“Denji” Specifications

1. Objectives

“ Denji” is a program to perform electromagnetic field analysis with FDTD method. The electromagnetic field is expressed by Maxwell equations in the condition which is the macro and is non relativity theory. FDTD method (Finite difference time domain method) is a method to analyze the electromagnetic fields by the different method of Maxwell equations, and in which a magnetic field and an electric field are different in a half grid.

"Denji" uses 64x64x64 mesh size; it can be set a dielectric constant, magnetic permeability and conductivity in each grid. The grid size can be set voluntarily. “Denji” can analyze the electromagnetic field of a wide frequency band including an electric wave and a light, but it is theoretically suitable for the band of MHz - GHz because the function of “Denji” is designed assuming the electronic circuit.

2. Backgrounds

In late years the problems that an electromagnetic wave emitted by an electronic circuit affects neighboring wireless units increase, and technology to restrain the emission of an unnecessary electromagnetic wave is demanded.

This electromagnetic wave is emitted to the space by antenna structure constituted by an electronic circuit, and an interchange electric current going in and out of an electronic device is an energy source by an electronic circuit.

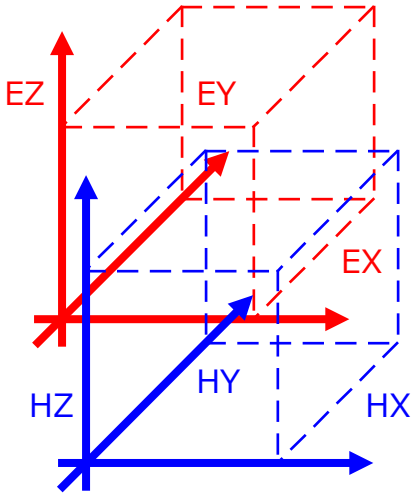
On the other hand, the design technology of the wireless unit continues rapid progress, and various methods such as small antenna or EBG (Electromagnetic band gap) structure are studied. The electromagnetic field analysis is the technology that is indispensable for these designs, and various tools are suggested. Unfortunately professional knowledge is necessary for these tools and needs "experience" to judge the design from a result.

I’m one who does not have such an experience, but I wanted to understand, “how is an electromagnetic wave still emitted by an electronic circuit?” before I developed “Denji”. With a 3D graphic function, “Denji” can display an electromagnetic field analyzing in real time. You can describe an arbitrary electronic circuit on this occasion by setting the physics fixed number in an analysis grid. But the analysis grids set into small numbers in consideration of a performance, and the boundary condition uses a brief thing for speedup of the processing again. I'm not going to attach the additional function as much as possible not to increase of analysis time. I recommend marketed various electromagnetic field analysis tools to a purpose to get precision and an analysis result.

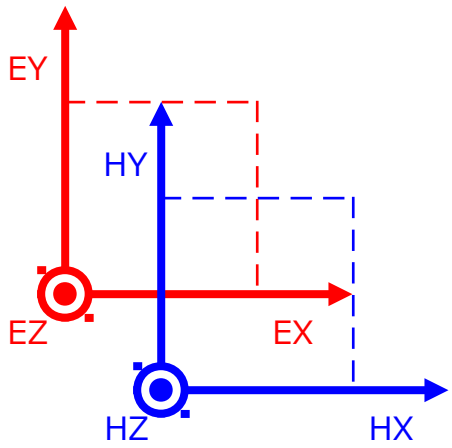
3. FDTD Method (Finite difference time domain method)

3.1. Coordinate Systems

By FDTD method, half Grid moves each coordinate system of a magnetic field and the electric field and posts it. The coordinate system is defined like 3D View of the left-hand figure in the main window, and like the right figure in the editing window.



3D View



Top View

In addition, the time axis defines it by the next expression. Here, dx/dy/dz are mesh size of the electromagnetic field, dt is mesh size of the time, C are speed of light in the vacuums. Attention is necessary when phase velocity in the analyzed medium is faster than the speed of light. The magnetic field is also drag 1/2 grids for an electric field about the time axis.

$$dt = \frac{0.99}{C\sqrt{\frac{1}{dx^2}+\frac{1}{dy^2}+\frac{1}{dz^2}}}$$

3.2. Maxwell equations

FDTD method calculates Maxwell equation by the difference method about space and time. The Maxwell equation to use is two sets of the next on this occasion.

$$\nabla \times E = -\mu \frac{\partial H}{\partial t}$$

$$\nabla \times H = \sigma E + \varepsilon \frac{\partial E}{\partial t}$$

The next come from conversion of this according to a former coordinate system by the difference method. Here is only the expression of the X ingredient of a magnetic field and the electric field. Please refer to commercial documents for the details.

