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Development of Standard Models for EMC Simulation

Takehiro Takahashi, Akihisa Sakurai
IBM Japan
Kanagawa Japan

Noboru Schibuya
Takushoku University,
Tokyo Japan

Abstract
In this report, the group activity of developing and proposing standard EMC models for numerical EMC simulation is presented. Our group has developed some basic and standard EMC models which contain the essential characteristics of EMC and has discussed about the calculated behaviors. These models can be used for studying EMC and EMC simulation and for comparing different simulators. The developed models are briefly presented. A model of differential transmission lines, for example recently took up, is explained as an example. The differential transmission line which has a difference in height on the middle of the line was developed to investigate the emission depending on the parameters of line height, line separation, phase of the driver and so on. For example, the contribution of the common and differential mode radiation was studied by changing phases of the differential drivers. From the calculated results, it is suggested that the emission from the line was dominated common mode radiation because the emission was almost proportional to common mode voltage of the differential drivers.

Keywords: EMC simulation, standard model, differential transmission, radiated emission, common mode

Introduction
When designing Electronic devices or equipments, electromagnetic compatibility (EMC) must be considered to satisfy EMC regulations and to accomplish lower interference with other devices. To consider EMC in the electronic design (this is called EMC design) experiences and empirical rules have been commonly referred, while computer simulation of the electromagnetic behavior (referred as EMC simulator) is widely used to support EMC design these days.

The EMC simulator enables one to estimate electromagnetic radiation from the device, interference with other device, immunity and so on. These numeric results, however, are influenced by the employed calculation method, input data, and condition of the calculation in the same way as most other type of simulation. Thus, to obtain the intended result, understanding and many experiments are needed.

Before calculation, the object device shape is adequately digitized and translated to the input data with many other kinds of calculated conditions. This process of making data is called modeling[1]. The model must be constructed without loss of its own essential electromagnetic characteristics. The model is, however, preferred to be as simple as possible, because it will require less computing time and storage.

The simple model such as micro-strip line, cable or board is also used in studying the general characteristics of EMC behavior. Studying simple structures is useful in the following points of view:

- understanding EMC fundamentals
- applicable to EMC reduction rule
- testing EMC simulator's features
- comparing different type of EMC simulators

The engineer, especially one who is not familiar with EMC simulation, can study the fundamental EMC behavior through the simulation with simple models. To design the simple educational models, however, some considerations are needed. What kind of model should be constructed? What care should be taken in construction? What kind of characteristics may be obtained? The standard model can help these problems.

The concept of the standard EMC model had been originally proposed and developed [2,3] by B. Archampbearult et.al. in 1994. Our group also developed a standard EMC model in 1996. The activity group is named “EMC modeling research group” organized in the JIEP (Japan Institute of Electronics Packaging) with about 10 – 20 members. In this group, typical and useful EMC simulation models that contain basic behavior of EMC are proposed and the calculated characteristics are discussed. These proposed models can be used for education of the EMC engineer and EMC simulation, and for comparison of the simulators.

Our group has proposed 8 standard models and discussed their characteristics using EMC simulator [4-11]. In the next section, the outline of these standard models is presented. Next, the discussion about the differential transmission line model, which is one of the proposed standard models, is presented. In this discussion, the dependency on the phase shift of the differential signal source and on the separation of the lines is explained. The phase shift of the signal source generates a common mode component in the transmission signal. From the calculation of the model with phase shifted signal, it is suggested that the radiation from the differential signal line almost completely depends on amplitude of the common mode component of the signal. And in the calculation with line separation, as the separation of the lines is large, radiation from the line also increases. From the discussion, it is suggested that the radiation depends on both the increase of the area between the lines and the decrease of the current by impedance. These results are well known behaviors in EMC. The details are described in the following sections.

Proposed Standard Models

Our group has developed 8 standard models and evaluated them [1-8]. These models are named as from M01 to M08 for convenience. These models are simply illustrated in Figure 1:

- Figure 1 (a) shows the model with a micro-strip line board (M01). In this model, the dependency of geometries of the line such as line width, line height and position of the line have been investigated.
- Figure 1 (b) and (c) are the model of the micro-strip line board with attached cable (M02) and another micro-strip line board added to the M02 model (M03). In these models, the radiation d from the cable was evaluated.
- Figure 1 (d) is the model of the micro-strip line board with metal plane placed over or under the board. Dependencies on the position and the size of the metal plane, and connection between board and metal plane were studied.
- Figure 1 (e) and (f) are the models which employee the metal box to investigate radiation leaks from the aperture (M05) and from the cable extended from inside to outside of the box through the aperture (M06).
- Figure 1 (g) shows the differential signal transmission lines model (M07) which has a difference in height between lines. Some discussions are described in the following sections.
- Finally power and ground plane model (M08) is shown in Figure1 (h). The noise reduction effect of decoupling capacitor and some other effects are studied.

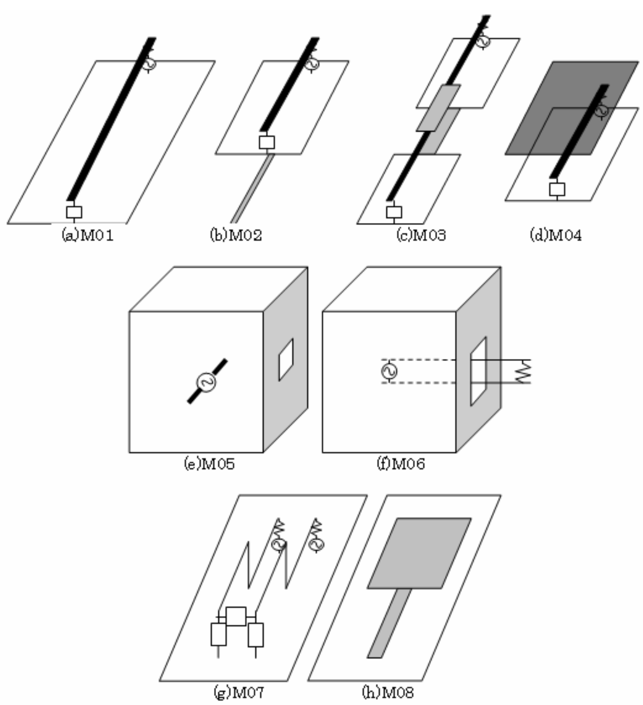

Figure 1 - Proposed Models

Discussion about the Differential Signal Transmission Lines Model

In order to study EMI characteristics from differential signal transmission line, model M07 was developed. This model has a difference in height between the lines as illustrated in Figure2. The radiation depending on following parameters are calculated and discussed:

- Presence of the ground plane
- Height of the line
- Impedance of the signal source

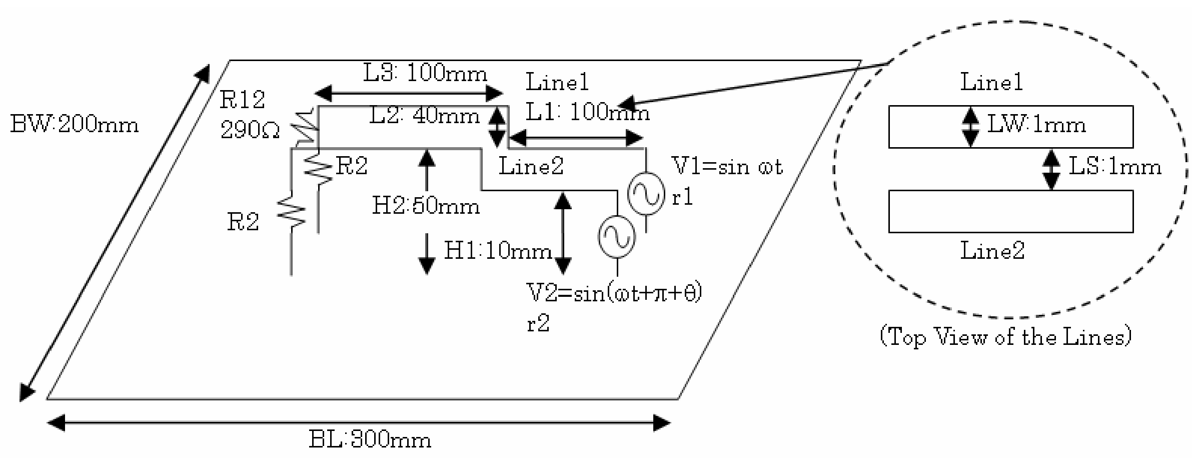

Figure 2 - The Model of Differential Signal Transmission Line with Difference in Height on the Line (M07)

In these discussions, the effects of the signal source phase and of the line separation[7] are explained here:

- Phase of the signal source
- Separation between lines
- Position of the difference in height

The Effect of the Phase Shift of the Signal Source

In the model M07, two individual signal sources, which are inserted at the terminal of the differential lines, are employed to generate differential signal. In the perfectly constructed differential signal sources each signal phase is opposite to the other. These signals generate only differential components on the transmission line. In reality, however, there is a phase shift between the differential signal sources.

