

## Control of Unintentional Electromagnetic Waves from Digital Circuits: Efficient EMC Modeling of Devices and PCBs

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**Abstract:** *A research project has been carried out for the last five years, the subject of which is to develop effective methods to control electromagnetic noise radiation from digital electronic devices. Engineering approaches were chosen and some new modeling methods of electromagnetic phenomena around a printed circuit board are shortly described in relation to EMI subjects. Those results have been combined into EMI simulator software, HISES, which works very rapidly still retaining enough accuracy in EMC issues.*

**Key words:** printed circuit board, device, model, EMI simulation, electromagnetic noise radiation, common mode

### 1. Introduction

A quick tool is desired with which a designer of a printed circuit board (PCB) can find the best compromise between the regulation and the performance of an end-product repeating trials. A physical insight will also intuitively support the designer to reach a compromise.

The authors and their group had developed a set of problem resolving system for EMI control of printed circuit board (PCB), which is the common structure of electronic products [1]. The system comprises three subjects.

1) PCB, that has a stacked two-dimensional structure, allows a simplification of Green's functions that express electromagnetic modes in it, especially in power-bus systems. A new electromagnetic solver has been developed which gives EM distribution far faster than ever tried, and was implemented as a software equipped with a versatile interface.

2) Common mode is one of the central concerns of a PCB designer. A new accounting was revived for the common mode excitation from a classical antenna and the transmission line theory, which will create a new transmission system with more flexible structure still retaining low emission. A new approach to tailor the phase of timing edges in synchronized digital system was examined. By shifting those edges, EM radiation will decrease.

3) An equivalent circuit adapted to EMI analysis of LSIs attached to PCB was developed.

All the above subjects have been examined experimentally as well as theoretically, confirming its reliability, accuracy and the limit of applicability as well as its effectiveness in terms of the operational speed.

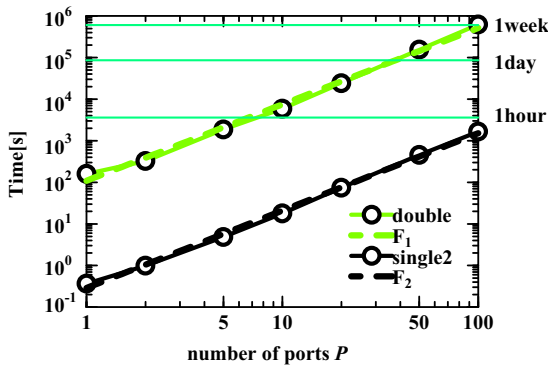
### 2. Electromagnetic Designing Tools for PCB

A printed circuit board, PCB, has a stacked planer structure and two-dimensional treatment is possible without serious deterioration of accuracy even for a practical and complicated structure of an end product.

The authors succeeded in expressing the electromagnetic field between the Vcc and GND conductor layers with a Green's function for a PCB of rectangular or right and isosceles triangular shape. Electric characteristics of the board are expressed in terms of an impedance matrix between the nodes where legs of LSIs or vias penetrate. The Green's function is once expanded in a series of sinusoidal functions exploiting homogeneity of PCB along both  $x$  and  $y$  directions of the surface: a double series. The function is further compiled into a single series benefited by a well-known mathematical formula. Furthermore efficient approximation was made for the dominant terms of the series and a consideration was made on the convergence by inspecting the EM mode structure at resonance and in antiresonance state.

The time required for the calculation was examined for various numbers of ports comparing two cases where single and double series were employed for Green's function as Fig.1. Remarkable improvement is recognized there for about 400 times [2-4]. Increase of the speed helps a PCB designer to examine a detailed arrangement of patterns and allocation of components allowing multiple trials within limited time period. Results are expressed in terms of impedance matrices for ports connected pins of LSIs. The designer will know effect of a decoupling capacitor placed just around an LSI power-supply pin moving it to-and-fro.

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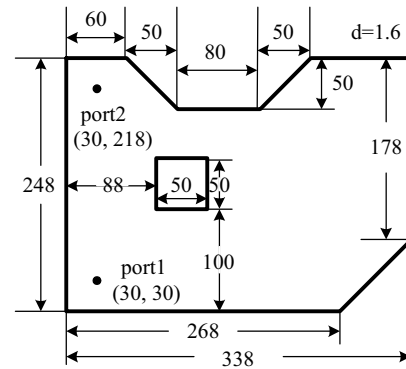
**Fig.1** Calculation time vs. number of ports on PCB. Modification of a double series for Green's function to the single allows a faster calculation.  $F_1$  and  $F_2$  are fitted lines.

