

Visual Graphic Design Software for EM Structure Analysis by FDTD Method

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1. Introduction

With the advance of information society recently, the radio and/or mobile communication industry are going to developing rapidly. A precision of analysis and design for EM structure of these fields is rigorously required and the commercial needs and applications of EM structure with high frequency such as antennas/RF circuits become increasingly. To solve these requirements, the numerical analysis methods of 3-dimensional structure with electromagnetic fields have been proposed and researched. Typical methods are MoM (Method of Moment), FEM (Finite Element Method), SDT (Spectral Domain Technique), FDTD (Finite Difference Time Domain) and so on. Since the FDTD method is able to predict the movement of electromagnetic wave in the time domain by differential equation for the finite structure, this method proposed by K.S. Yee [1] has been researched with remarkable attention. It used Maxwell's equation with a differential form for analysis of arbitrary finite construction composed of dielectric substance and conductor [2]. Although analysis of nonlinear circuit by FDTD method has comparatively some advantage due to the time domain calculations, the extended FDTD algorithm expressed the equivalent voltage-source and current-source circuit of nonlinear circuit composed of a lumped element has not been almost researched. Because this algorithm has to consider the complicated expression for the lumped devices, the constant stability by time-space step size and the complex of analysis model design. This paper presents reliability of visual graphic design software to analyze the EM structure composed of active and passive devices by FDTD method. This proposed software is called SRANT\_FDTD and development of visual graphic software for analysis of the EM structure is attempted the first time in Korea. The FET NE3210S01 of the NEC Co. as an active device is considered in theoretical design and measurements. The visual CAD graphic format realized by GUI technique using Borland C++ Builder language offers easy input, multi window output for various results and real time 3-D animation picture of electric fields. In order to confirm accuracy of the proposed software, the LPF(Low Pass Filter) as passive device and LNA(Low Noise Amplifier) as active device were analyzed and designed. The calculated results of example structures were also compared with the measured ones as well as the calculated ones by commercial tool.

2. FDTD analysis theory

FDTD method uses a center difference equation to solve a scattering problem as well known. Eq. (1) shows general forms applied the center difference equation for space and time domain [2].

$$\frac{\partial F^n(i, j, k)}{\partial x} = \frac{\partial F^n(i+1/2, j, k) - \partial F^n(i-1/2, j, k)}{\Delta x} + O[(\Delta x)^2] \tag{1a}$$

$$\frac{\partial F^n(i, j, k)}{\partial t} = \frac{\partial F^{n+1/2}(i, j, k) - \partial F^{n-1/2}(i, j, k)}{\Delta t} + O[(\Delta t)^2] \tag{1b}$$

Where F(i,j,k) is arbitrary function of space domain, an exponential n is time step, and function  $O[(\Delta x)^2]$  and  $O[\Delta t]$  are truncation error for x-direction step and time step, respectively. Electromagnetic component set at each mesh's corner and center. Fig. 1 shows arrangement of electric and magnetic components in mesh structure by Yee cell structure.

Electromagnetic components are evaluated by eq. (1) and Maxwell's equation in a differential form. Eq. (2) shows general electromagnetic components.

$$H_x^{n+1/2}(i, j, k) = H_x^{n-1/2}(i, j, k) - \frac{\Delta t}{\mathbf{m}} \left[ \frac{E_x^n(i, j, k) - E_x^n(i, j-1, k)}{\Delta y} - \frac{E_y^n(i, j, k) - E_y^n(i, j, k-1)}{\Delta z} \right] \quad (2a)$$

$$E_x^{n+1}(i, j, k) = E_x^n(i, j, k) - \frac{\Delta t}{\mathbf{e}} \left[ \frac{H_x^{n-1/2}(i, j+1, k) - H_x^{n+1/2}(i, j, k)}{\Delta y} - \frac{H_y^{n+1/2}(i, j, k+1) - H_y^{n+1/2}(i, j, k)}{\Delta z} \right] \quad (2b)$$

Where,  $H$  is magnetic component,  $E$  is electric component, and these components are appeared by space increment ( $i\Delta x, j\Delta y, k\Delta z$ ) and time increment ( $t = n\Delta t$ ). Space increment should be smaller than approximately  $1/10 \lambda \sim 1/20 \lambda$  in the material medium and time increment has to satisfy Courant's stability condition. A suitable boundary condition has to be applied to truncate a computational domain for open region analysis because the computer cannot store an unlimited amount of data. If do so, electric field component at the outer of analysis region cannot calculate by center difference equation. Therefore, electric field component at the outer of analysis region calculates to apply ABC(Absorbing Boundary Condition). The proposed SRANT\_FDTD program used Mur's ABC [3].

