

# Electromagnetic Wave Simulation Software “Poynting”

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The analysis of electromagnetic behavior by computer simulation has become quite active in recent years. In the research and development of electronic devices, electromagnetic analysis tools have become indispensable for shortening development times and reducing costs. This is because the research and development of microwave devices has intensified with the rapid spread of mobile communications. Moreover, as the frequencies of electrical signals in electronic circuits have risen, it has become necessary to examine electromagnetic behavior and deal appropriately with the leakage of electromagnetic waves. To meet this simulation need, Fujitsu has developed “Poynting”, an electromagnetic wave simulation software package that it markets and supports. This paper describes Poynting’s basic functions, parallel computation function, computer-aided design data conversion functions, and function for linking its simulation with a circuit simulator and presents Poynting calculation examples for a patch antenna, meander line, and printed circuit board.

## 1. Introduction

Recent years have seen much activity in the analysis of electromagnetic behavior by computer simulation. The introduction of electromagnetic analysis tools has become an integral part of research and development in the field of electronics to shorten development times and reduce costs. This can be attributed to accelerated research and development of microwave devices due to the explosive growth of mobile communications as well as the need to examine the electromagnetic behavior of high-speed electrical signals and deal appropriately with the leakage of electromagnetic waves. Fujitsu has developed electromagnetic wave simulation software called “Poynting”<sup>1)</sup> in response to these needs and has been marketing and supporting it.

This paper describes Poynting’s basic functions, parallel computation function, computer-aided design (CAD) data conversion functions, and function for linking simulation

with a circuit simulator. In addition, it presents calculation examples for a patch antenna, meander line, and printed circuit board (PCB) performed using this simulation software.

Poynting comes in two versions: for microwave or optics simulations. This paper deals only with the former. For the latter, we refer readers to reference 2) for information.

## 2. Poynting basic functions and application fields

This section describes the calculation technique used in Poynting, the basic functions of the system, and application fields.

### 2.1 Calculation technique

The simulation of electromagnetic waves involves the use of numerical computing to solve Maxwell’s equations describing the behavior of electromagnetic waves. Poynting uses the finite difference time domain (FDTD) method<sup>3)-7)</sup> for

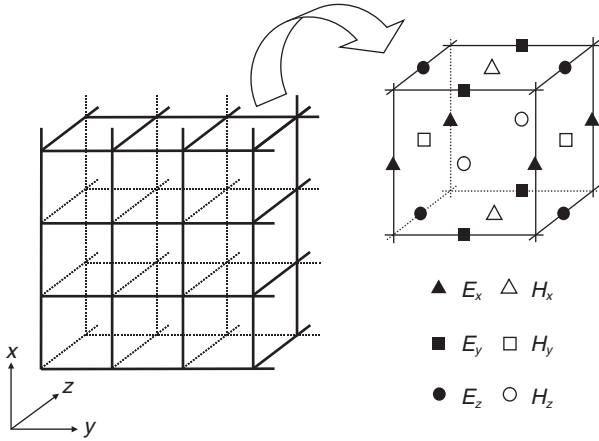


Figure 1  
Electromagnetic field arrangement for FDTD method.

electromagnetic simulation. This method divides the computational domain into minute cells, each having the form of a rectangular parallelepiped, and arranges electromagnetic field components in each cell in the manner shown in **Figure 1**. The cells are called a "Yee lattice" after its inventor (Kane Yee). They are also called "staggered cells" because the physical quantities to be calculated (here, the electric field and magnetic field components) are defined at different positions.