Figure3 shows the radiated emission from the differential signal lines with phase shift of the signal source. The horizontal and vertical axes are the phase shift in degree and electric field strength, respectively. In this figure 0 degree phase shift means the perfect differential signal. When the phase is shifted 30 degrees, the radiation increases almost 25 ~ 30 dB. Though the radiation was calculated at 350, 900 and 1550 MHz, there is no clear difference between them in the signal.

When one of the signal phases is slightly shifted, a common mode component is generated and contained in the transmission signal. This suggests that the radiation increases depending on the differential and common mode components. So the common mode component of the phase shifted signal source was calculated. The voltage of the differential sources V1 and V2 with is given by:

$$V1 = \sin(\omega t)$$
$$V2 = \sin(\omega t + \pi + \theta)$$

Here ω is an angle frequency and θ is a phase shift. The common mode component Vc generated by these two signals is given by:

$$Vc = \frac{V1 + V2}{2} = \frac{\sin(\omega t) + \sin(\omega t + \pi + \theta)}{2}$$
$$= \frac{\sqrt{2}}{2}\sqrt{1-\cos\theta}\,\sin\left(\omega t + \pi + \theta + \tan^{-1}\frac{\cos\theta}{1-\cos\theta}\right)$$

The phase shift dependency of Vc is plotted in Figure 4. The Vc increases depending on the phase shift. The trend of the increase is almost same as the calculated field strength shown in Figure 3. Thus this result shows that the radiation is dominated by the common mode component of the signal.

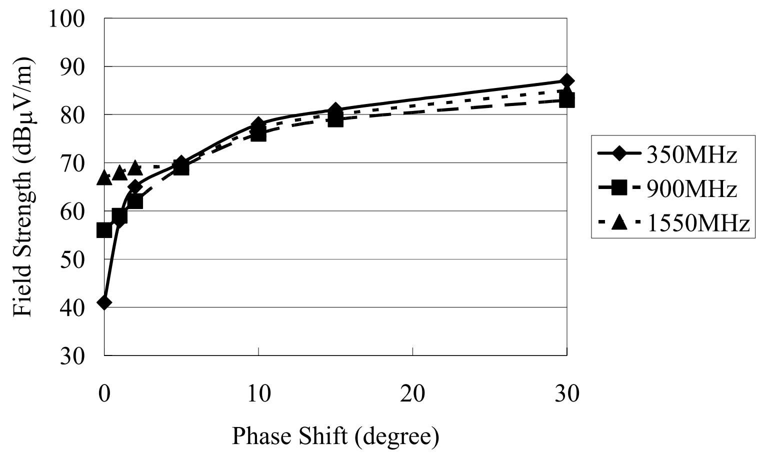

Figure 3 - Calculated Field Strength (Vertical) vs. Phase Shift of the Differential Signal

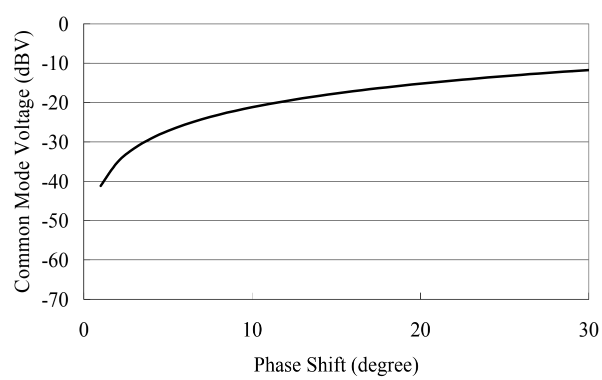

Figure 4 - Amplitude of the Common Mode vs. Phase Shift of the Differential Signal

The Effect of the Line Separation

The radiated emission does not depend on only the signal source but on many geometrical parameters such as line height, width, length and so on. Here line separation dependency of the radiated emission is discussed.

The line separation is changed from 20μ to 200μm and the radiation is calculated. When line separation is changed, the characteristic impedance of the line is also changed. In this case, if the impedance of the signal source is fixed, some resonant peaks appear in the radiation because the signal source does not match to the line impedance. This peak prevents us from comparing the results. To avoid this, as the line separation changes, the signal source impedance is also changed to the matching impedance.

The calculated result is shown Figure 5. The horizontal and vertical axes are frequency and field strength, respectively. From the Figure 5, as the line separation increases, the radiation also increases. The ratio of the increase of the field strength against line separation at 500 MHz is plotted in Figure6. The radiation increases linearly with the line separation and it's slope is about 3~4 dB/oct. The slope is almost same at any frequency in Figure 5 above 500 MHz.

It is well known that as the line separation is increased, the field strength increases due to the increase of the area surrounded by the lines. Since increase of the area is linear to the line separation, it is expected that the field strength increase is also linear which is represented by 6dB/oct. The slope of the field strength increase, however, was lower.

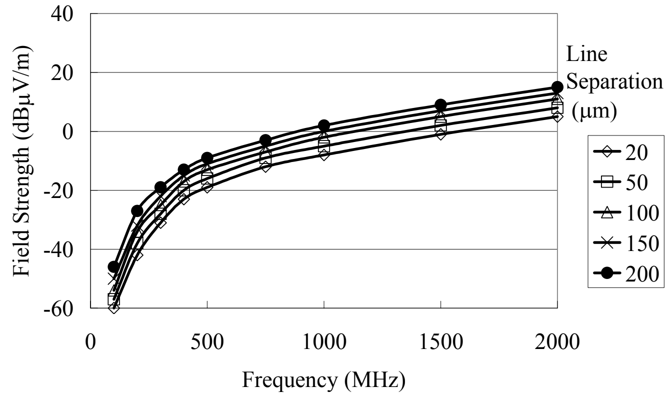

Figure 5 - Field Strength vs. Line Separation

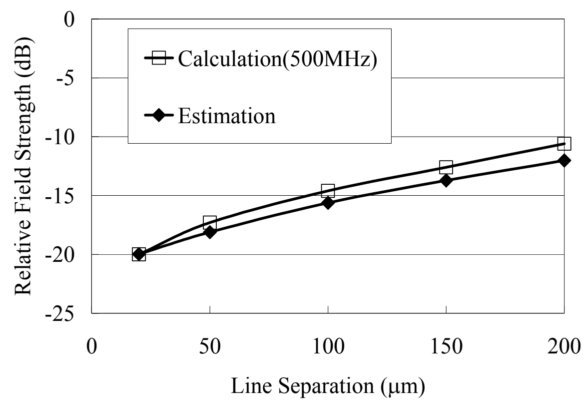

Figure 6 - Calculated Electric Field and Estimation Considering Area Increase and Current Decrease (500MHz)

To explain this, the effect of the source impedance is considered. As the source impedance increases, current flow on the line decreases. This current reduction possibly reduces field strength. The estimated field strength considering line separation and current reduction is plotted on the Figure 6 (denoted as estimated). The calculated and estimated field strength shows good agreement.