PCB of electronic products is often canted off on an edge, drilled for holes and cut for slits. These structures are obstacles of undergoing methods of numerical analysis. The authors' method of EM analysis allows the segmentation of the whole board of irregular pattern into rectangles and right isosceles triangles allowing arbitrary perimeter and holes inside. Electromagnetic coupling between adjacent segments are expressed with virtual nodes placed on the border. These are compiled into a software system, HISES, equipped with a tractable interface. A slit can also be included, being expressed as a transmission line composed of edges facing each other over the slit [5, 6]. An examples of test PCB is illustrated of its shape in Fig.2, and of measured and calculated  $S_{11}$  in Fig.3. Results of the calculation were obtained in ten minutes with an alpha machine of 400MHz, and both results agree within a few dB. Effort was made to equip an elaborate interface easy to use HISES. The time required to operate HISES is included in the turn-around time.

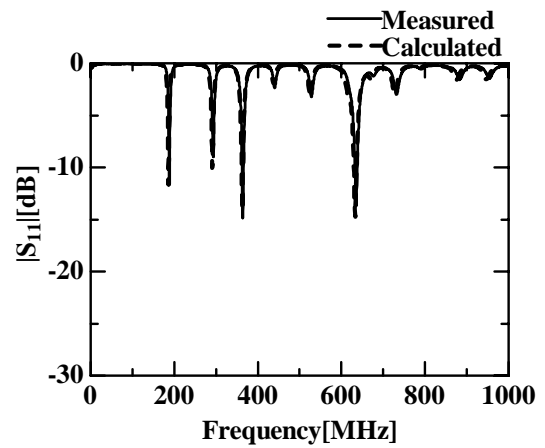
The idea of power islands to confine the EM energy within a limited space in a PCB has been found effective. It is, however, a problem how to connect the signal lines across the moat. One cannot but bridge a part of the moat in the Vcc layer to provide a signal transmission. The authors can find how many capacitors are required and where to be placed, employing HISES looking over the total frequency range.

PCB with an imperfect power-island pattern of Fig. 4 was examined, and effect of stitching decoupling capacitors of Fig.5 was examined with HISES solver. Repeated trials are possible because of the swift operation till a compromise is reached.

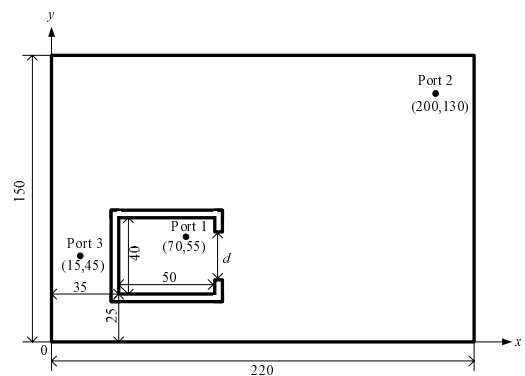
Confinement of EM energy within the peripheral domain of the source LSI has also been tried by adding an inductor in addition to the decoupling capacitor. Resistive layers attached to both inside of the conductive layers of Vcc and GND layers were examined giving quantitative results of the effects on lowering the Q values of the Vcc-GND cavity [7].



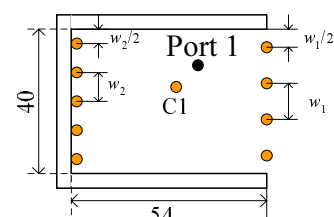
**Fig.2** The printed circuit board analyzed. Sizes in mm.



**Fig.3** Power reflection coefficient,  $S_{11}$ , obtained with experiment and the calculation for PCB of Fig.1.



**Fig.4** PCB with an imperfect power island.



**Fig.5** A Power island stitched with capacitors.

These techniques, together, will efficiently decrease the EM noise that leaks out from an LSI into the whole PCB, as well as to attached cables.

### 3. Another Accounting of Common-Mode Excitation

The common mode is excited on PCB with a ground plane of a limited size. The authors found the mechanism that can be quantitatively explained by introducing a notion of “imbalance driven mechanism” [8,9], in which the common-mode current is determined by the current division factor between a couple of conductors composing a transmission line.