Cells and electromagnetic field components are specified by index notation. Given the electromagnetic field in Figure 1, Maxwell equations are expressed in terms of temporal and spatial finite differences. For example, Eq. (1) consisting of the electric-field  $X$  component and the magnetic-field  $Y$  and  $Z$  components can be converted to finite differences, as shown by Eq. (2).

$$\varepsilon \frac{\partial E_x}{\partial t} + \sigma E_x = \frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} \quad (1)$$

$$E_x^{n+1}(i+1/2, j, k) = \frac{2\varepsilon(i, j, k) - \sigma(i, j, k)\Delta t}{2\varepsilon(i, j, k) + \sigma(i, j, k)\Delta t} E_x^n(i+1/2, j, k) + \frac{2\Delta t}{2\varepsilon(i, j, k) + \sigma(i, j, k)\Delta t} \cdot [\{H_z^{n+1/2}(i+1/2, j+1/2, k) - H_z^{n+1/2}(i+1/2, j-1/2, k)\} / \Delta y(j) - \{H_y^{n+1/2}(i+1/2, j, k+1/2) - H_y^{n+1/2}(i+1/2, j, k-1/2)\} / \Delta z(k)] \quad (2)$$

In Eq. (2),  $E$  is the electric field,  $H$  is the magnetic field,  $\varepsilon$  is the permittivity,  $\sigma$  is the conductivity,  $\Delta t$  is the time step size,  $\Delta y$  and  $\Delta z$

are the cell size in the  $Y$  and  $Z$  directions, respectively,  $n$  is a time index, and  $i, j$ , and  $k$  are  $X, Y$ , and  $Z$  coordinate indices, respectively.

What this finite difference system means is that the  $X$  component of the electric field is updated in terms of the  $Y$  and  $Z$  components of the magnetic field. Other electromagnetic components are expressed as finite differences in the same way, and the temporal changes in the electromagnetic field are calculated by updating the electric and magnetic fields alternately. In the course of these calculations, processing is performed to ensure that previously set material characteristics, boundary conditions, and excitation conditions are satisfied, and time series data for the electromagnetic field are output.

## 2.2 System configuration

The Poynting system configuration is shown in **Figure 2**. Poynting consists of Solver that executes electromagnetic field simulations, Analyzer that analyzes output data, and a graphical user interface (GUI) that performs preprocessing and post-processing.

The GUI consists of Modeler that performs preprocessing and Graphics that performs post processing. Modeler creates computation models, automatically creates finite difference cells, and enables boundary conditions, material characteristics, and wave sources to be specified in a pop-up window. This function simplifies the creation of input data. Graphics visualizes computed numerical data in two- and three-dimensional graphs and by animation. It helps the user to check and evaluate computation results more effectively and to develop an intuitive understanding of the results.

Solver executes numerical computations based on the FDTD method, calculates time series data for each electromagnetic field component within the computational domain, and calculates voltage/current temporal waveforms at previously specified points. Performing calculations on such a large scale often requires extensive memory

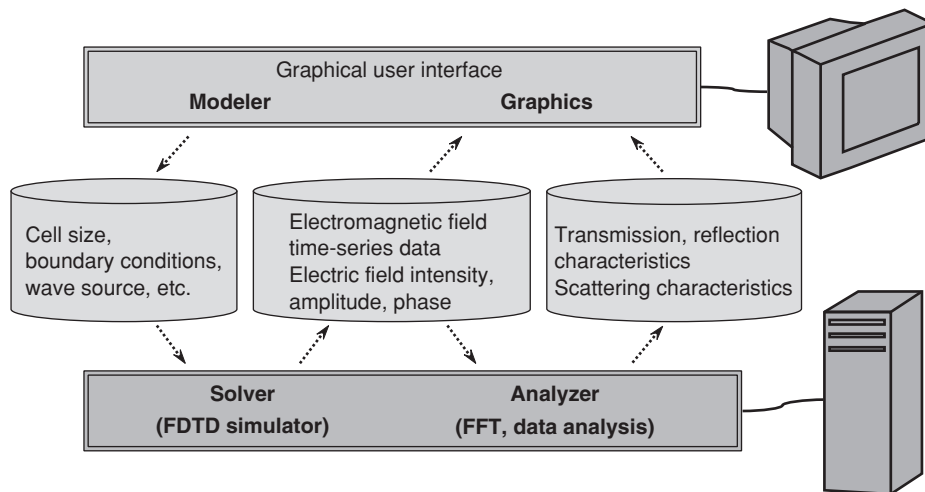


Figure 2  
Poynting system configuration.

and a very long computing time, which calls for a high-performance computer.