Conclusion

The overview of the proposed EMC model for EMC simulation and some discussions about the calculated results are presented. Our group has continued this activity to develop other models. The further work is development of the effective application to spread these works widely.

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Takehiro Takahashi (Takushoku Univ.)
Akihisa Sakurai (IBM Japan)
Noboru Schibuya (Takushoku Univ.)
Shigeo Nara (Tokyo Univ. of Science)

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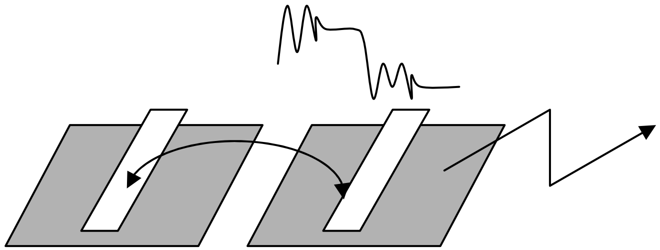
Contents

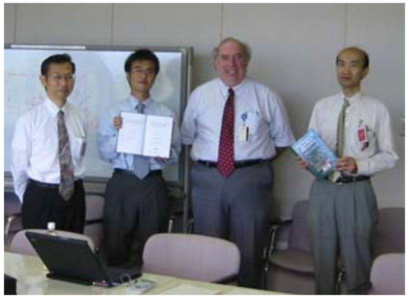
1. Introduction

- EMC (Electromagnetic Compatibility) consideration on electronics design is important.
  - Signal distortion, induction and coupling, radiation
- EMC simulation tools are widely used.
  - MoM, FDTD, PEEC, TLM, FEM et. al.
- EMC simulation tools are difficult to use.
  - Modeling Know-How
  - Understanding complex computed results



2. Standard EMC Model

A Concept of Standard EMC model for EMC simulation is proposed (1994 B.Archambeault IBM)



- Typical Model of Component for EMC
  - Classify the component into basic element
    - PCB, Cable, Shield box et. al.
  - Complex model can be constructed by combination of them.

- EMC Model of Typical EMC Problem
  - Signal distortion, Crosstalk, Coupling, induction, radiation, shielding, cabling et. al.
  - Help study of these behavior.

•B. Archambeault, C. Brench: "Proposed Standard EMI Modeling Problems", Proc. IEEE EMC Symp., pp.173-176, 1994

•B. Archambeault, C. Brench: "Modeled and Measured Results from Two Proposed Standard EMI Modeling Problems", Proc. IEEE EMC Symp., pp.394-352, 1995

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EMC modeling research group

- In Japan,
  EMC modeling research group
  （1996～ JIEP: Japan Institute of Electronics Package）
  Leader: Prof. N.Schibuya (Takushoku Univ.)
  10～15 members (EMC simulation tool user)

Aim:
Development of standard EMC model for

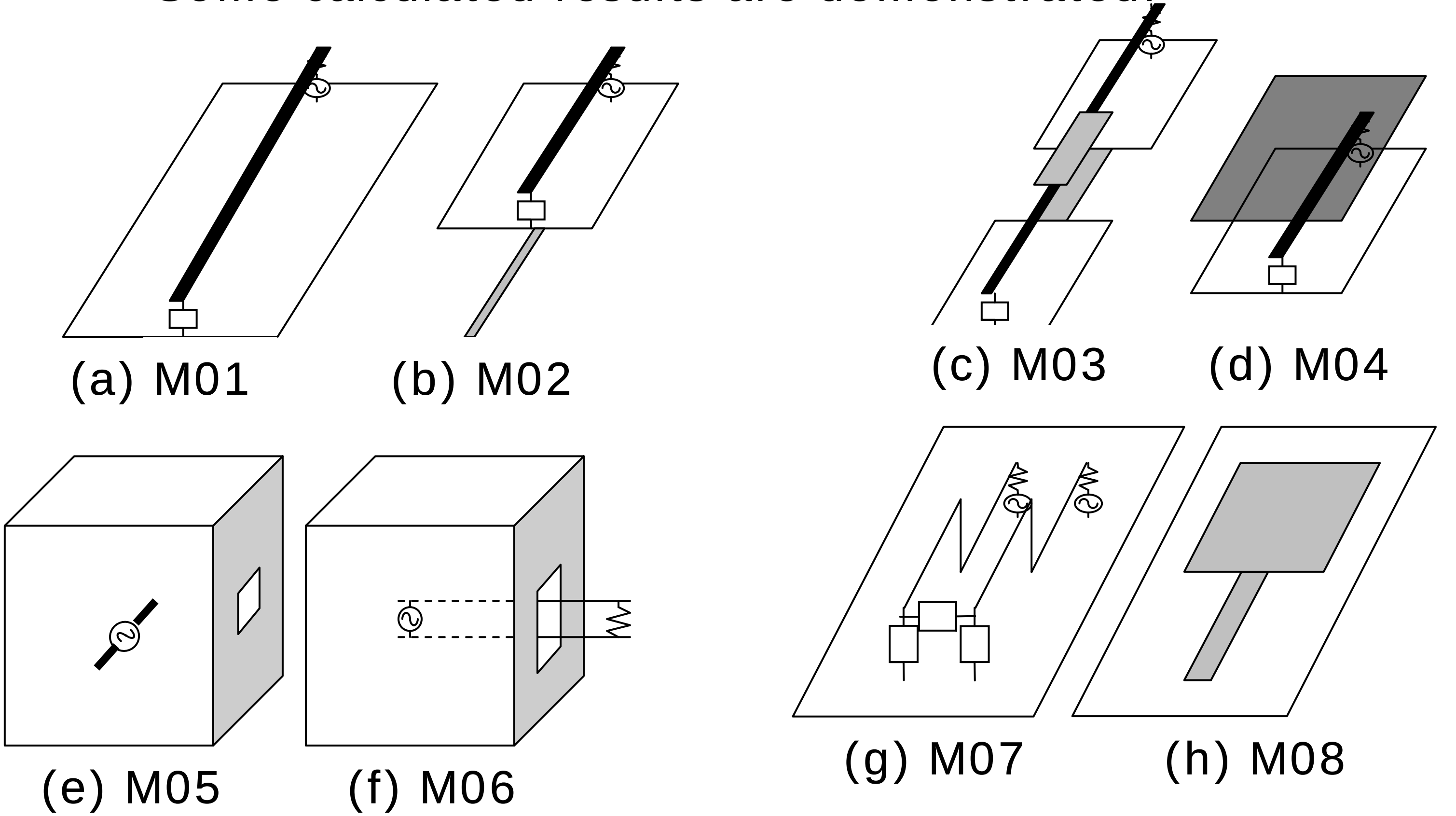
- Understanding basic EMC behavior
- Comparing EMC tools
- Reducing the cost of complex EMC model

Activity:

- Developing standard EMC model
- Calculation and discussion about the model

3. Models and some calculated results

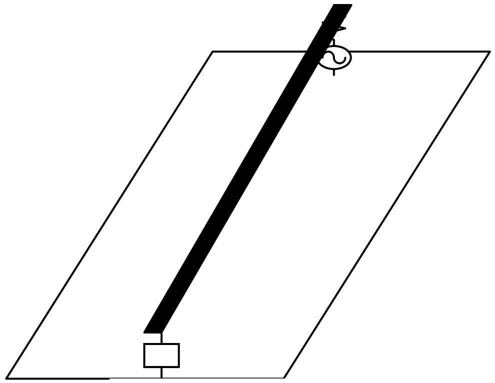
- Developed Models (M01～M08)
- Some calculated results are demonstrated.