Consider a transmission line of two strip conductors enough long and TEM electromagnetic distribution is retained as Fig.6. The common-mode current is divided into each line with a “current division factor”  $h$ , as

$$I_{CS} = hI_C \quad (1)$$

$$I_{CR} = (1 - h)I_C \quad (2)$$

The factor  $h$  is found by the charge portioned out between the two lines with TEM environment. The line as a bundle of common mode currents has a characteristic impedance specific to itself and “virtual” common mode voltage  $V_C$  can be defined.

Difference of imbalance between two transmission lines connected at a point induces the common mode current driven by the difference of the “common mode voltage” of each transmission line. The current division factor  $h$  can be calculated with the surface charge method that can be solved numerically with moderate calculation resource for a practical PCB configuration compared with other numerical method as FDTD or FEM. Application was tried to calculate the effect of guard-band placed just at the edge of PCB, or the increase of common mode for clock lines place at the blow of PCB edge. Experiments were also executed for the same specimen. Calculated and measured results agreed within a few dB in almost cases.

This new idea will not only evaluate the common mode but also improve or create a new transmission system. Ultimate results is stated as, “Even unbalanced transmission lines will not cause common mode current so far as the common mode voltage of the connected lines are consistent”, which may give a hint to a PCB designer who is pressed to locate the clock but near an edge of PCB. The “quasi differential line” has been proposed [10].

Strictly coherent operation of clock lines composing a bus system will drag heavy electromagnetic energy around the bus system. The amount can be reduced with slightly shifting edges of the signal. The idea was experimentally examined as well as with theoretical calculation. This technique

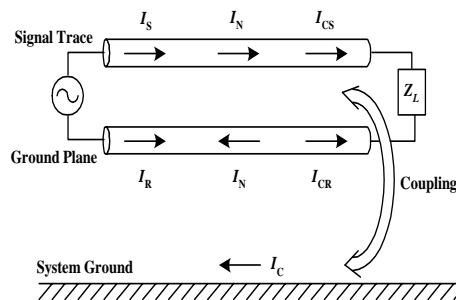


Fig.6 Common- and normal- mode current along an unbalanced transmission line.

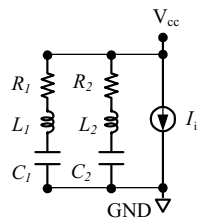
will take effect employed along with the quasi-differential transmission line [11].

### 4. Device Model

An electronic device is composed of LSIs as well as of PCB. They couple each other through signal and power/ground connections, and form a complicated resonating system. A simple device model, which represents electrical characteristics of the device looked from those pins, is necessary to analyze the total resonating system. In order to cope with this problem, “linear equivalent circuit and current source: LECCS” model has been developed by the authors though object semiconductor devices are currently limited to CMOS. Different from foregoing SPICE or IBIS model, LECCS employs transistors expressed with a linear equivalent circuit corresponding to the steady state of digital devices. The transient state is neglected at the first stage as its contribution to EM dynamics of the total system is regarded to be small. Impulsive EM energy is assumed to be generated only by a transient of internal gate expressed with a current source. Its mode of dynamics is determined by other devices in a steady state and also by the boundaries including PCB and attached cables, or possibly by casings. Thus a linear expression is possible for the “passive” transistors, and it is easily combined with PCB expressed in terms of Z matrix in the frequency domain. The calculation made in frequency domain is mostly quick. Physical parameters deep inside a transistor will not contribute the dynamical properties of EM dynamics and can be neglected: only a few parameters are sufficient to explain the dynamical characteristics of the LSI looked from the pin.

LECCS modeling was made twofold. For “the core of LSI”, LECCS-core model was proposed and has already been applied to practical products.

Another model, “LECCS-I/O” can express the strong H/L state dependence of I/O interface, which can represent a heavy dependence on load impedance. Equivalent circuits are prepared separately for the H and L states, respectively. These are expected as a future standard model whose application is focused on EMI analysis [12-14].



**Fig.7** LECCS-core: linear equivalent circuit and current source model. A model of a power supply port of an LSI core.

### 5. Conclusion

Many tools and ideas have been developed in these five years by the authors assisted by experimental examination as well as theoretical consideration. Anticipation of EM noise radiation has become possible in a short period for printed circuit boards and unbalanced transmission lines. LSIs connected to PCB can be concisely expressed with LECCS models which allow a short calculation time. Physical intuitions employed on the way of these developments will also help engineers who work on PCB design to create new configurations of faster digital circuit implementation.

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