Analyzer performs secondary analysis of data output by Solver. It converts time domain data into frequency domain data by Fourier transformation, performs temporal and spatial integral processing, and calculates the S-parameter, impedances, radiation patterns, radiation spectrums, and other data required for research and development.

Solver and Analyzer come in either a standalone version executed on a single central processing unit (CPU) or a parallel version executed on multiple CPUs such as a personal computer (PC) cluster. There are optional functions for importing PCB CAD data and three-dimensional CAD data and for linking a simulation with a circuit simulator, which is explained below.

### 2.3 Application fields

Poynting can be used in the following fields.

- 1) Analysis of signal integrity, power integrity, electromagnetic interference, and electrostatic discharge phenomena for various types of PCBs
- 2) Analysis of input impedance, radiation

pattern, gain, and axial ratio of various types of antennas

- 3) Analysis of S-patterns of various types of microwave components
- 4) Analysis of electromagnetic wave absorption and electromagnetic wave shield characteristics for various types of materials and objects

### 3. Parallel computation function

One key feature of Poynting is its parallel computation function using a PC cluster, which is a system for connecting multiple PCs over a network to perform parallel distributed processing. A PC cluster can be constructed at relatively low cost and can demonstrate high performance depending on the application.

The concept of parallel computation in the case of a 4-CPU PC cluster is shown in **Figure 3**. The computational domain is partitioned according to the number of CPUs so that each CPU performs calculations for only one computational sub-domain. Electromagnetic field data near the boundaries of sub-domains is exchanged among the CPUs. The volume of such transmitted data is small in the case of the FDTD method, which is conducive to good scalability (the extent to which

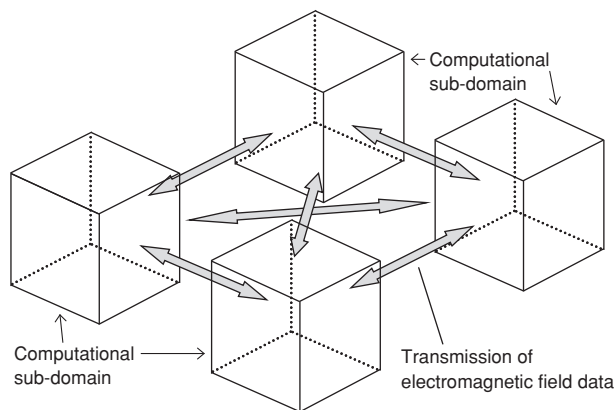


Figure 3  
Concept of parallel computation.

computation speed increases by the addition of more processors).

The scalability of parallel computation in Poynting is shown in **Figure 4**. The computational environment here consists of Xeon 3.8-GHz CPUs, an InfiniBand network, and Red Hat Enterprise Linux operating system with FJMPI<sup>note 1)</sup> used for the parallel library.

In the figure, the increase in computation speed means multiples of the computation speed with one CPU. It can be seen from these results that speed increases well as the number of CPUs is increased and that parallel computation performance is quite high.

This parallel computation function means that calculations for a problem that would require a large amount of computational time with one PC can be completed in a relatively short time. It also enables a large-scale problem that was traditionally considered impossible to simulate to be computed in a realistic period of time.

#### 4. CAD data conversion functions

To efficiently create a simulation model at the product-design stage, CAD data must

note 1) MPI (message passing interface) developed by Fujitsu. MPI is an interface for achieving a program that performs parallel processing while exchanging data among the processors.