$$H_x(i,j,k,t+\frac{1}{2})=H_x(i,j,k,t-\frac{1}{2})+\frac{dt}{\mu}\left[\frac{E_y(i,j,k+1,t)-E_y(i,j,k,t)}{dz}+\frac{E_z(i,j,k,t)-E_z(i,j+1,k,t)}{dy}\right]$$

$$E_x(i,j,k,t+1)=\left[1-\frac{\sigma\, dt}{\varepsilon+\sigma\, dt/2}\right]E_x(i,j,k,t)$$
$$+\frac{dt}{\varepsilon+\sigma\, dt/2}\left[\frac{H_z(i,j,k,t+1/2)-H_z(i,j-1,k,t+1/2)}{dy}+\frac{H_y(i,j,k-1,t+1/2)-H_y(i,j,k,t+1/2)}{dz}\right]$$

In addition, FDTD go ahead through by axial grid 1/2 in time. At first it push forward 1/2 in time and calculate a magnetic field and it can go ahead through 1/2 next in time and calculate an electric field and can go ahead through the calculation until arbitrary time by repeating this.

3.3. Boundary Conditions

FDTD method expresses the space with a grid and analyzes a limited analysis domain. Because the boundary of the analysis domain cannot perform analysis correctly, it arranges boundary condition around an analysis domain. "Denji" uses the first order Mur condition. Here is only the calculating formula of the Hx ingredient of z=0 side. Please refer to commercial documents for the details.

$$H_x(i,j,0,t+1)=H_x(i,j,1,t)+\frac{vdt-dz}{vdt+dz}\left[H_x(i,j,1,t+1)-H_x(i,j,0,t)\right]$$

$$\because\ v=\frac{1}{\sqrt{\varepsilon\mu}}$$

3.4. Electric Field Sources

FDTD method realizes electromagnetic field analysis by changing an electric field and the magnetic field of an arbitrary point with time. "Denji" can put an electric field source to the arbitrary grid. The electric field value can define two kinds, but the direction can define only one direction as the frequency of the electric field to supply. This assumed proximity such as the strip line and electric field (+/-) to impress to face. The waveform of the electric field source can use one kind from all over four kinds of things of the CW (continuous wave), the gaussian pulse, the step pulse, the switching resistance other than the DC source. The frequency faces each other besides a DC source and is effective. "Material of Source" can define the medium of the electric field source position in Material of Source. When you use an electric field source as a voltage source of a place saying in Spice, you appoint conductors medium that the conductivity is high here. On the other hand, you appoint insulators medium same as the outskirts here when you do drive of an antenna.

(1) DC Source

The DC source is a source equivalent to the voltage source of a place saying in Spice. A conductor of 10^{10}[S/m] is set conductivity at the conductor position. A value same as a + side source is used for the electric field value.

(2) CW (Continuous Wave) Source

The CW source occurs in a continuous waveform of the frequency that I appointed. I am suitable to observe the resonance mode in the specific frequency.

(3) Gaussian Pulse Source

The Gaussian pulse source occurs in a Gaussian pulse according to the next expression. The frequency of the electric field source is ignored even if it is appointed. Because the Gaussian pulse has a uniform frequency characteristic, it is useful to analyze the frequency characteristic of the analysis object.

$$E_w(t)=m\frac{e^{-(\frac{t-T}{0.29T})^2}}{dw} \because T=0.646\frac{dt}{0.02}$$

(4) Step Pulse Source

The step pulse source occurs in 20 analysis steps or a step waveform changing by either short time of 20% of the waveform period. The electric field of time 0 is beginning without depending on the appointed voltage. The source which appointed the positive voltage stands up just after an analysis start, and transition begins, and the source which appointed the negative voltage stands up after progress in a period in the analysis start latter half, and transition begins. It is used at the time of the transmission line analysis of the digital code.

