

# PORTABLE HIGH PERFORMANCE COMPUTING FOR MICROWAVE SIMULATION BY FDTD/FIT MACHINES\*

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## Abstract

This paper presents a development of fully customized printed circuit board of a dedicated computer for FDTD/FIT method which is aiming to portable high performance computation for microwave simulation. In the construction of dedicated computer hardware, it is very important to carefully consider parallel properties hidden in the target application scheme of the dedicated computer to achieve its maximum performance. In addition, judgement on tread-off between calculation performance and flexibility for various target applications is also very important in concrete design of the dedicated computer architecture. In this paper, basic concept and concrete design of the FDTD/FIT dedicated computer architecture are described, and a printed circuit board which is manufactured according to these concepts are presented.

## INTRODUCTION

Due to strong requirements of high performance computation (HPC) for electromagnetic microwave simulation in not only science but also industry, a method of FDTD or FIT dedicated computer has been actively investigated in the last several years [1-8]. One of most important advantages of the method of dedicated computer in a regime of HPC technologies is possibility of portable computing. That is to say, in most cases, HPC hardware such as supercomputer and PC cluster is installed at apart from user computers because such the HPC hardware are basically multi-user system, therefore those kinds of HPC environment are not familiar with industrial applications such as microwave simulation connecting with CAD system which are usually carried out in user personal computers. Then the method of the dedicated computer is one of powerful solutions to those requirements. Especially appearance of large size rewritable LSI hardware such as FPGA and GPU, very useful LSI design tool and low price Printed Circuit Board (PCB) development service enhance such the activities of dedicated computer researches. Authors also have been working in development of dedicated computers of the FDTD or FIT method for high performance computation in microwave simulation [5-8]. The method of dedicated computer allows us to construct highly optimized hardware architecture and high performance computation dedicated into the calculation

scheme of the target application by comparably small size hardware. Especially a problem of Neumann bottleneck related to memory access overhead, which is essential problem for achievement of HPC in Neumann architecture based computer system, can be avoidable in the method of dedicated computer. This paper presents a design of the dedicated computer specialized into FDTD / FIT method and its hardware implement.

## PARALLEL PROPETIES HIDDEN IN FDTD METHOD AND CONCEPTUAL DESIGN OF DEDICATED COMPUTER

### Parallel properties hidden in FDTD method

To achieve efficient computation in use of dedicated computer, we need to embed parallel properties hidden in the FDTD method ( (1) and (2) ) into the hardware architecture of the dedicated computer.

$$E_{x i,j,k}^{n+1} = E_{x i,j,k}^{n-1} + \frac{\Delta t}{\epsilon \Delta l} \left[ H_{z i,j,k}^n - H_{z i,j-1,k}^n - H_{y i,j,k}^n + H_{y i,j,k-1}^n \right] \quad (1)$$

$$E_{y i,j,k}^{n+1} = E_{y i,j,k}^{n-1} + \frac{\Delta t}{\epsilon \Delta l} \left[ H_{x i,j,k}^n - H_{x i,j,k-1}^n - H_{z i,j,k}^n + H_{z i-1,j,k}^n \right]$$

$$E_{z i,j,k}^{n+1} = E_{z i,j,k}^{n-1} + \frac{\Delta t}{\epsilon \Delta l} \left[ H_{y i,j,k}^n - H_{y i-1,j,k}^n - H_{x i,j,k}^n + H_{x i,j-1,k}^n \right]$$

$$H_{x i,j,k}^n = H_{x i,j,k}^{n-1} - \frac{\Delta t}{\mu \Delta l} \left[ E_{z i,j+1,k}^n - E_{z i,j,k}^n - E_{y i,j,k+1}^n + E_{y i,j,k}^n \right] \quad (2)$$

$$H_{y i,j,k}^n = H_{y i,j,k}^{n-1} - \frac{\Delta t}{\mu \Delta l} \left[ E_{x i,j,k+1}^n - E_{x i,j,k}^n - E_{z i+1,j,k}^n + E_{z i,j,k}^n \right]$$

$$H_{z i,j,k}^n = H_{z i,j,k}^{n-1} - \frac{\Delta t}{\mu \Delta l} \left[ E_{y i+1,j,k}^n - E_{y i,j,k}^n - E_{x i,j+1,k}^n + E_{x i,j,k}^n \right]$$

There are roughly three kinds of parallel properties in the FDTD method,

- dataflow property in the FDTD calculation structure
- parallel calculation of x-, y-, z- three field components
- parallel calculation of different grid field components

The FDTD dedicated computer implementing all of these parallel properties (we call this "full dataflow architecture FDTD/FIT machine") indeed gives us extremely high performance computation, however its hardware size is quite large and especially 3D FDTD machine will be impossible in the next several years even beyond remarkable progress of recent LSI technology [6]. Accordingly the FDTD/FIT dedicated computer based on the first two parallel properties is practical solution in the present LSI technology (we call this "memory architecture FDTD/FIT machine").