### 3. Nonlinear circuit analysis theory

Newton-Raphson method is considered for analyzing nonlinear element. This method is the way that presumes the root of equation by the slop. It is useful in the nonlinear equations because the successive chord iterative method implicitly uses a constant linear circuit model for each nonlinear element[4]. Circuit model of MOSFETs and nonlinear capacitors are used to analyze as linear-centric approach. Fig. 2 (a) and (b) are shown FET NE3210S01 embodied by linear element and a TriQuint's Cwn Model of Fig. 2(a), respectively. Electric fields derived by eq. (2) can be expressed gate and drain voltages as shown in eq (3).

$$V = - \int E dl \quad (3)$$

The unknown drain current  $I_d$  of Fig. 3(b) is found by Newton method using the impressed voltage  $V$  in eq (3). Other FET parameters of the NE3210S01 in order to obtain  $I_d$  values are offered by a product company as form of the data sheet[5]. Voltage  $V$  of eq. (4) is derived by equivalent voltage-source model using drain current  $I_d$  obtained by Newton method. The equation of model is given by

$$V = L_i \frac{\partial I_d}{\partial t} + V_d(I_d) \quad (4)$$

Gate and drain electric fields are found by eq(5). The Voltage ( $V$ ) of eq. (5) is expressed by the values obtained from eq. (4). The equation of electric fields considered characteristic values of FET is given by

$$E = -\nabla V \quad (5)$$

The electric fields equation of active element obtained by eq. (5) is applied to FDTD algorithm.

### 4. SRANT\_FDTD software using GUI

The proposed SRANT\_FDTD software corresponds to the commercial program developed for electromagnetic wave analysis. The proposed software with a visual CAD graphic format realized by GUI technique using Borland C++ Builder language is the first attempt for commercial use in Korea. The important functions of a proposed software to provide the visual 3-D CAD graphic structure of a desired antenna or RF circuit including active device are easy input window, multi output windows for various results and real time 3-D animation picture of electric fields. Especially, several functions such as zoom, pan, overlapping, color control, real time play and so on are very useful for design and result estimation in the precise analysis of a desired EM structure. Fig. 3 shows input window example of the proposed software. This Input window is divided the display window and the input data tab sheets.

The display window shows a desired design construction. It can be freely controlled the 2 dimensions (that is looked in XY plane, XZ plane or YZ plane) and the 3 dimensions of construction. The input data tab sheets are placed at the right side of the input window. These are composed of total size sheet of construction, dielectrics sheet, conductors sheet, Xmetal sheet, Ymetal sheet, Z-metal, FDTD sheet, antenna sheet and FET sheet. Fig. 4 shows an example of output window with respect to the calculated results when it is calculated by the data of design construction using input window of Fig. 6. Result window appears calculation results of construction with 3-D electric or magnetic field's distribution, input/output voltage pulse, S-parameter, input impedance and radiation pattern. Specially, The 3-D animation picture of electric or magnetic field's distribution can help to understand electromagnetic waves that do not look in eyes.

## 5. Accuracy of SRANT\_FDTD software

### 5.1. Low-pass filter design

In order to confirm reliability of the proposed software, low-pass filter using a teflon substrate with a relative dielectric constant of 2.5 is designed and measured. Fig. 5 shows design parameters and structure of LPF Fig. 6 shows comparison with the calculated and measured results of LPF. The compared results agree well with each other. It means that the proposed software has a reliability and accuracy.