(5) Switching Resistance

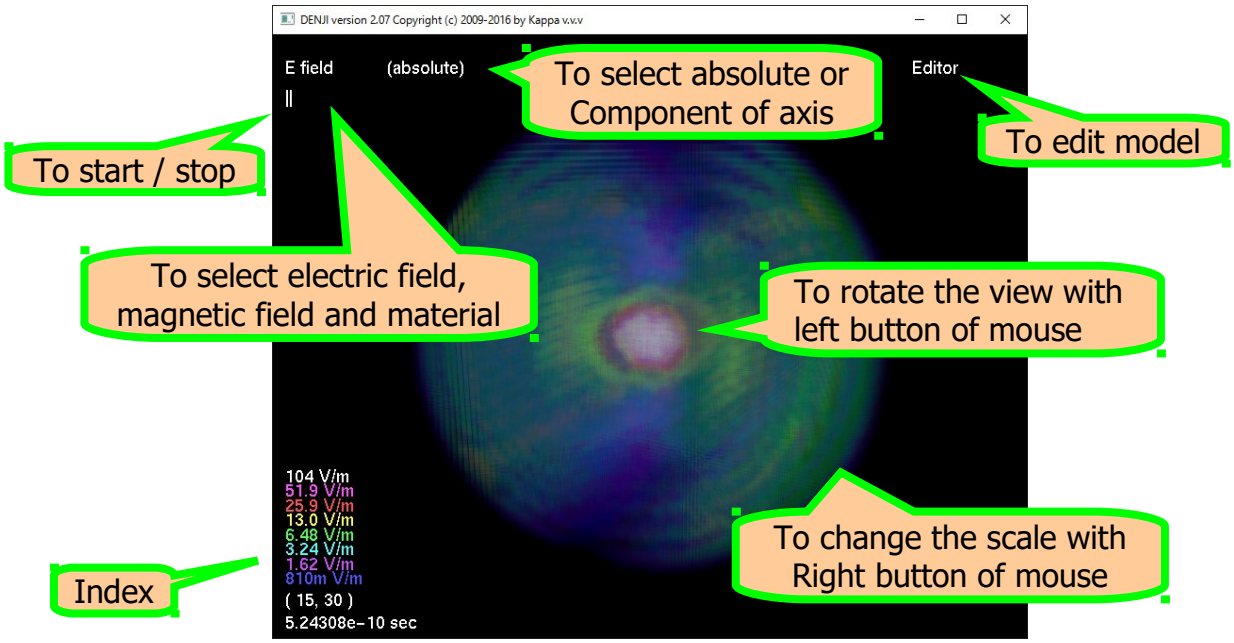
The switching resistance is the element that conductivity changes. It becomes the insulator of conductivity 100n[S/m] in Off and becomes the conductivity that appointed as a medium of the electric field source position in On. Each conductivity interval changes by either short time of 20 analysis steps or 20% of the waveform period. Because It does not have the function of the electric field source, you use switching resistance oneself while supplying a power supply by a DC source.

3.5. Wave Form Observation Point

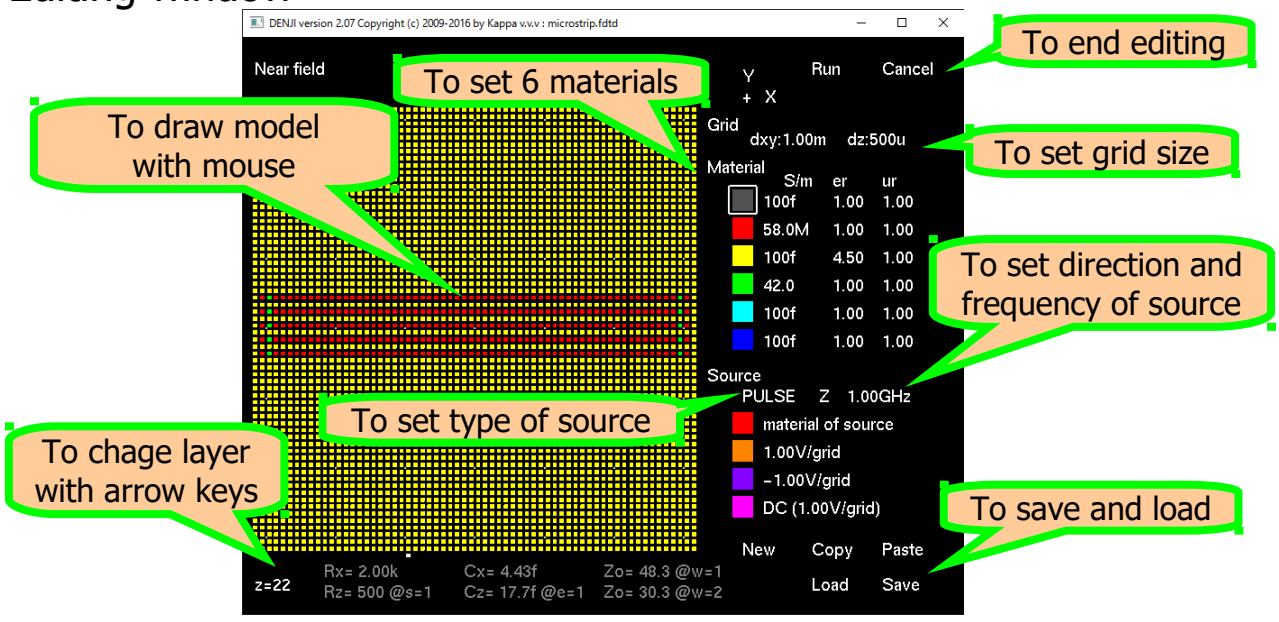
There is a function to monitor places of voltage and an electric current in an analysis field in "Denji". You can do an earmark of the observation point with a central button (or right and left both buttons same time) of a mouse with an editing window. The voltage and electric current wave of the observation point display in a wave form window. There are time domain waveform and a frequency domain wave, which is Fourier transformation of the time domain waveform, in a wave form window. But the frequency domain wave form at the time of the current indication displays impedance.

