Implementation of Microwave Simulation at Dispersive Material in Dataflow Architecture FDTD Dedicated Computer

H. Kawaguchi[1] (*Member, IEEE*), and S. Matsuoka[2]

[1]Muroran Institute of Technology, Muroran 050-8585, Japan, kawa@mmm.muroran-it.ac.jp
[2]National Institute of Technology, Asahikawa College, Asahikawa 071-8142, Japan, matsuoka@asahikawa-nct.ac.jp

To aim to achieve high-performance computing of a microwave simulation with small size hardware and low power consumption, authors have been working in a development of a dataflow architecture FDTD dedicated computer. One of main tasks of the method of the dedicated computer for the microwave simulation is flexible design for various kinds of numerical models. The previously developed FDTD machine was designed to be able to deal with arbitrary 3-D shape numerical model, any dielectric material and PML distributions with the same FDTD machine hardware. This paper proposes a modified FDTD dedicated computer architecture for the microwave simulation in dispersive materials.

***Index Terms*—Microwave simulation, FDTD method, High-performance computing, Dedicated computer, Dispersive material.**

I. Introduction

IN ACCORDANCE WITH remarkable progress of high-performance computing (HPC) technology in the last two decays, applications of microwave simulation have been widely spread out to not only scientific researches but also various kinds of industry. However, computer performance of existing high-end computers is still not sufficient for practical large scale simulations. For example, 10,000 time step FDTD simulation for 1,000 x 1,000 x 1,000 grid space needs about 80GB memory and more than 10 hours cpu time even by a supercomputer. To aim to achieve much higher performance computation for the microwave simulation by much smaller hardware size and lower energy consumption, a method of a dedicated computer for the FDTD method have been considered, and several types of hardware architectures are proposed [1]-[5]. In particular, a dataflow architecture FDTD dedicated computer may give us extremely high performance computation [6]. On the other hand, the method of the dedicated computer has essential two tasks, utilization of flexibility of various numerical model and large scale simulations. As to the former task, authors propoesed a unified digital circuit for arbitrary distribution and shape of perfect electric conductors (PEC), dielectric materials and PML grid regions, which means that the same hardware machine can deal with such kinds of various numerical models. To aim to expand applications of the dedicated computer to wider area of microwave simulations, this paper presents an implementation of the FDTD calculation function in a dispersive material so that the dedicated computer treats microwave phenomena in water, weakly ionized plasma and so on.

II. Dataflow Architecture FDTD Dedicated Computer

For later reference, we here simply summarize an overview of the previously developed dataflow architecture FDTD dedicated computer [6].

It is widely known that the biggest bottleneck in the FDTD simulation is memory access, which often occupies more than 90 % of entire calculation time. Accordingly it is essential to reduce the memory access operation for the speed-up of throughput performance of the FDTD simulation. For this purpose, the concept of the dataflow architecture is employed for the FDTD dedicated computer indicated in Fig.1. All of electromagnetic field values and material constants are stored in registers individually. These registers are prepared for all grids in 3-D calculation domain. Then, at the grids in the bottom layer, the registers are connected each other via arithmetic circuits which execute the FDTD scheme automatically synchronizing with a system clock. This unit circuit for six electromagnetic fields components in a single grid are connected each other to construct 2-D *xy* grid plane, which execute the FDTD scheme for all grid of the *xy* plane with a single clock cycle. And, after the single clock FDTD calculation, the field values in all registers are shifted down to the lower layer by a round-robin rule (see Fig.1). To repeat these calculation and vertical shift operations, one time step FDTD calculation for the entire grid space is executed, which means that extremely high-performance computation for microwave simulation can be performed by this FDTD machine. In addition, the dedicated computer circuit is flexibly designed to cover various numerical models, such as arbitrary 3-D model shape, any distribution of dielectric material and PML regions. The dedicated computer circuit was designed by a hardware description language, VHDL, and it was confirmed that the FDTD dedicated computer with the dataflow architecture operates normally by using VHDL logic circuit simulation [6].

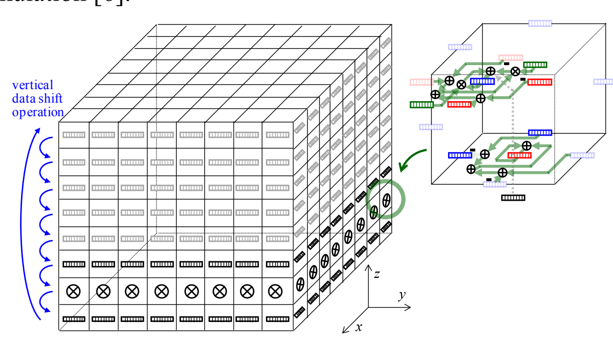


Fig.1. Overview of dataflow architecture FDTD dedicated computer

III. Modified Digital Circuit for Dispersive Material

It is readily understood that the dataflow architecture machine of Fig.1 requires very large hardware size. Accordingly we need to suppress the circuit size in the individual grid as possible. In Fig.2, circuits for e_z and b_z components of previously developed FDTD dedicated computer are indicated. In these circuits, microwave simulations for arbitrary PEC shapes, any dielectric material and PML regions can be commonly executed. Then the most of hardware resources are occupied by four multipliers in each circuit, that is, other parts such as adders, registers occupy negligible size hardware compared with the multipliers. Accordingly, we need to design the modified FDTD scheme circuits for the dispersive material to avoid to use additional multipliers.