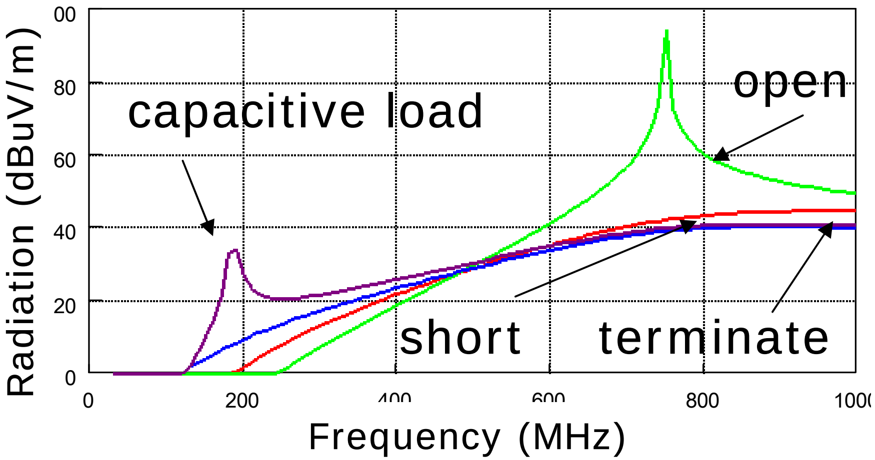
M01: Microstrip Line

- Parameters
  - Termination
  - Line Position
  - Calculation Method

Line Length 100mm
⇒λ/4 resonance : 750MHz



(a) M01



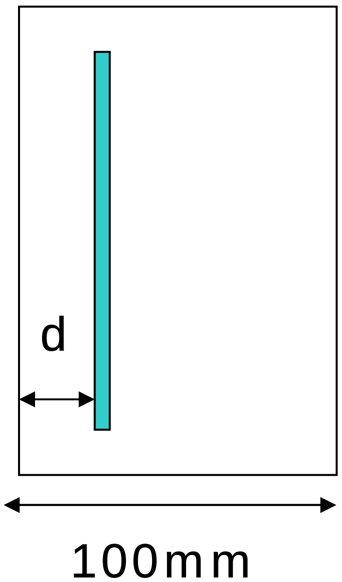
Radiation from open, short, terminated and capacity loaded trace

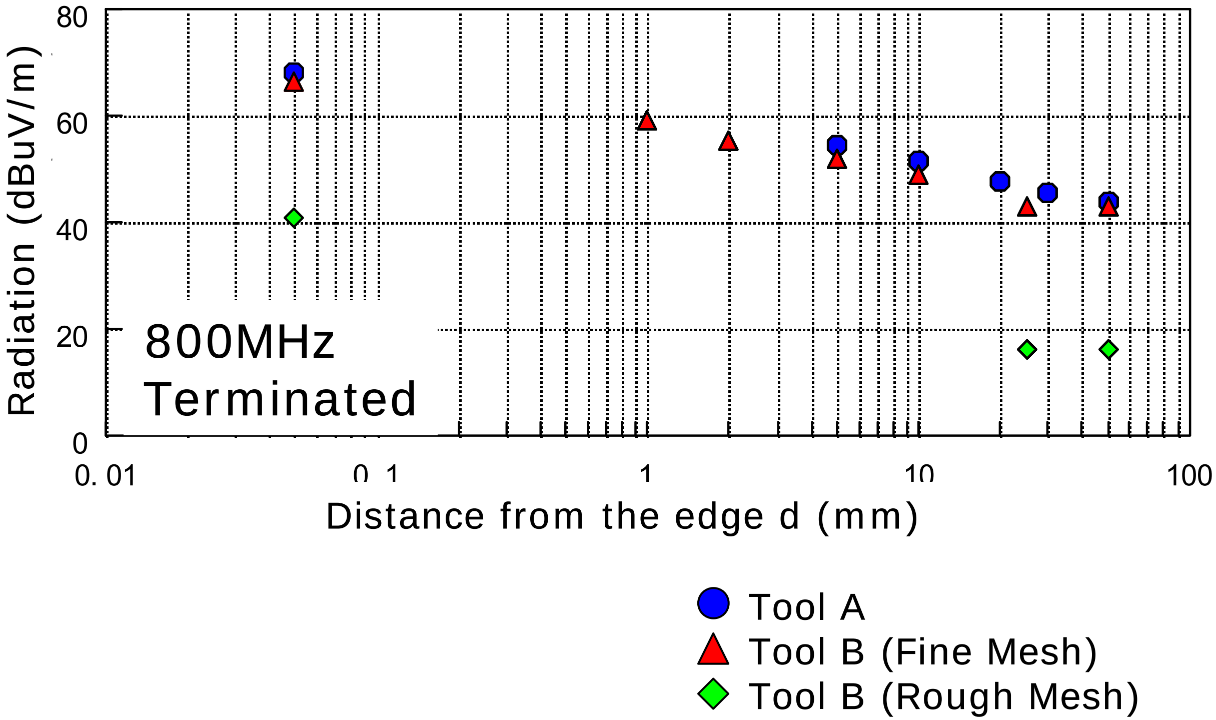
A Calculated Result on M01

- Effect of Line Position

  Trace near the edge radiates more.

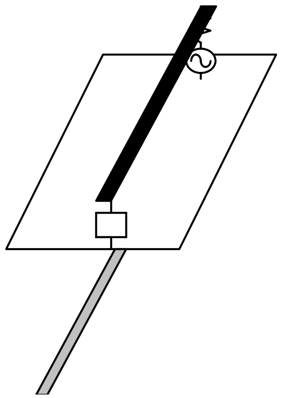
  Mesh technique is important.