4. Windows

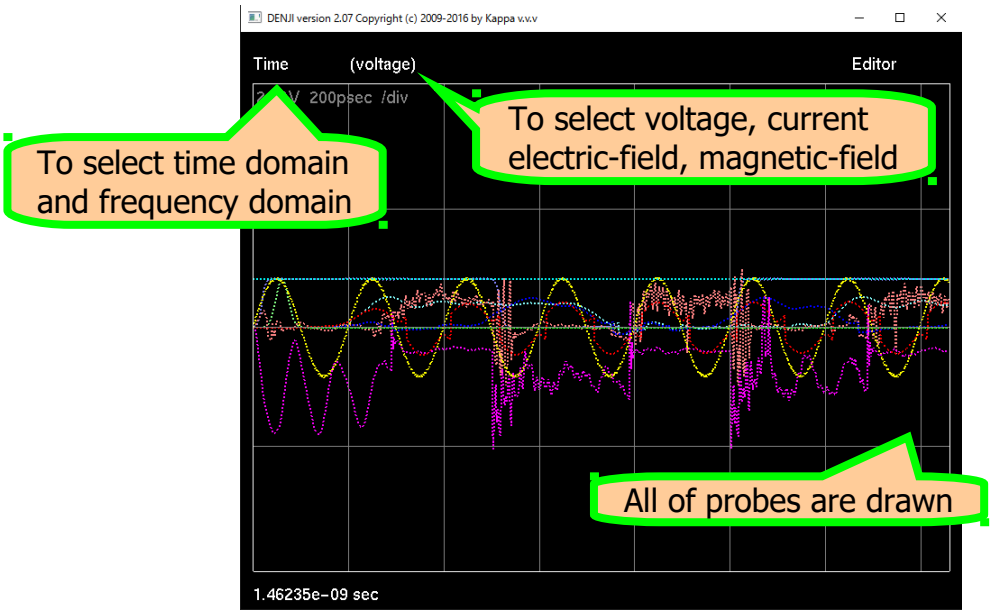
4.1. Main Window



4.2. Editing window



4.3. Wave form window



5. File

The drawing data of "Denji" can be saved as binary file in an arbitrary directory, and it can be loaded again when you analyze it in the next time. The file format is as follows.

5.1. Real number format

A real number is stores in the BDC form of the 4 bytes floating decimal. First 3 bytes are real part region, and last 1 byte is index region.

* Byte #0: Columns #5 and #6 of real part number. (=R/10000)
* Byte #1: Columns #3 and #4 of real part number. (=(R/100)%100)
* Byte #2: Columns #1 and #2 of real part number. (=R%100)
* Byte #3: Index number. (from -99 to 99)

5.2. File records

The file is divided into four records greatly.

(1) Medium definition record

It stores conductivity / a dielectric constant / the magnetic permeability of six kinds of mediums with a real number. The first medium stores away the parameter of the vacuum and stores the parameter of a medium displayed by an editing window into from #2 to #6.

(2) Various parameter records

It stores other parameters displayed by an editing window. It is XY axis grid size, Z-axis grid size, electric field source frequency, #1 (+) electric field source electric

field value, #2 (-) electric field source electric field values, an electric field source direction, the medium of the electric field source (higher 4bit types a wave pattern), an X coordinate / a Y coordinate / a z-coordinate of the wave pattern observation point sequentially. The direction stores with 1 byte, 0 is X-azis, 1 is Y-axis and 2 is Z-axis. The coordinate of the waveform observation point is stored with for each 1 byte. Other values are stored with a real number.

(3) Figure information record

Figure information of 64x64x64 is stored as a medium index of 1 byte per each grid. The medium index expressed with an integer from 0 to 5 in order of the medium which defined by a former medium record.

(4) End record

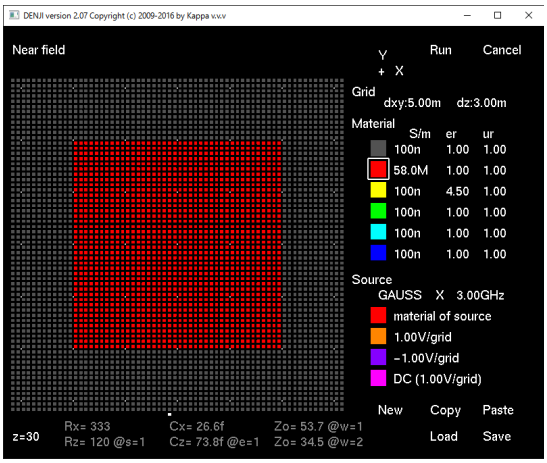
It stores a file version at 1 byte. Version confirmation is performed at the time of reading and if it is different, "Denji" abandons a reading and initialize data on the memory.

