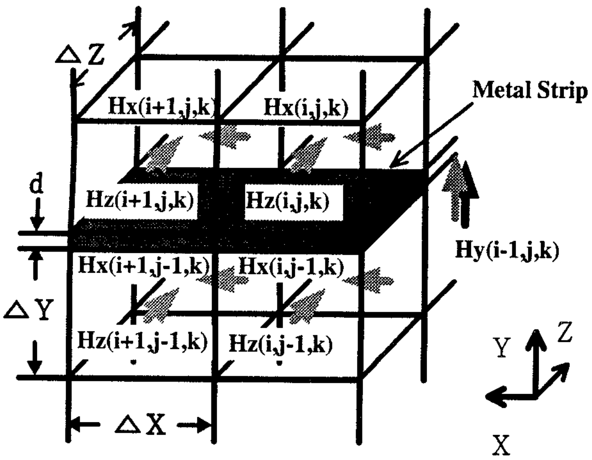

Figure 1. Surface impedance boundary implementation. H-field components enclosing the metal strip were expressed by using SIBC. Effective conductivity σ^* ($=\sigma\ d/\Delta Y$) was used for the components on metal strip sides. In this figure, it was expressed by the allow with shadow.

Figure 1 shows the surface impedance boundary implementation on Yee cell structure. If the same σ in (2) were used for side parts, adjacent Hy field components would recognize a metal strip thickness as the length of unit cell. As demonstrated in the Results section, the effect of finite thickness of the metal must be included so that σ should be replaced with the effective conductivity. By adopting a geometrical average, effective conductivity for the side walls was set as follows;

$$\sigma^* = \sigma\frac{d}{\Delta Y} \tag{3}$$

where d is the metal thickness, ΔY is the Yee cell size which is shown in Fig. 1.

When frequency dependence of surface impedance was taken into account, equation (1) was replaced to the formulation as follows[6];

$$H_y^{n+1/2}(i,j,k+1/2) = H_y^{n-1/2}(i,j,k+1/2) - \frac{Z_{x1}}{1+Z_{x1}Z_0}\sum_{i=1}^{10}\psi_i^n(i,j,k+1/2) - \frac{\Delta t}{(1+Z_{x1}Z_0)\mu_0\Delta X}\cdot\left[E_z^n(i,j,k)+\frac{\Delta X}{\Delta Z}\left\{E_x^n(i,j,k+1)-E_x^n(i,j,k)\right\}\right] \tag{4}$$

where,

$$\psi_i^n(i,j,k) = a_i e^{\alpha_i}\left[H_y^{n-1/2}(i,j,k) - H_y^{n-3/2}(i,j,k)\right] + e^{\alpha_i}\psi_i^{n-1}(i,j,k),$$

$$Z_{x1} = \frac{1}{\mu\Delta X}\sqrt{\frac{\mu\Delta t}{\pi\sigma}},\quad Z_0 = \sum_{i=1}^{10} a_i \tag{5}$$

a_i and α_i are the Prony constants. In frequency dependent case, effective σ^* was also used in the expression (5) for H-field components on the edges of metal strip.

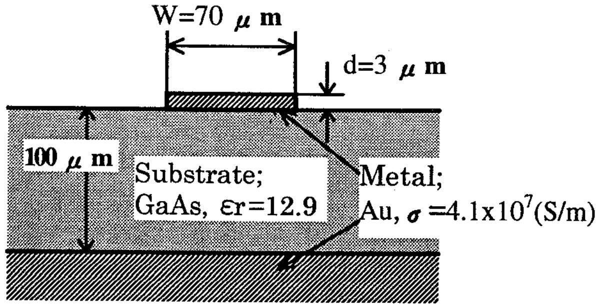

Figure 2. Cross-sectional view of object structure.

Figure 2 shows the cross-sectional view of an object structure. The combination of substrate height and metal width in the figure is typical for achieving 50 Ω line in millimeter-wave application. Yee cell dimensions (Δ X/Δ Y/Δ Z) were 23 μ m x 25 μ m x 50 μ m. Time step(Δ t) was 5.0 x 10^{-14} sec. Mur's first boundary condition was used for absorbing boundary walls. Gaussian pulse of 6.67 x 10^{-12} sec was used for source signal excitation.

Since absolute value of the transmission loss of a microstrip is very small, its evaluation by FDTD algorithm should be treated carefully. The pulse was excited in the square region below the strip. To avoid the singularity problem of the H-field on both sides of the excited region, which degrades the accuracy of the results, simulations were made in two steps. the E-field distribution was monitored in preliminary step and was used for the main simulation as a source excitation field. To achieve accurate results, the pulse width was determined such that almost all the surface modes which might be excited by the source signal become evanescent modes. The only exception was the TM_0 mode which has zero cut off frequency. Side boundary walls were set so as to absorb the TM_0 mode efficiently.