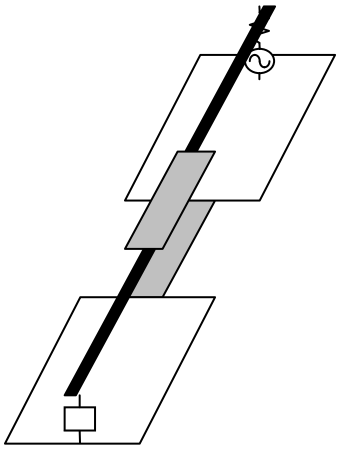


M02, M03: Combination of Microstrip Line and Cable

- Parameters
  - Cable Length
  - Ground Plane Width



(b)M02

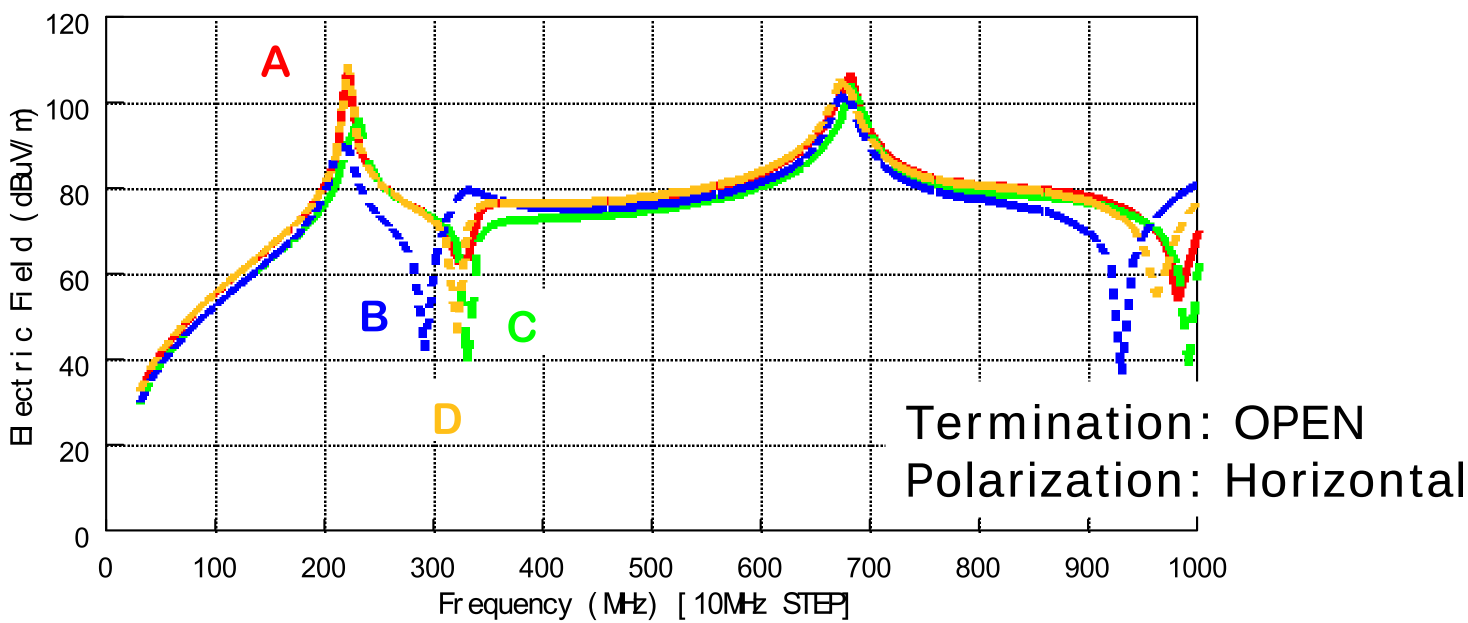


(c)M03

A Calculated Result on M02

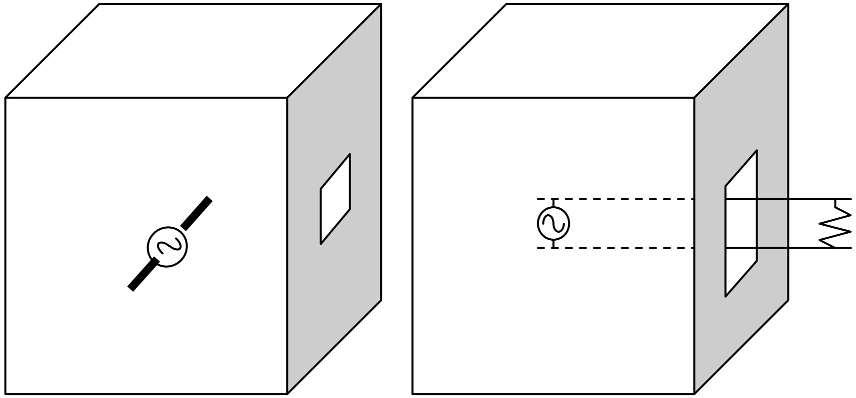
- Calculation Result of Same Model
  - A : Tool A (MoM)
  - B: Tool B (Combination of MoM and PEEC)
  - C: Tool B (MoM)
  - D: Tool B (MoM)

Same Tool but Different Mesh



M05, M06: Enclosure and Cable

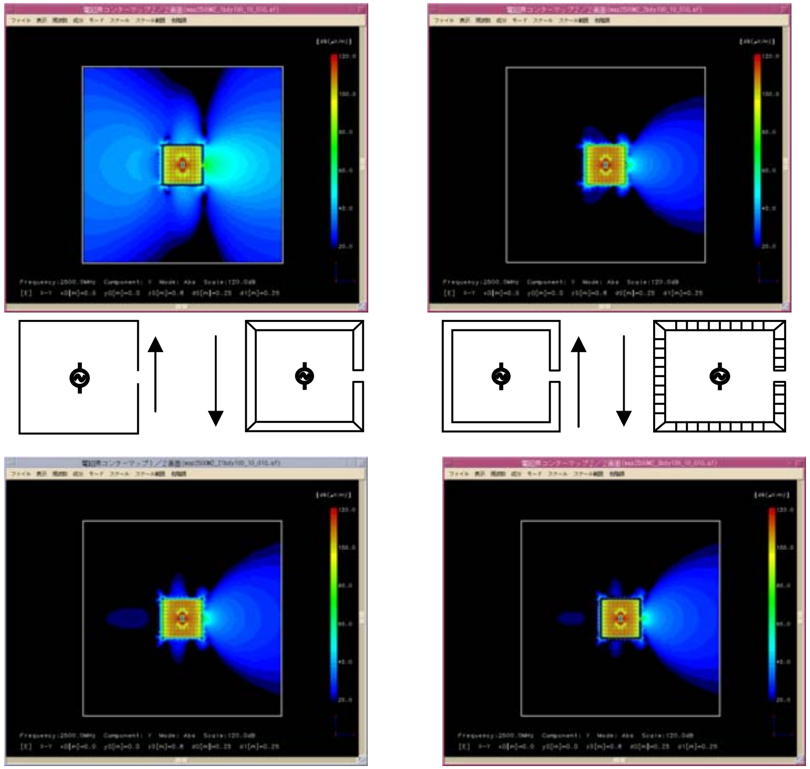
- Parameters
  - Aperture size
  - Cable parameter
  - Connection
  - Shield plate structure

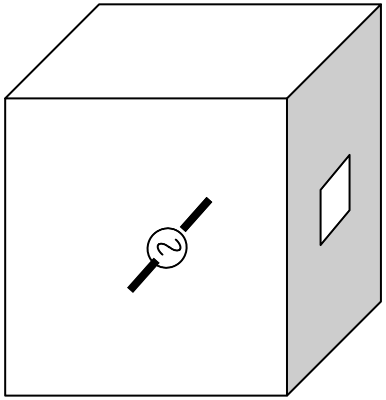


(e)M05 (f)M06

A Calculated Result on M05

- Shield Plate Structure
  - Single layer
  - Double layer
  - Double layer
    with connection
  (rough pitch, fine pitch)