6. Use example

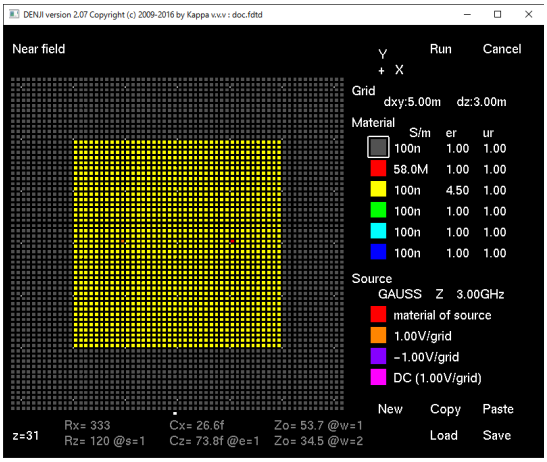
"Denji" is able to use for various electromagnetic field analysis. I introduce an example to use for an electronic network analysis here.

6.1. Making of a circuit

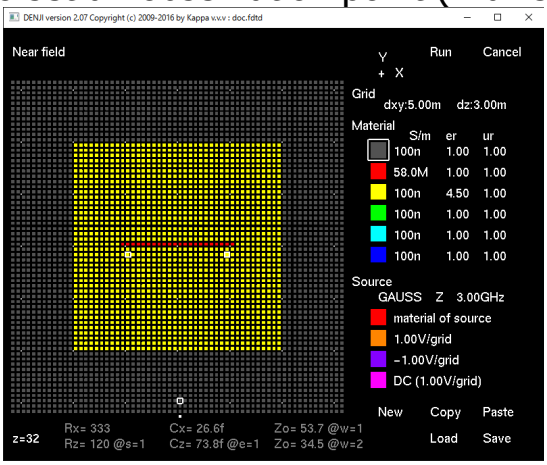
(1) To set grid size in dxy=5mm, dz=3mm. To arrange GND plane in the 30 layer.



(2) To arrange an electric field source (Z-axis direction) in the 31 layer.

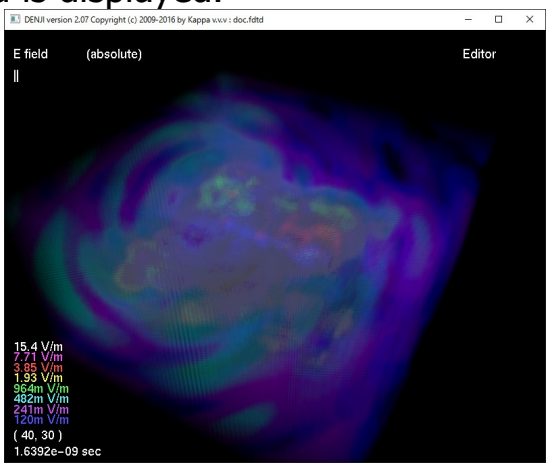


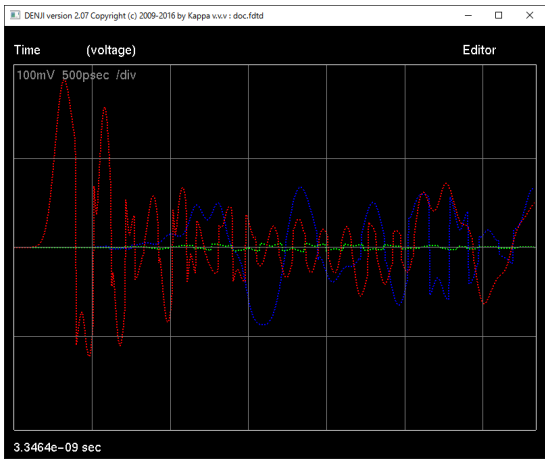
(3) To do signal wiring in the 32 layer. The terminal short to GND in the 31 layer. Furthermore, to set an observation point (X-axis direction).