### Design of memory architecture FDTD machine

The figure 1 shows an overview of the FDTD/FIT dedicated computer architecture. The hardware mainly consists of two parts, calculation and memory modules. All components of electromagnetic field values, material

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constant distributions, boundary conditions are stored in the memory module, and x-, y-, z- three component FDTD scheme calculation for one grid are executed in the calculation module. The fundamental operation of this machine is as follows, (a) downloading electromagnetic field components from the memory module to the calculation module, (b) execution of one grid FDTD calculation ( (1) or (2) ) and PML calculation at the calculation module, (c) uploading the calculated field components from the calculation module to the memory module.

Then calculation module is composed of three same dataflow circuits for both of normal FDTD grid (see Fig.2 for (1)) and PML grid to perform three components FDTD calculation of (1) or (2) in single computer clock cycle. This structure of the calculation module realizes the first two parallel properties of the FDTD method.

*Parallel memory access architecture*

The FDTD method is heavy memory access scheme, for example, at least 12 different field component values are needed in three components calculation as in the right hand side of (1) or (2). This mean that 12 times memory access are required if the memory module is composed by simply single RAM. To avoid this quite inefficient machine operation for the FDTD calculation, we adopt parallel memory access architecture for the FDTD/FIT dedicated computer as shown in Fig.1. That is, in the memory module, each field component value is stored individually in four physically different RAMs. In this memory structure, all field components which are needed in three component calculation of (1) or (2) can be loaded from the memory module to the calculation module within only single memory access cycle.

*Automatic boundary condition setting*

Implementation of boundary condition setting in the dedicated computer is also one of most important matter for practical use of the FDTD/FIT machine. There are mainly three kinds of fundamental boundary conditions,

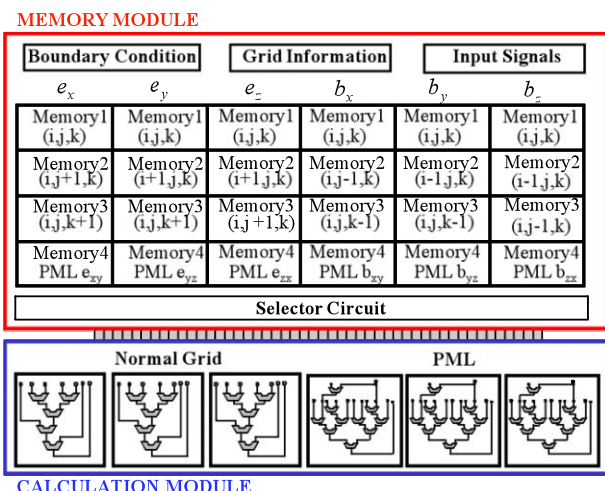


Fig.1 Hardware of architecture FDTD/FIT machine

**Computer Codes (Design, Simulation, Field Calculation)**

material boundary condition, perfect conductor boundary condition and absorbing boundary condition such as PML. These boundary conditions can be automatically imposed by hardware circuit of the dedicated computer [see ref. 5 and 6]. Especially various kind of numerical models can be treated by rewriting the contents of memory module, then it is not necessary to change hardware circuit.

**FULL CUSTOM PCB OF FDTD/FIT DEDICATED COMPUTER**

The figure 3 shows fully custom made printed circuit board (PCB) for the FDTD/FIT dedicated computer according to the memory architecture of Fig.1. The memory module is composed by 16 SRAMs and all other complicated circuits such as calculation module, address generator, machine operation scheduler, etc. are embedded in one FPGA. As an example of microwave simulation based on this FDTD / FIT dedicated computer, microwave radiation from rectangular wave guide is simulated here (see Fig.4). The numerical model is stored in one of SRAMs and then machine hardware automatically executes FDTD microwave simulation for this numerical model without any software program code. It is confirmed that simulation results show good agreement with software simulations.

**CONCLUSION**

This paper has presented a development of the FDTD/FIT dedicated computer aiming portable high performance computation of electromagnetic microwave simulation. Especially highly optimized memory access architecture dedicated into the FDTD scheme are introduced to achieve high throughput performance including memory access. And then real PCB hardware of the dedicated computer has been shown.

Based on the development of the prototype FDTD/FIT machine, we are now planning to proceed to further improvements such as introduction of DDR like high speed SDRAM, parallel calculation by interlocking operation of the dedicated computer PCBs, etc.