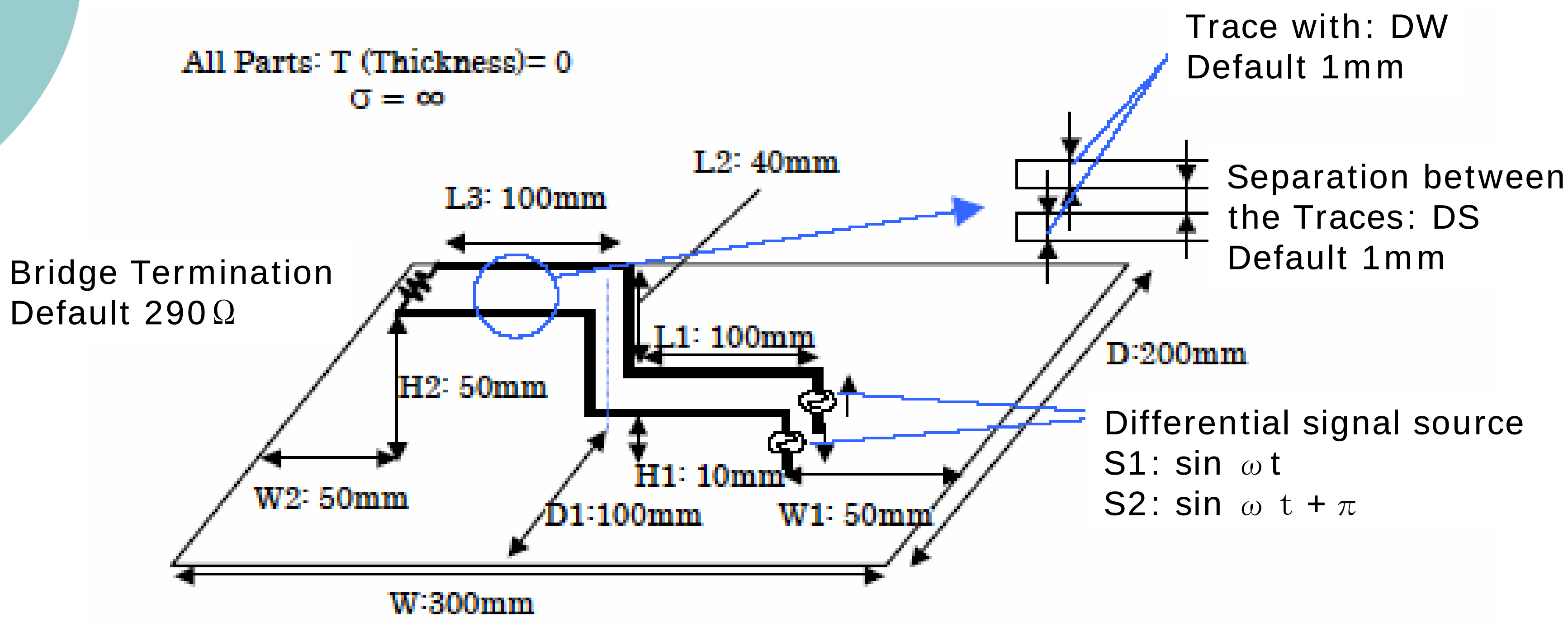


(e)M05

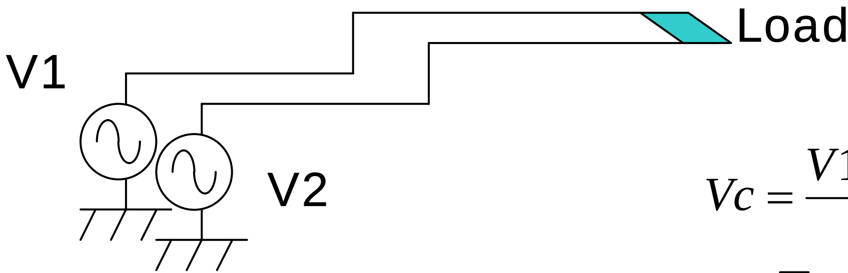
Radiation depending on the structure of the enclosure model.

M07: Differential Transmission Line Model

- Differential Transmission Line Model



Radiation from Differential Transmission Line
A. Effect of Signal Phase Shift

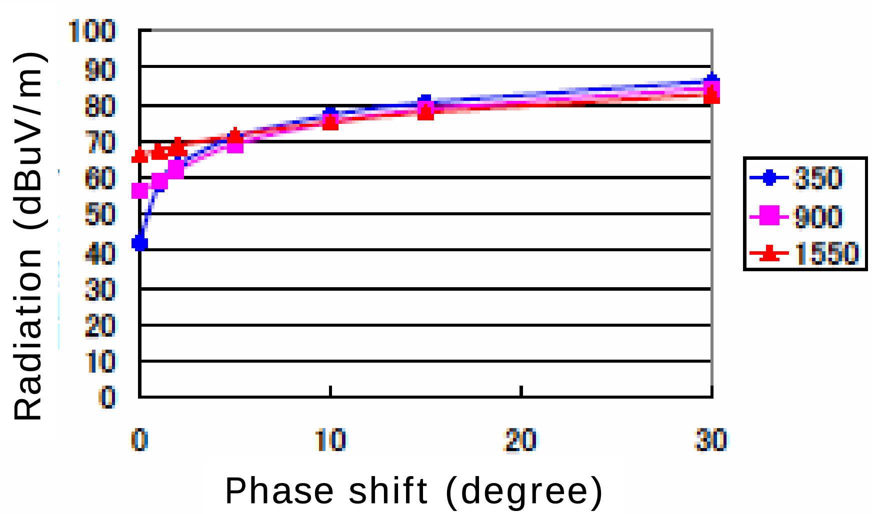


$$V1 = \sin(\omega t)$$

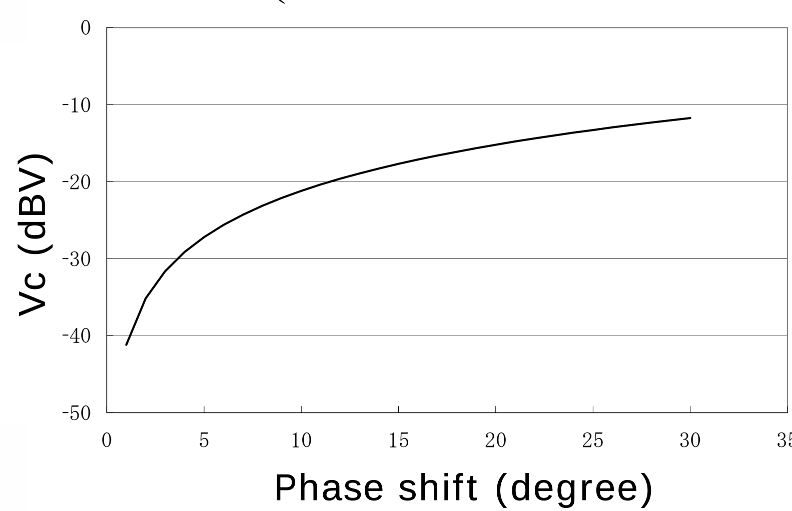
$$V2 = \sin(wt + \pi + \theta)$$

$$Vc = \frac{V1 + V2}{2} = \frac{\sin(\omega t) + \sin(wt + \pi + \theta)}{2}$$

$$= \frac{\sqrt{2}}{2}\sqrt{1 - \cos\theta}\,\sin\left(\omega t + \pi + \theta + \tan^{-1}\frac{\cos\theta}{1 - \cos\theta}\right)$$