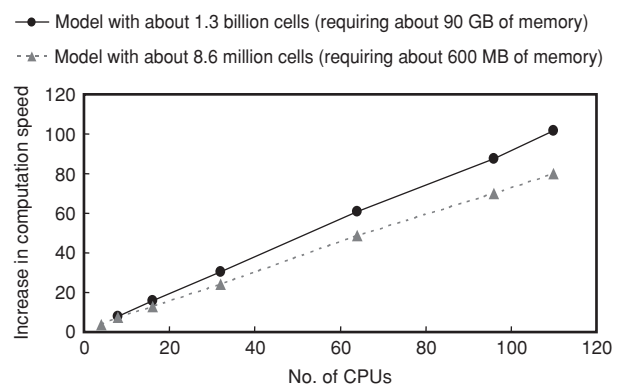


Figure 4  
Scalability of parallel computation.

be converted to model data. Poynting provides ECAD-LINK, an optional function for converting CAD for PCBs, and MCAD-LINK, another optional function for converting three-dimensional CAD data.

The ECAD-LINK function supports CR-5000/BD, Allegro, and CAD that can output data in ODB++ format. MCAD-LINK supports CAD that can output data in STL format. The concept of CAD data conversion is shown in **Figure 5**.

#### 5. Function for linking simulation with a circuit simulator

The function provided by Poynting for directly linking with a circuit simulator enables electromagnetic phenomena in the wiring section of a PCB and nonlinear operation of semiconductor elements to be analyzed in a uniform manner.

The numerical method for linking a simulation of the electromagnetic simulator with a circuit simulator is shown in **Figure 6**. It is assumed here that a two-terminal circuit element is set on one side of a finite-difference cell used in the FDTD method. As described earlier, the electric field ( $E$ ) and magnetic field ( $M$ ) in space are calculated alternately in the FDTD method. The cycle from magnetic field calculation to electric field calculation is as follows. First, the magnetic field in space is calculated according to

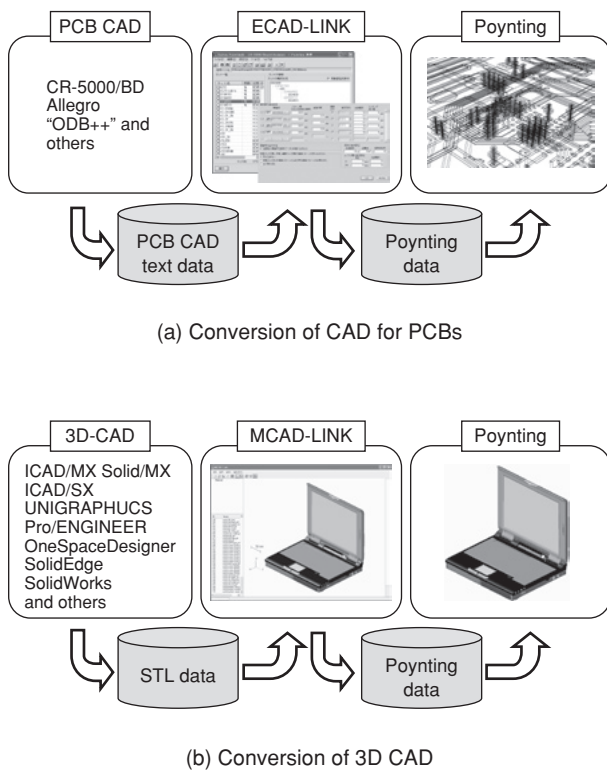


Figure 5  
Concept of CAD data conversion.

the normal FDTD procedure. Next, the current ( $I$ ) flowing in the element due to the magnetic field surrounding the element is calculated and set as the current source in the circuit simulator. After this, circuit analysis is executed and the voltage ( $V$ ) between the terminals is calculated. Finally, the value of the electric field on the side of the finite-difference cell where the element is set is calculated from the voltage between the terminals. All other electric field values are calculated according to the FDTD procedure.<sup>8),9)</sup>

