Electromagnetic characterization of PCB cards for mobile phones

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Abstract- **In this article we focus on the EMC characterization of PCB cards for mobile phones especially the filtering part in order to position the best way the components on the routing. To be precise, all the electrical characteristics of the cabling including the inductive couplings have to be taken into consideration. To achieve this modeling, the PEEC method (partial element equivalent circuit) has been used to obtain an electrical equivalent circuit of the connections of the PCB structure. This model takes into account all the parasitic elements. A study of the transfer function of the filter can be obtained and Spice-like simulations can give the waveforms of current and voltage in time domain. Moreover, solving the circuit equations on the global electrical model, the current distribution in the PCB tracks can be drawn and "hot" points can then been identified. Several configurations of a PCB card for mobile phone have been studied according the value of some geometrical parameters or the position of passive component on the PCB.**

I. Introduction

More a product reaches its final state, more the price linked to the EMC (Electromagnetic Compatibility) requirements is important .Thus, it is necessary to "think EMC" during the design phase of the electrical circuit. The complexity of phenomenon which interferes during the EMC study shows the necessity to use modeling techniques to predict the electromagnetic perturbations inside and outside the structure. The required CAD tool to achieve this modeling will allow taking in consideration the electromagnetic compatibility at the design phase versus standards.

The industrial applications field under study in this paper concerns mobile phones cards and specially their power part. Technological developments in power electronics has led to a significant increase in the number of converters in all industrial fields [1]. The increase of power and speed of these converters led to electromagnetic disturbances in an increasingly important way. Some electrical aspects, previously neglected, must be addressed now to ensure proper functioning of the structure. The study of electromagnetic compatibility is therefore becoming unavoidable for designers of power electronic circuits.

This article describes how the influence of wiring can be taken into account in the development of electronic structure due to the influence of the position of passive components on the circuit or some geometrical parameters of conductors for example. The studied circuits will be PCB structures, two layers or multi-layers on which the passive and active components are connected, principally on the top side.

The design stage (placement and routing) of a printed circuit board is particularly important, and previous works have shown that the position of components on the layers changes the characteristics of transfer functions [2-3]. Indeed, considering the studied frequency range (some Megahertz), the discrete electronic components as well as the voltage source of PCB cards, only few millimeters of connections can introduce parasitic elements or alter the impedance characteristics. This is illustrated on Fig. 1 where measurements on two configurations of capacitors cabling on a PCB card show that only some millimeters have an impact on the resonance frequency of the transfer function of the studied filter. So a good routing can significantly reduce many problems of disturbance and improve the behavior of devices.

Experiment alone is not enough to design a reliable behavior of the structure. Knowing that, it is very difficult or even tricky to efficiency measure many data on this kind of devices.

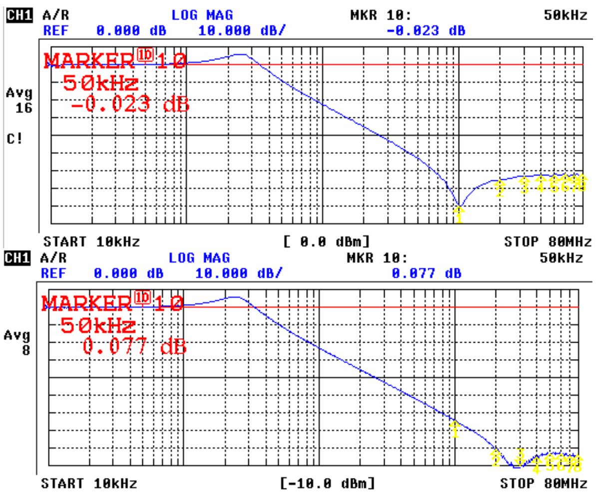

Fig. 1 Measurements of the transfer function for the two configurations for capacitors position on the electronic card.

Thus, the use of modeling will allow predicting some crucial characteristics. The simplest model in power electronics is to evaluate an electrical equivalent circuit of the cabling of the structure as well as an electrical model of passive components of the structure in order to simulate the complete electrical behavior of a device.

In this article, the following part is dedicated to the modeling process to evaluate an electrical equivalent circuit for cabling and for the passive components that will be used to predict the waveforms of currents and voltages. The use of such an equivalent circuit is detailed to show how to obtain global value such as equivalent impedance or losses but also local characteristics inside the structure such as current distribution. In the third part, the studied device will be presented. The results using the proposed method on this example will be detailed in the last part. The influence of some parameters such as position of capacitors or geometrical sizes for conducting parts is also studied.