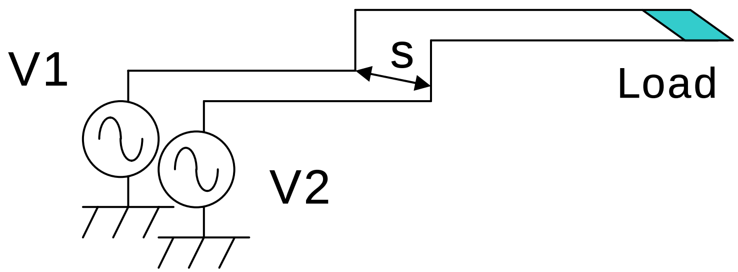


Simulated radiation



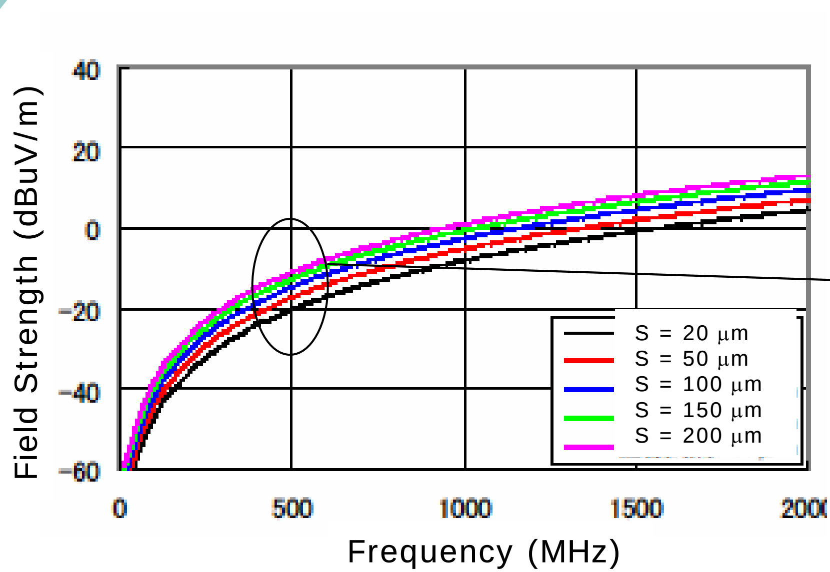
Predicted common mode voltage Vc

Radiation from Differential Transmission Line
B. Effect of Trace Separation

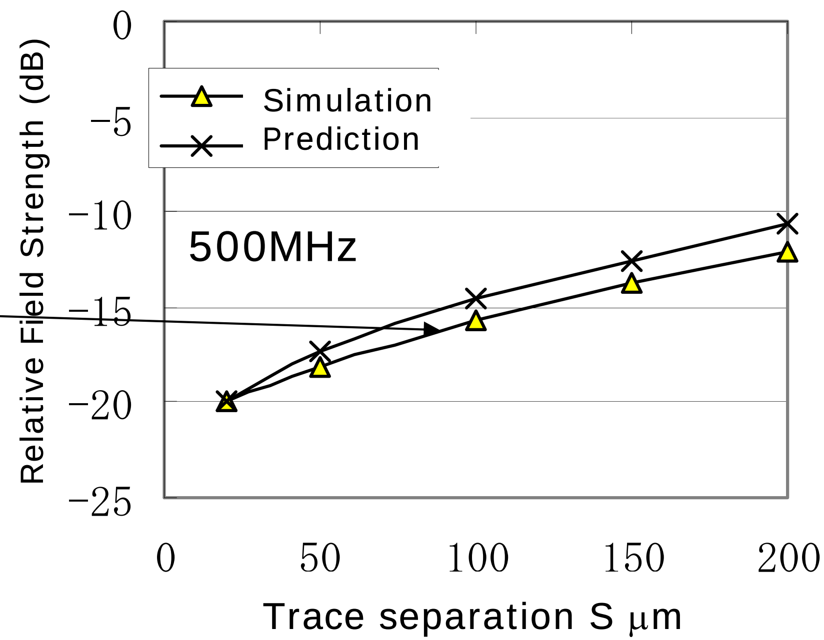


As Separation increase,

- Impedance increase
  ⇒ radiation decrease
- Loop area increase
  ⇒ radiation increase



Simulated radiation



Predicted Radiation considering effects of both impedance and loop area.

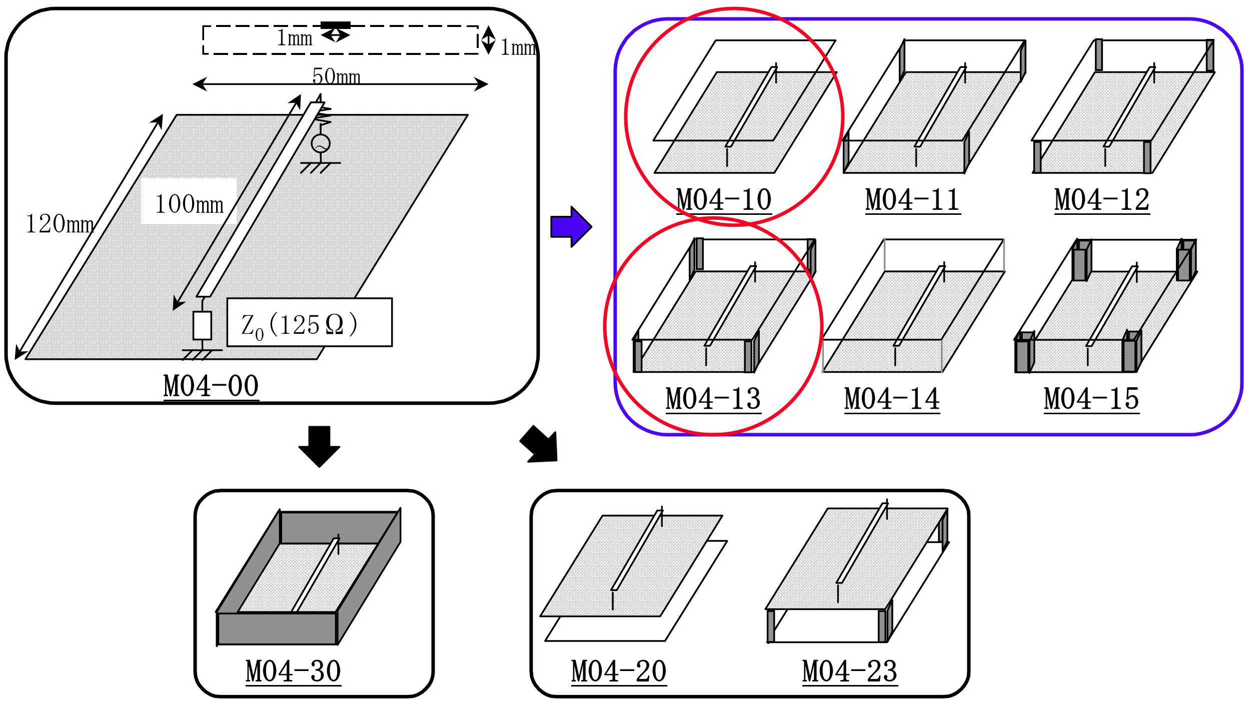
4. Conclusions

- Concept of standard EMC model is explained.
  - Basic components for EMC
  - Suitable for EMC education
  - Reducing cost of constructing complex model

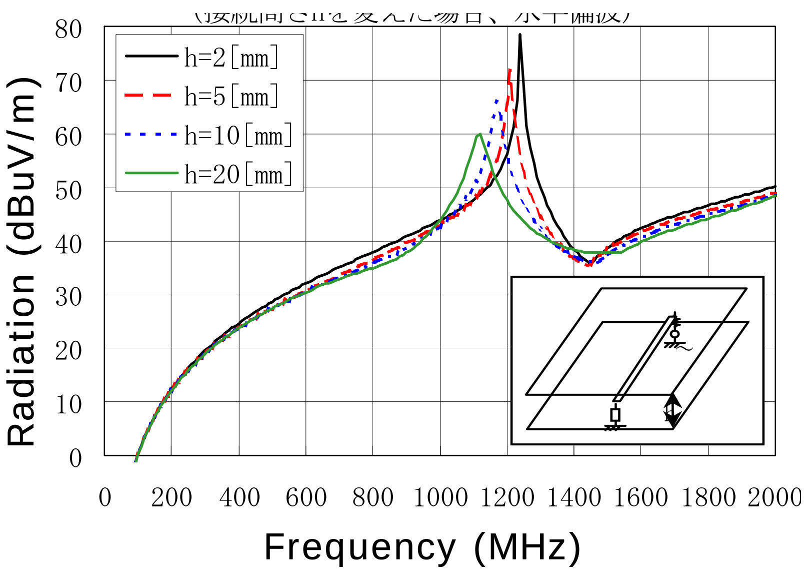
- Developed 8 models are presented and some calculated results are demonstrated.
  - Results are different by the technology of the tools and mesh skill.
  - Understanding characteristic of the tool and improvement of modeling skill are necessary.
  - Discussion about the complex result.

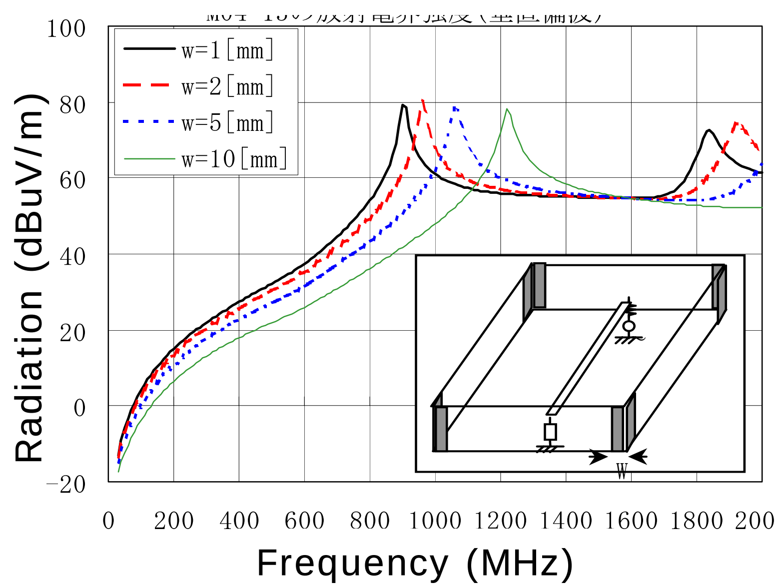
M04: PCB (Microstrip Line) with Metal Plate

- Parameters
  - Distance between Board and Plate
  - Connection between Board and Plate