RESULTS

Figure 3 shows transmission loss of the microstrip line. In the figure, data were plotted from 10 GHz. At that frequency, metal thickness became more than three times larger than skin depth. The surface impedance formula (1) can be applied to such frequency region.

Calculations were made both frequency dependent case and frequency independent case. Dashed lines shows the frequency independent result. Surface impedance Zs(f) at 20 GHz, 40 GHz and 60 GHz were used for each of the lines. The solid line shows the data calculated by frequency dependent formula. As expected, each dashed line intersects the solid line at the frequency where the fixed value of surface impedance was defined in each calculation. Even though fixed surface impedance was used for dashed line, Loss value increased slightly with frequency. It was due to the change of current distribution with frequency.

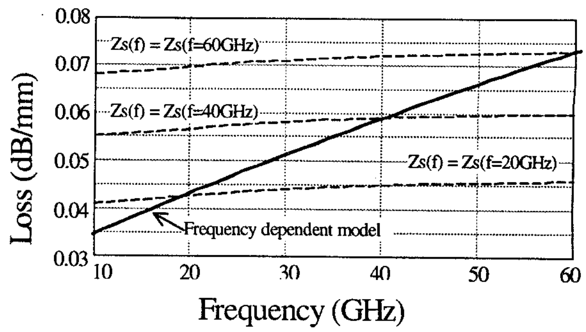

Figure 3. Microstrip line transmission loss. Solid line shows the result with using frequency dependent surface impedance formula. Dashed lines show the results with using frequency independent surface impedance formula.

Figure 4 compares the calculated transmission loss and measurement data. Solid line and thick dashed line show the data calculated by FDTD analysis with surface impedance boundary condition. The effective conductivity was taken into account for the solid line and was not taken into account for the thick dashed line. Marks "o" and "x" show the measured data which were depicted from the reference [7]. Calculated data by using commercially available CAD tool (Line Calc 2.0, HP EEsof) was also added as thin dashed line for comparison.

Without taking into account strip edge effect, FDTD simulation with SIBC derived fairly low loss value compared with the measured data and calculated data by analytical CAD tool. By taking into account the side effects, the discrepancy between the FDTD data and the measured data was decreased to 0.01 dB/mm at 37 GHz and was within the error bar of the measured data at 11 GHz. Since current flow was concentrated on both strip edges, introducing effective conductivity on metal strip sides caused a significant improvement in the FDTD simulation results. The discrepancy between measured data and calculated data increased with frequency. It is because current distribution along the x axis changed rapidly compared to the cell size and coarse grids gave lower loss value than actual one.

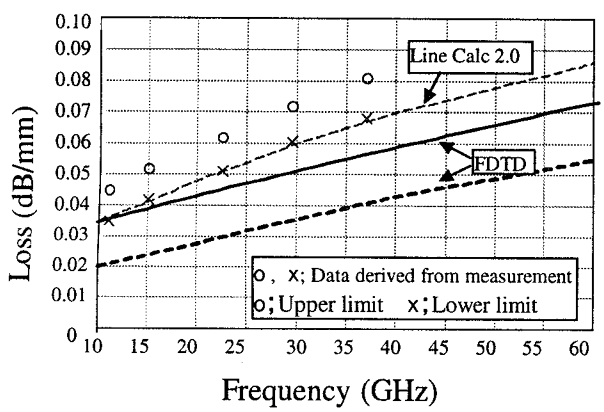

Figure 4. Microstrip line transmission loss. Solid line shows the result of this paper. Side effect of strip line was taken into account. Thick dashed line also shows the result of this paper. Side effect of the strip line was not taken into account. Marks "o" and "x" show the measurement data from reference [7]. Thin dashed line shows the data calculated by Line Calc 2.0.

CONCLUSIONS

In a FDTD algorithm, microstrip line transmission characteristic due to metal loss was evaluated with using SIBC. The effective conductivity was used to reflect the finite metal thickness. When coarse grids were used for the simulation with standard SIBC, the metal loss was underestimated more than 40% compared to the measured results. By introducing effective conductivity concept on the strip edges, without enlarging the number of grids, the discrepancy between acquired results and the measured data was improved within 0.01 dB/mm at 37 GHz and within the error bar of measured data at 11 GHz. With taking into account the side effect, the SIBC technique in FDTD algorithm was proved to be applicable to account the metal loss of a planar transmission line.

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