An example of calculation results for linked electromagnetic and circuit simulations is shown in **Figure 7**. In Figure 7 (a), a driver and receiver consisting of CMOS transistors are connected by a differential microstrip line (MSL) for transmitting a clock signal. The operation of the driver and receiver circuits is calculated by the circuit simulator while the transmission characteristics of the differential MSL are calculated by the electromagnetic simulator. Figure 7 (b)

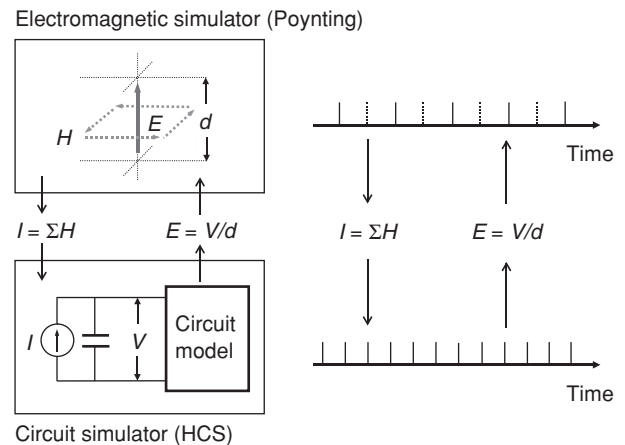
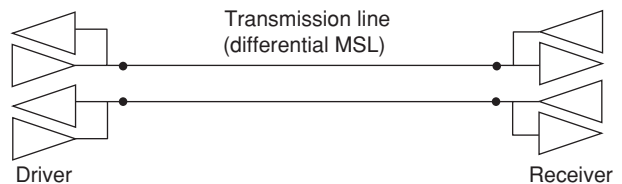
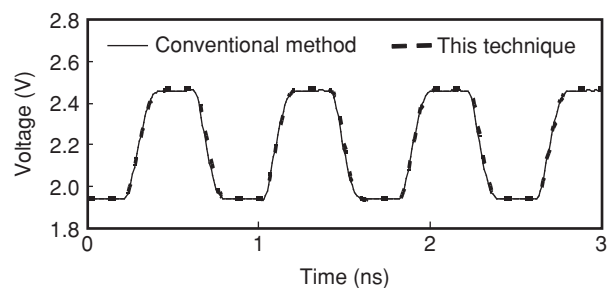


Figure 6  
Numerical method for linking simulations of electromagnetic and circuit simulators.



(a) Simulation model



(b) Calculation results

Figure 7  
Example of calculation results when linking simulation.

shows the voltage waveform at the receiver. The solid line represents results calculated using the conventional method (which approximates the transmission line by a ladder circuit) and the dashed line shows ones calculated by the technique presented here. The two sets of results agree well, demonstrating the validity of this