In Fig.3, the modified circuits for the dispersive materials are indicated. Then it is assumed that the dispersive material can be described by the following Lorentz's or Drude's models,

$$\frac{d^2\mathbf{P}}{dt^2}+\gamma\frac{d\mathbf{P}}{dt}+\omega_0^2\mathbf{P}=\varepsilon\omega_0^2\mathbf{E},\quad \mathbf{J}=\frac{d\mathbf{P}}{dt} \tag{1}$$

$$\frac{d^2\mathbf{P}}{dt^2}+\gamma\frac{d\mathbf{P}}{dt}=\varepsilon\omega_0^2\mathbf{E},\quad \mathbf{J}=\frac{d\mathbf{P}}{dt} \tag{2}$$

which means the FDTD scheme circuits of Fig.3 can execute the microwave simulation for water, weakly ionized plasma, finite conductivity conductor, and so on, in addition to the previously implemented functions of arbitrary PEC model shape, any dielectric material and PML regions. Then it is noticed that the number of the multipliers does not increase from the previously developed circuits of Fig.2. The operation modes of the vacuum, PEC, dielectric material, PML and dispersive materials are switched to refer to download information from a host computer in advance of the execution of the simulation in the same circuits as Fig.3.

IV. Numerical Example

The detail circuits of the modified FDTD dedicated computer (Fig.3) are designed by the VHDL. To make sure a validity of the designed circuits, we use the numerical example of a waveguide model which contains plasma region indicated in Fig.4(a). In Fig.4(b), distribution of electric field intensity on the middle horizontal plane, which is a result of the VHDL circuit simulation for the FDTD machine operation, is indicated. It is confirmed that Fig.4(b) has good agreement with that of C software simulation, which means that the designed circuit operates normally.

V. Summary

This paper has presented a modified circuit of previously developed dataflow architecture FDTD dedicated computer for microwave simulation of Lorentz's and Drude's dispersive materials. The proposed circuit is designed to be commonly used for the dispersive material in addition to conventional functions of the vacuum, PEC, dielectric material and PML. It is confirmed that the FDTD machine operates normally by using the VHDL logic circuit simulation.

References

[1] R.N.Schneider, M.M.Okoniewski, and L.E.Turner, "Finite- difference time-domain method in custom hardware", Microwave and Wireless Components Letters, IEEE, Vol:12, Issue:1, pp.488-490, 2002.

[2] P.Placidi, L.Verducci, G.Matrella, L.Roselli, and P.Ciampolini, "A custom VLSI architecture for the solution of FDTD equations", IEICE Trans. Electron., Vol.E85-C, No.3, pp.572-577, March, 2002.

[3] H.Kawaguchi, K.Takahara, and D.Yamauchi, "Design study of ultra-high speed microwave simulator engine", IEEE Transactions on Magnetics, Vol:38, Issue:2, pp.689-692, 2002.

[4] J.P. Durbano, F.E. Ortiz, J.R. Humphrey, M.S. Mirotznik, and D.W. Prather, "Hardware implementation of a three- dimensional finite-difference time-domain algorithm", IEEE Antennas and Wireless Propagation Letters, Vol.2, pp.54-57, 2003.

[5] K.Sano, Y.Hatsuda, L.Wang, and S.Yamamoto, "Performance evaluation of finite-difference time-domain (FDTD) computation accelerated by FPGA-based custom computing machine", Interdisciplinary Information Sciences, Vol:15, Issue:1, pp.67-78, 2009.

[6] H. Kawaguchi, and S. Matsuoka, "Conceptual design of 3D FDTD dedicated computer with dataflow architecture for high performance microwave simulation", IEEE Trans. Magn., Vol.51, Issue 3, 7202404, 2015.

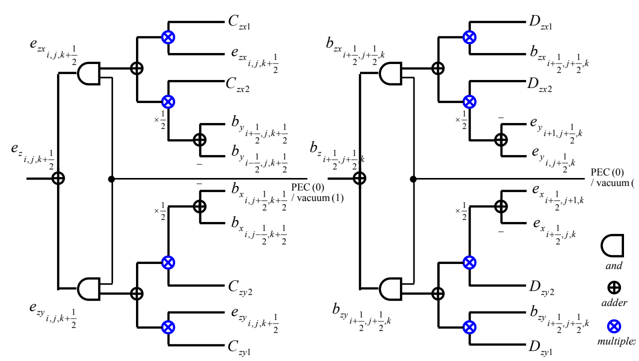


Fig.2. FDTD calculation circuit of conventional machine

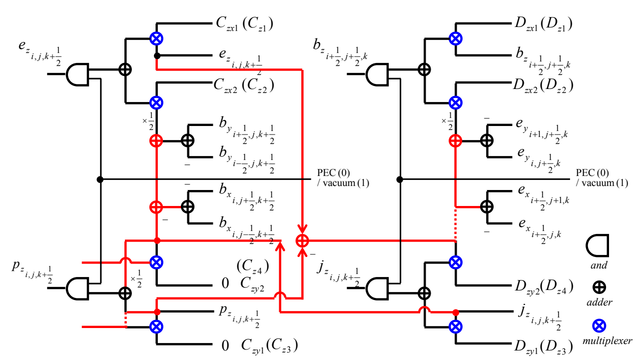
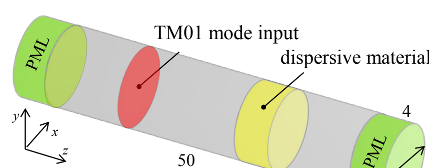
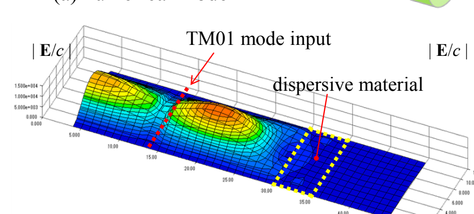


Fig.3. Modified FDTD calculation circuit for dispersive material



(a) numerical model



(b) VHDL circuit simulation of machine

Fig.4.Numerical model (a) and result (b) of circuit simulation of machine