### 5.2. LNA design

Fig. 7 shows the layout of LAN used FET of NE3210S01 as a nonlinear active device as device. The improved FDTD for analyzed nonlinear element and MWO for commercial use are adopted in the LNA design. Fig. 8 shows measurement results and calculation ones by the improved FDTD and by MWO using harmonic balance analysis. In calculation results, Both results of the improved FDTD and MWO show reasonable agreement though a little bit difference between two data is existent. Furthermore, the experimental results of fabricated LNA show better agreement with the calculation ones by the improved FDTD than results by MWO.

## 6. Conclusion

This paper describes reliability of the proposed SRANT\_FDTD software that is able to analyze the EM structure such as planar antenna and RF circuits by FDTD method. This software provides visual 3-dimensional CAD graphic structure of a desired antenna or RF circuit including active device for users and software development is originally attempted in Korea. It shows multi window functions for various result characteristics of EM design structure as well as real time 3-D animation picture of electric fields. An active element is also analyzed by an equivalent circuit equation using Newton method for nonlinear element. In order to confirm accuracy of EM structure calculated by the proposed software, a simple LPF and LNA were analyzed and designed. The calculated results by SRANT\_FDTD were compared with measurement ones as well as the calculated ones of commercial tool. The calculated results of example structures such as a LPF and a LNA shows fine agreement with the measured ones and the theoretical prediction by commercial one.

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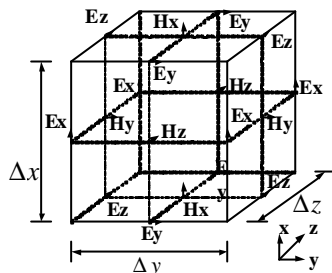


Fig. 1 Electric and magnetic component arrangement in mesh structure.

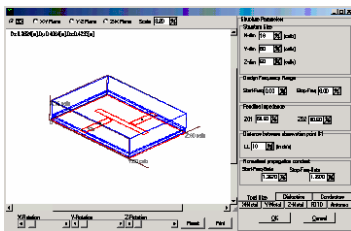


Fig. 3 Input window example of SRANT\_FDTD software.

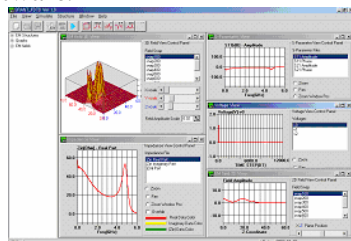


Fig. 4 Output window example of SRANT\_FDTD Software

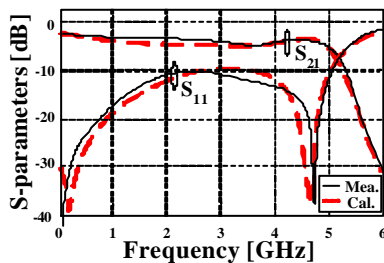
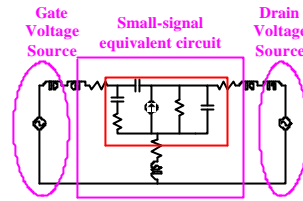
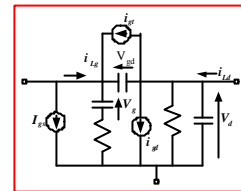


Fig. 6 Comparison between the measured and the calculated results.



(a) Embodied FET NE3210S01 by linear element.



(b) TriQuint's Cwn Model.

Fig. 2 Equivalent circuit of FET NE3210S01.

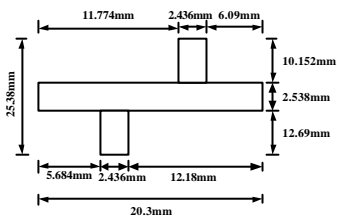


Fig. 5 Design parameters and structure of low-pass filter.

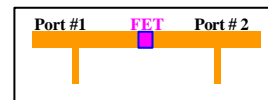


Fig. 7 Layout of LNA.

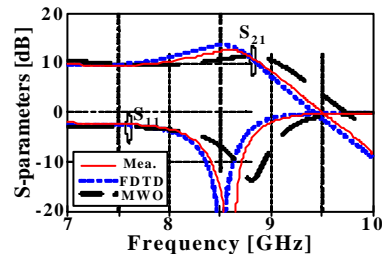


Fig. 8 Measured and calculated results of LNA.