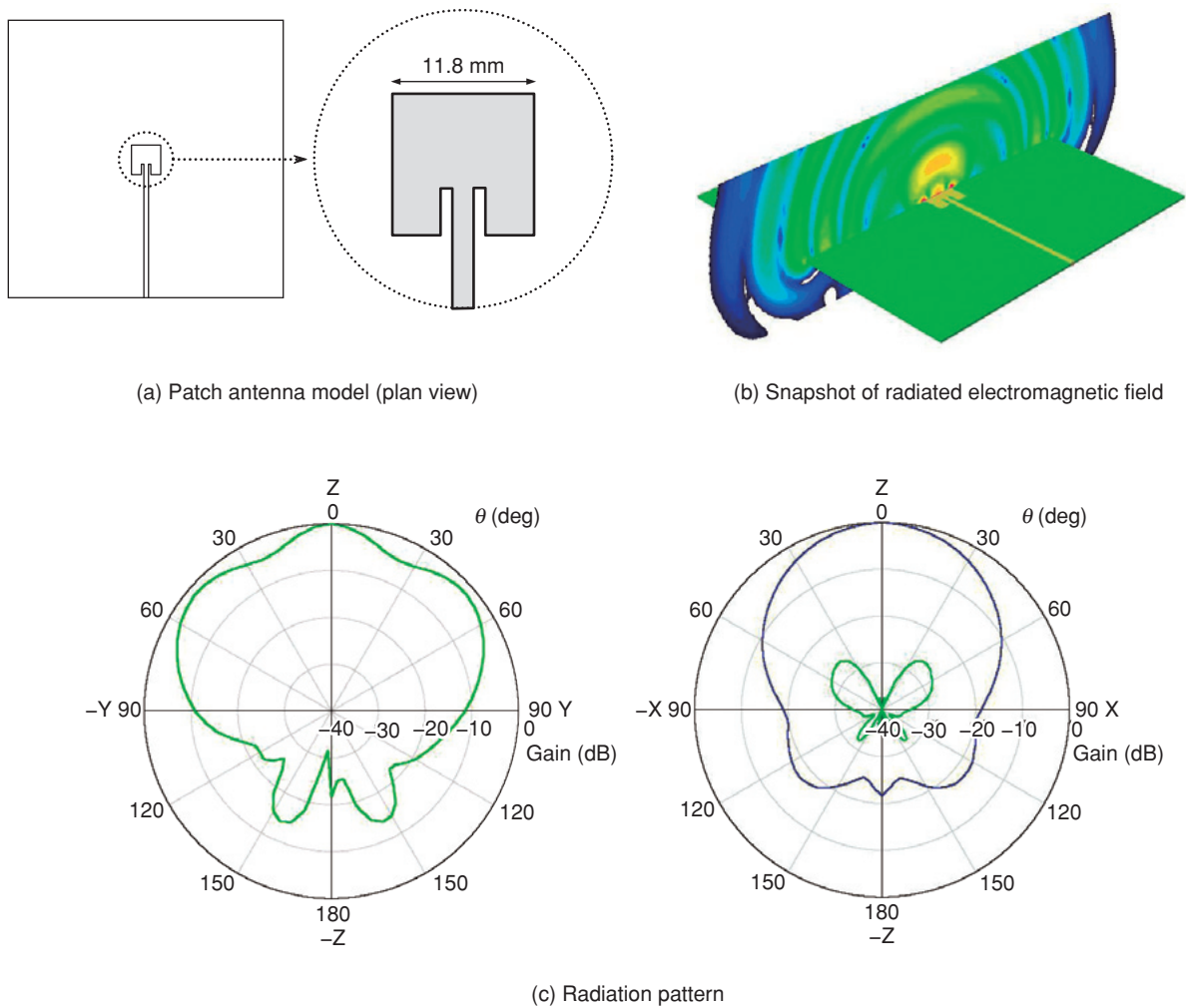


Figure 8  
Calculation results for patch antenna.

technique.

## 6. Calculation examples

This section presents several examples of calculations performed using Poynting.

### 6.1 Patch antenna

Calculation results for a patch antenna are shown in **Figure 8**. Figure 8 (a) shows a model of a square patch antenna 11.8 mm on each side formed on a board with relative permittivity of 3.274. A Gaussian pulse is applied to the antenna via an MSL power feed. Figure 8 (b) depicts the electromagnetic field radiated from the patch

antenna and Figure 8 (c) shows the radiation pattern. This radiated electromagnetic field was calculated using a function that converts the electromagnetic near field computed by FDTD into an electromagnetic far field. The radiation pattern agrees with measured values within  $\pm 1$  dB.<sup>10)</sup>

### 6.2 Meander line

An example of calculation results for a meander line (a MSL with turns) is shown in **Figure 9**. The S-parameter was calculated for three models (patterns: A1, A2, and A3) having different meander-line pitches, as shown in