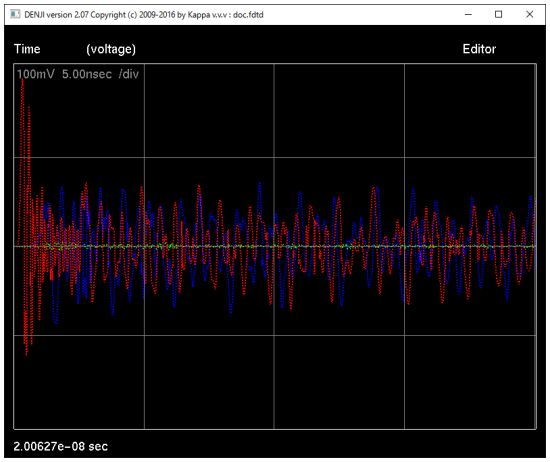
6.2. Practice of the analysis

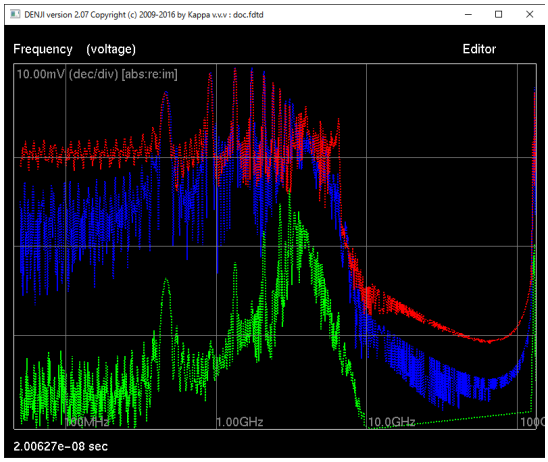
(4) To carry out electromagnetic field analysis. The change of the electromagnetic field is displayed.



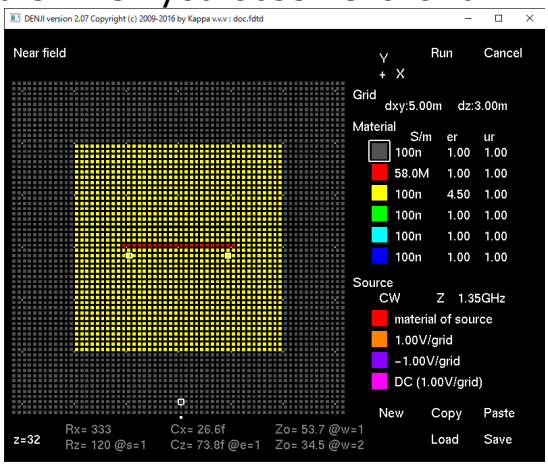


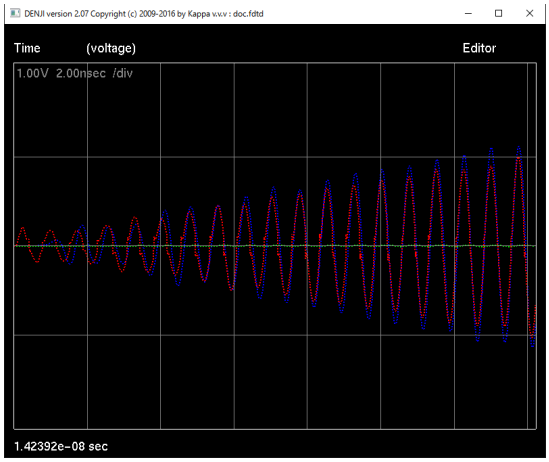
(5) Because analysis time got worse to 20ns (50MHz), to confirm a frequency characteristic. There is a resonance peak to 450MHz, 900MHz, 1.35GHz.



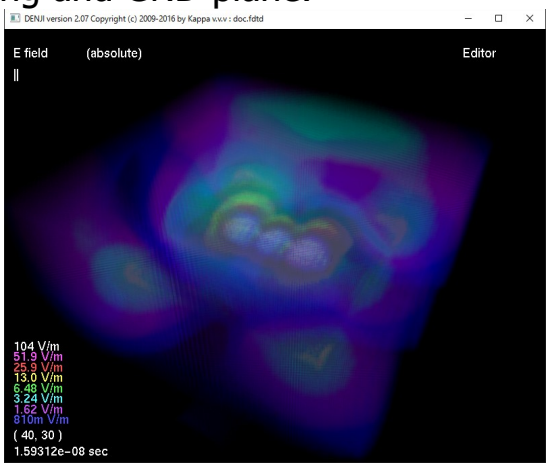


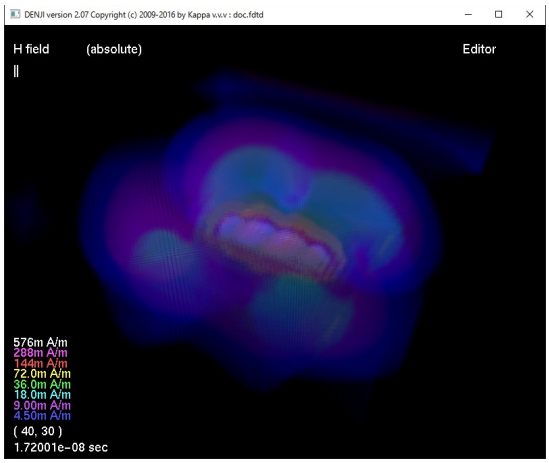
(6) To change an electric field source to 1.35GHz and analyze it again. Resonance occurs when you observe it for a while. To wait till resonance is stable.