A Calculated Result on M04

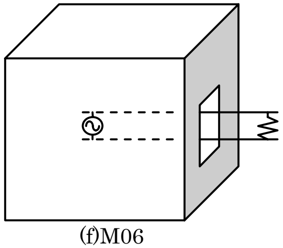




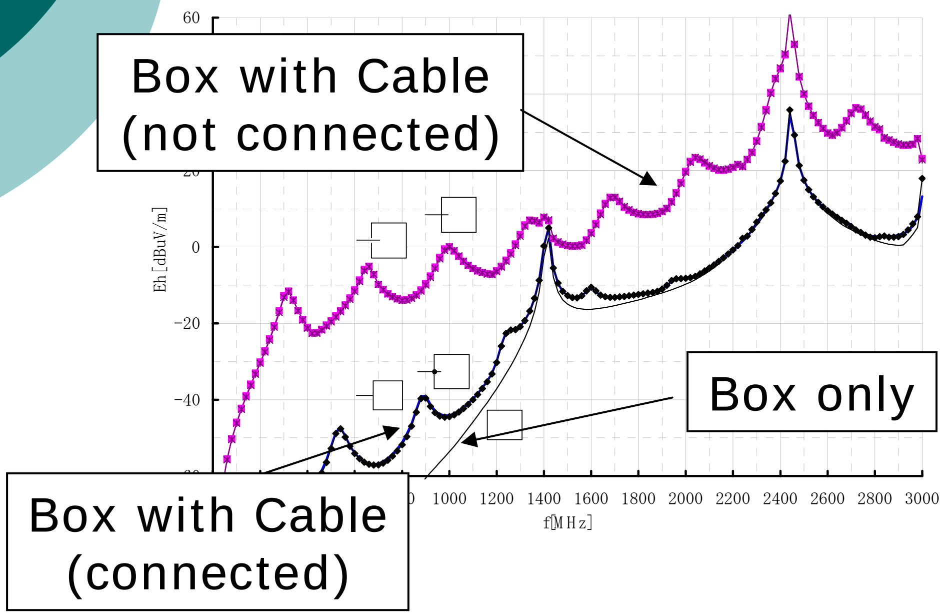
A floated metal plate is located on the trace side of the board. Distance between board and plate is changed.

Metal plate is connected to the board with small connector plate. Width of the connector plate is changed.

A Calculated Result on M06

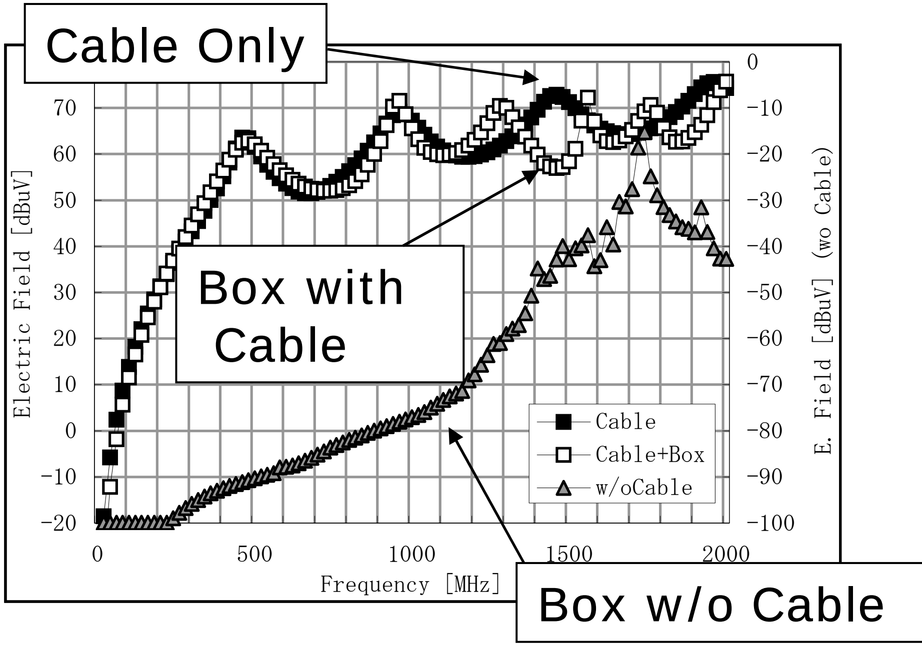


Cable is not attached to the source.



Radiation is reduced when the cable is connected to the box.

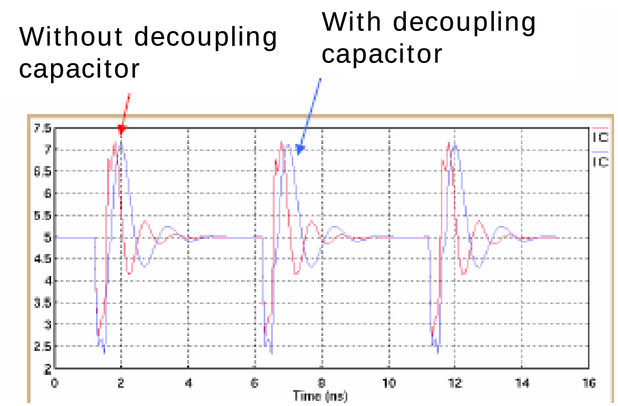
Cable is attached to the source.



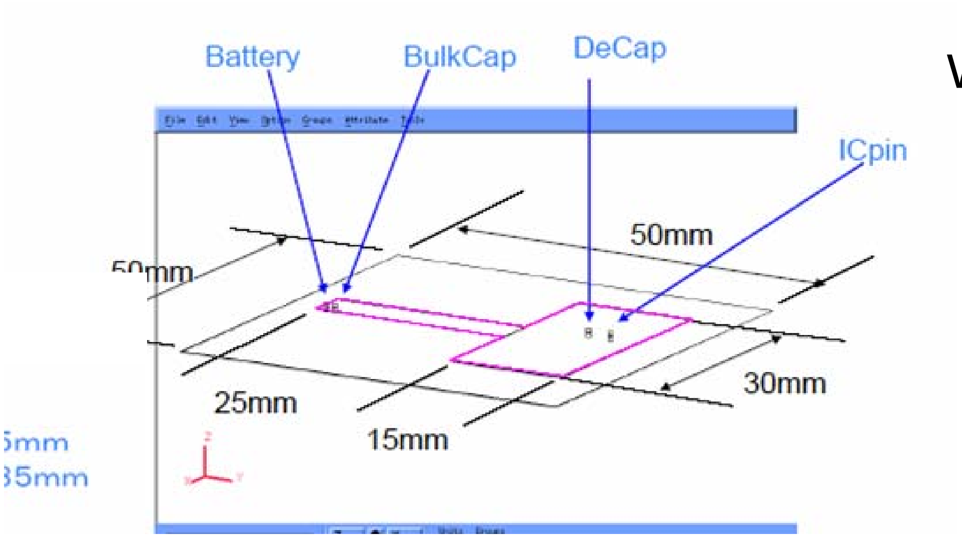
Radiation from the cable is dominant.

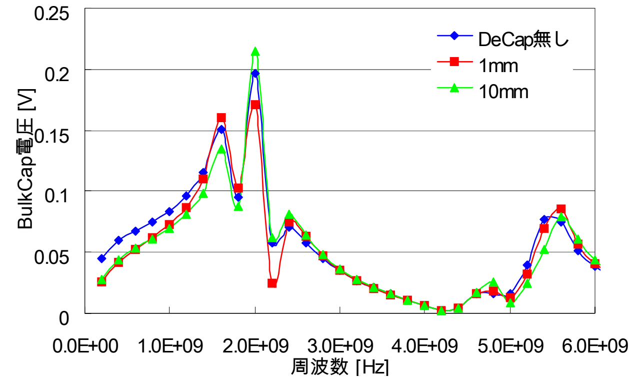
M08: Power-Ground Model

- Parameters
  - Position of the decoupling capacitor



Waveform of Switching Noise





Spectrum