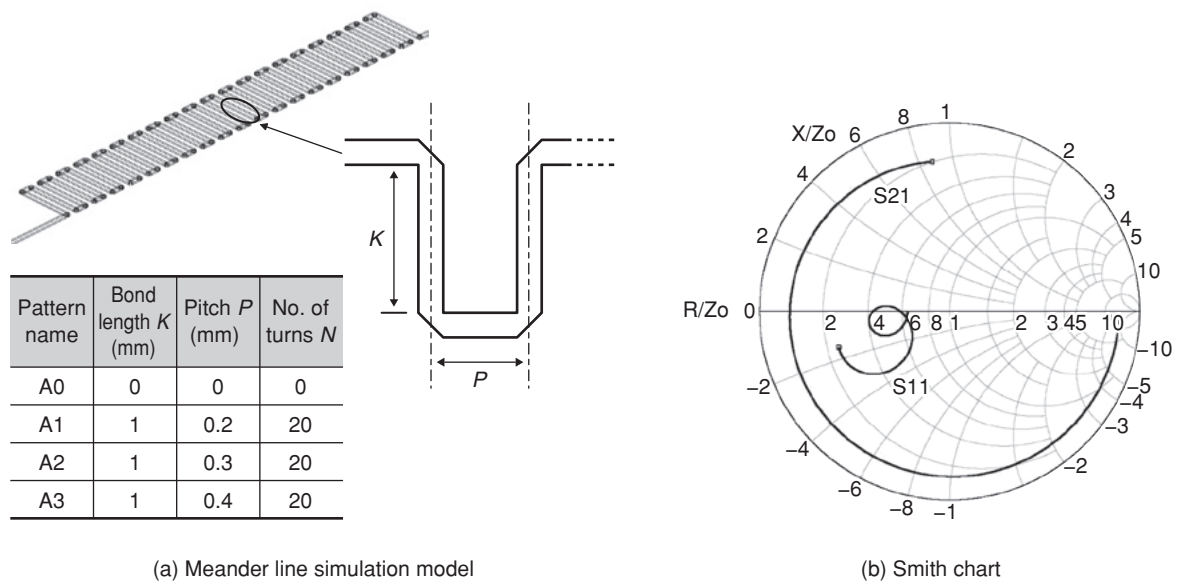


Figure 9  
Calculation results for meander line.

Figure 9 (a). Figure 9 (b) shows a Smith-chart display of the S-parameter. Calculated and measured phase values, where the values given are relative to an MSL with no turns (straight line MSL; pattern: A0), are shown in **Table 1**. The calculated and measured values show good agreement.

### 6.3 PCB

There are many types, causes, and mechanisms of noise problems on PCBs and they are mutually related. To simulate the reproduction of such phenomena and the effectiveness of counter-measures, one must analyze the entire board. However, electromagnetic analysis of an entire board using the FDTD method is very computationally intensive, and such an analysis has, in the past, been impossible for all practical purposes. In recent years though, parallel computation on a PC cluster has come to provide sufficient capacity for large-scale analyses of this type.

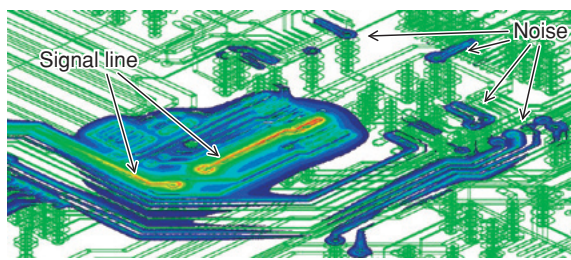
Here, we give an example of analyzing a 10-layer board with dimensions of 185 mm  $\times$  87 mm  $\times$  2 mm and a circuit line width of about 100  $\mu$ m. The simulation model was prepared

Table 1  
Comparison of meander-line phase relative values (relative value at 1 GHz).