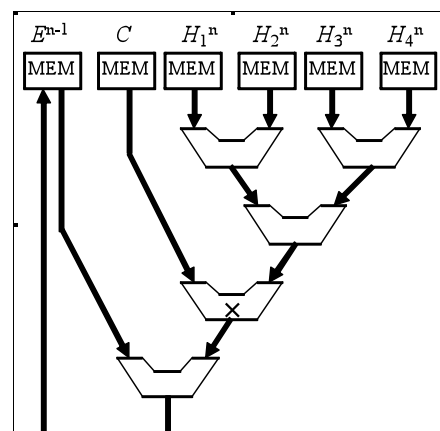


Fig.2 Dataflow circuit for FDTD/FIT basic calculation

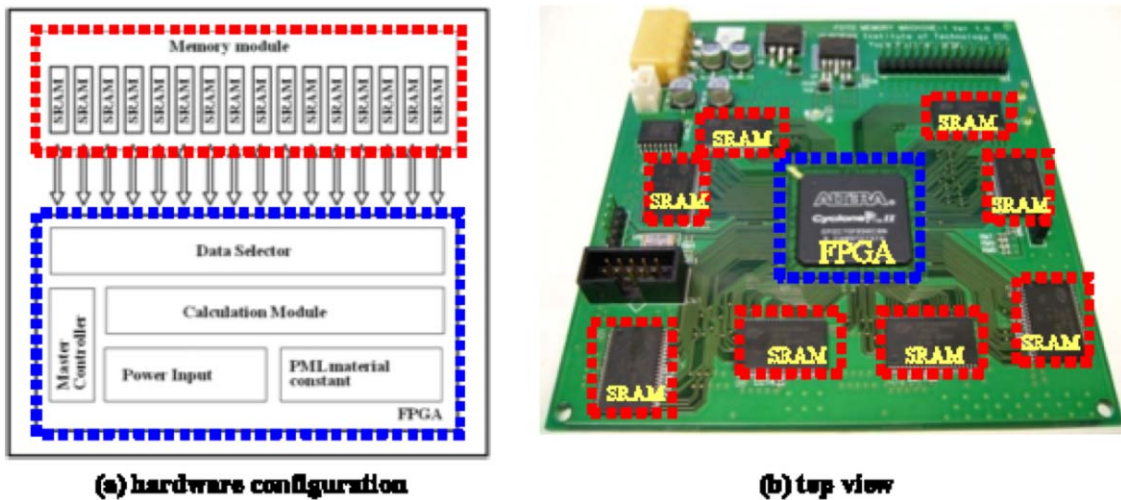


Fig.3 Full custom printed circuit board of FDTD / FIT dedicated computer

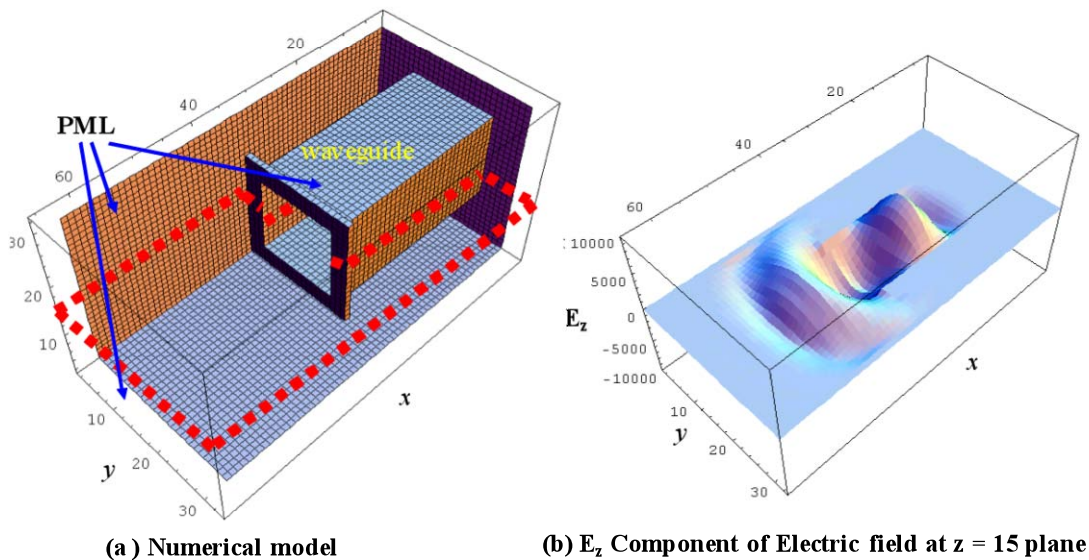


Fig.4 Numerical example of FDTD/FIT machine operation for radiation from waveguide

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