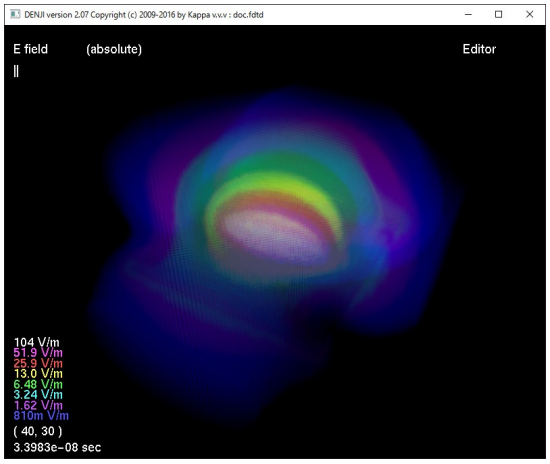


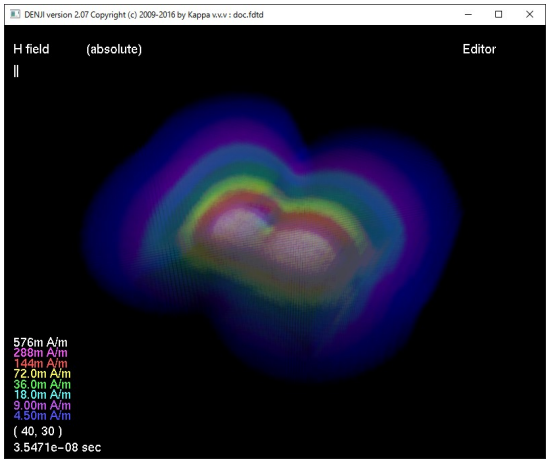
(7) You can observe the state that an electric field (the left) and a magnetic field (the right) of complicated shape are discharged between the space by signal wiring and GND plane.





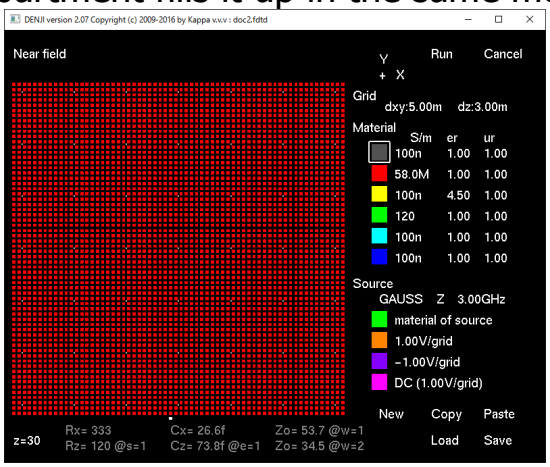
(8) To change an electric field source to 450MHz and observe it. An electric field (the left) vibrates on center of signal wiring. And a magnetic field (the right) synchronizes on both ends of signal wiring and vibrates.

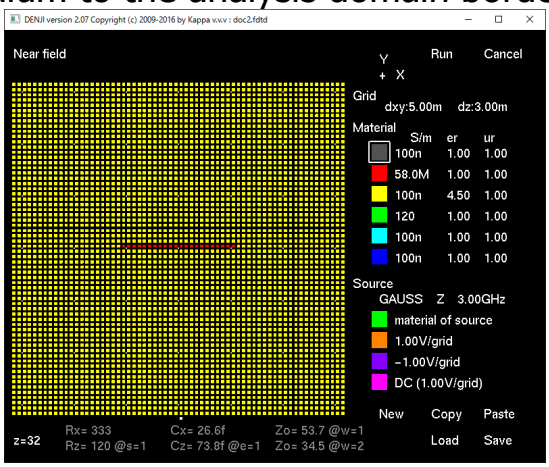




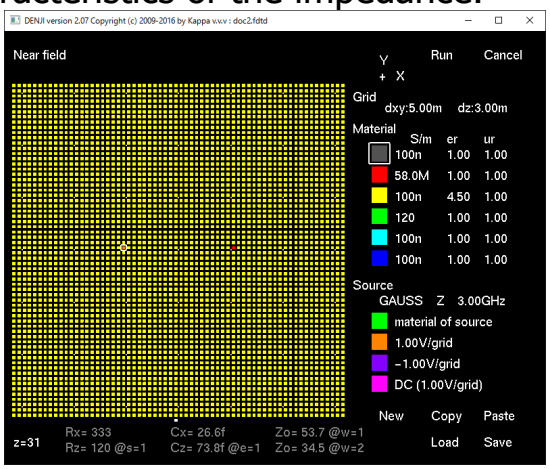
6.3. Inspection of the circuit characteristic.