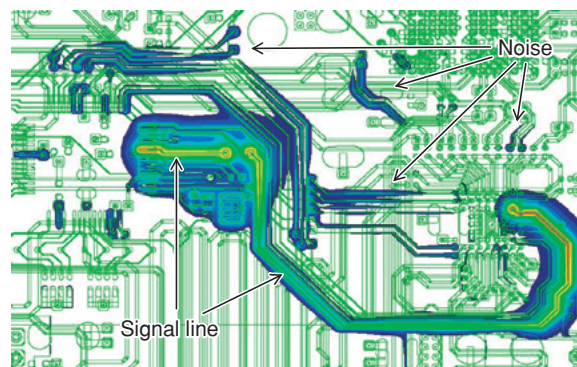
	A1/A0	A2/A0	A3/A0
Calculated value (%)	82.4	88.1	94.2
Measured value (%)	86.5	91.5	92.1

by importing PCB CAD data. The number of cells generated by domain decomposition was about 210 million and the number of time steps was 25 000 (physical time: 1.3 ns). One end of a certain wire was set with a signal source and the other end with a terminating resistor and a trapezoidal wave was applied. Matched termination was applied to all surrounding wires.

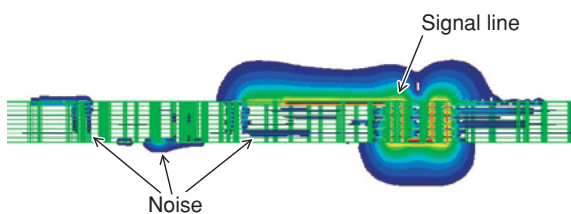
**Figures 10 (a)–(c)** show the board's electric-field distribution. These results show that electric-field intensity in the vicinity of the wire set with a signal source is high, that noise occurs in surrounding wires, and that noise diffuses along the insulator layer between the power supply and ground. While these results are snapshots of electric-field distribution at a certain time, they can also be depicted in animated form. The intensity distribution for a specific



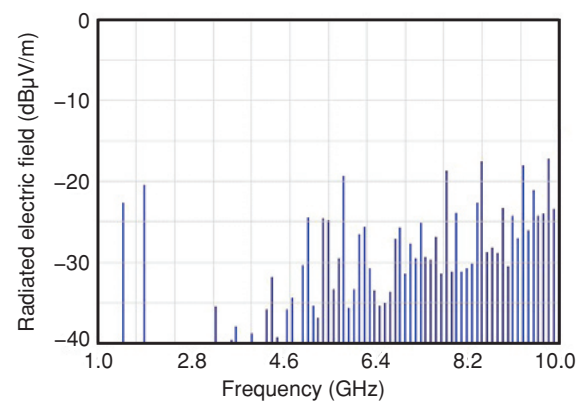
(a) Electric-field intensity (bird's-eye view)



(b) Electric-field intensity (plan view)



(c) Electric-field intensity (cross section)



(d) Radiation spectrum

Figure 10  
Calculation results for PCB.

frequency can also be calculated.

**Figure 10 (d)** shows the radiation spectrum corresponding to the 10-m method.<sup>note 2)</sup> These results were obtained using a function that converts the electromagnetic near field around the board into an electromagnetic far field, the same as in the antenna example above.

When the above simulation was executed on a 32-CPU PC cluster (CPU: Xeon 3.6 GHz), the computation time and required memory per CPU came out to be 3.75 hours and 542 MB, respectively.

note 2) A method that measures electromagnetic radiation from an electronic device by using an antenna set 10 meters away in accordance with an international standard.

## 7. Conclusion

This paper outlined the Poynting electromagnetic wave simulation software, described its key functions, and presented calculation examples. To meet growing expectations for electromagnetic simulation and analysis as target problems become more complex and diverse as well as larger in scale, we plan to expand the functions of Poynting.

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