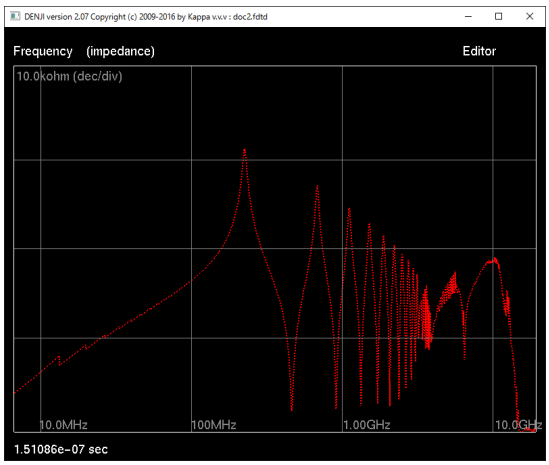
(9) Extend GND plane and a dielectric to a lot of editing domains. There is the analysis domain to eight grid outside from the editing domain, but the medium which you arranged in the editing domain most circumference department fills it up in the same medium to the analysis domain border.



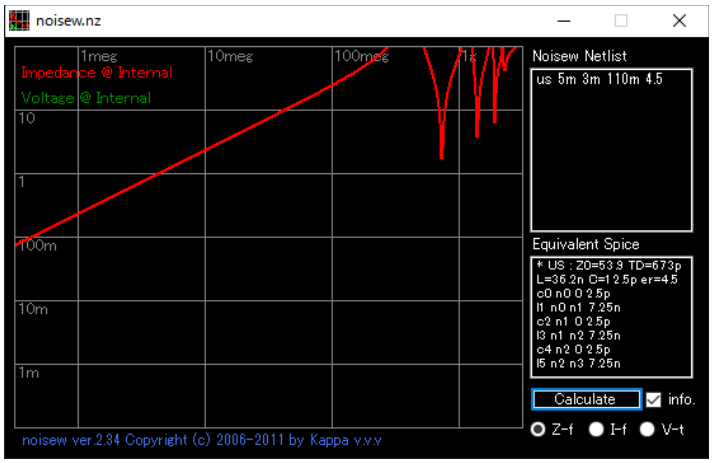


(10) To change observation point at the same position of the electric field source and make it Gaussian input again. To the electric field source to the low resistance (1Ω), it will be assigned to the medium of conductivity 120. After the analysis 10000 step (75nsec), and observe the frequency characteristics of the impedance.





(11) Try to compare it with impedance upshot of the micro-strip line calculated by "Noisew". The impedance of "Denji" is slightly higher, but it is almost the same.



7. Command Line

DENJI version 2.07 Copyright (c) 2009-2016 by Kappa v.v.v
usage: denji [options] [FDTD_FILE]
    FDTD_FILE : input .fdtd file made by editor in denji.

options)
    -help : message here.
    -batch : batch execution for quick calculation.
    -n <STEP> : maximum time step for FDTD calculation.
    -cuda <GPU#> : FDTD calculation with CUDA on GPU#.
    -minfreq <MINFREQ> : culling data for lower freq analysis [Hz].
    -far : far field mode with extended area(128x128).
    -timelog <TIMELOG> : extension for time domain results.
    -freqlog <FREQLOG> : extension for frequency domain results.

* following are only for CSV input instead of FDTD_FILE.
    -mat <ID> <MATERIAL> : assign material parameter to ID.
    -area <X> <Y> <Z> : total calculation area [grids].
    -unit <X> <Y> <Z> : grid resolution length [m].
    -layer <Z> <CSV> : assign CSV on Z layer.

MATERIAL= <SG>:<ER>:<UR>
        SG : electrical conductivity [S/m].
        ER : relative electric permittivity.
        UR : relative magnetic permeability.
    SPACE : same as 0:1:1.
    AIR : same as 1e-13:1:1.
    CU : same as 58e6:1:1.
    GOLD : same as 41e6:1:1.

```
        IRON            : same as 10e6:1:5000.
        SI              : same as 440e-6:12:1.
        FR4             : same as 0:4.7:1.
        WATER           : same as 10e-3:80:1.

CSV column format)
        <ID>[ <PROBE>]  : CSV is X-Y matrix formed by ID and PROBE.

PROBE= <NAME>           : unique NAME for probing, except following.
    CW:<D>:<V>:<F>      : continuous wave source.
                    D   : direction of the source. X, Y or Z.
                    V   : peak voltage of the source [V].
                    F   : frequency of the source [Hz].
    GAUSS:<D>:<V>       : gaussian waveform source.
    PULSE:<D>:<V>:<F>   : pulse waveform source.
    DC:<D>:<V>          : DC source. for using with SWITCH.
    SWITCH:<M>:<ID>:<F> : conductivity pulse switch.
                    M   : model type of the switch, 'P' or 'N'.
                    ID  : material when the switch is off.
                    F   : frequency of the switch [Hz].
```

8. Addresses

If there are questions about this program, please feel free to contact me. In addition, please forgive that there is the case that cannot reply by circumstances of diversity beforehand.

Akimoto Tetsuya (kappa.v.v.v@nifty.com)