II. Modeling Process

It is well known that a modeling method based on the PEEC method (Partial Element Equivalent Circuit) is well adapted to transform the three dimensional cabling of a structure into a passive electrical equivalent circuit (resistance, mutual and partial inductance) [4-5]. This equivalent circuit has to be completed with passive components models possibly connected to the structure (Fig. 2) (resistor, capacitor or inductor).

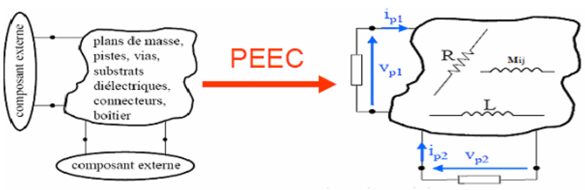

Fig. 2 Transformation of a 3D structure into a passive equivalent circuit.

A. Assumptions

To apply the PEEC method, the current density inside conductors must be uniform. But concerning the studied application, frequency range is some Megahertz. Moreover, tracks on the PCB can be very close together. So proximity effect and skin effect have to be taken into account in this kind of application because current density can not be supposed uniform in the conductors.

So, a judicious meshing of the geometry should be adopted. It consists of subdividing the conductors into smaller elements in which the current density can be considered uniform without approximation. This meshing can be adapted to their form to represent the path of current lines as it is shown on Fig. 3. Depending on assumption about current path, only cross section or also length of conductors is subdivided. .Using PEEC method, a RL series equivalent circuit is associated to each subdivision. All inductances are coupled with mutual inductances (M). The values of equivalent circuit components are evaluated using analytical formulations [6] or 0-order Galerkin numerical solving. The obtained circuit can be very dense with some thousands of elements.

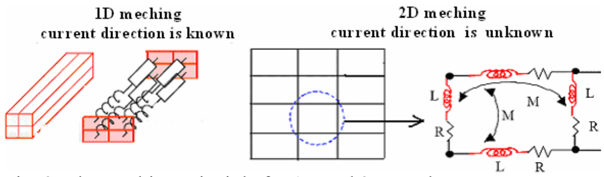

Fig. 3 The meshing principle for 1D and 2D conductors

B. Model use

From the obtained electrical equivalent model, several evaluations may be considered [7-8]:

- The equivalent complete circuit can be reduced to obtain the transfer function of the studied device. Then a frequency study of it can be achieved to perform resonance characteristics for example.
- The electrical circuit, completed with models of other components of the structure can be simulated on a Spice-like software in order to evaluate voltage and current waveforms so that over-voltage, overload and time characteristics can be deduced.
- Finally, the full equivalent circuit, before any reduction, can be powered by the voltage source calculated at the studied frequency and the current distribution evaluated in different parts of the wiring.

III. The Studied Structure

A. Electrical function

The studied structure is part of a PCB card for mobile phones (Fig. 4). It is composed of three layers of 0.035mm, top, bottom and intermediate layers for a total thickness of 1.6 mm. The position of intermediate layer can vary inside the structure. “Vias” are used to connect the top and bottom layers through the intermediate layers. It is a DC-DC converter, more particularly a Switched Mode Power Supply (SMPS).

On Fig. 4, a battery is connected to two decoupling capacitors of 4.5 µF and the track is named VBAT. VBOOST is connected on one side to a capacitor of 100 µF and on the other side is connected to (VBAT+3.5V) (internally voltage booster).

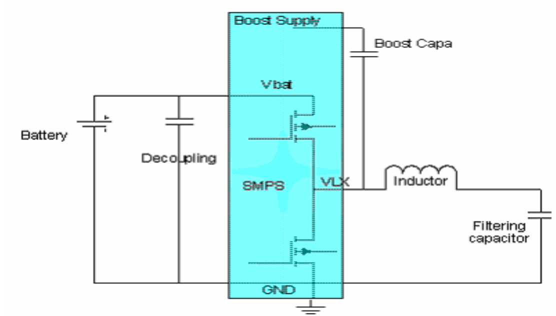

Fig. 4 The theoretical electrical function of the studied structure

The track named VLX is connected to one side to two switches and on the other side to a filter made of a 1µH inductor and a 22 µF capacitor. The switching function is realized with two mosfets whose parasitic elements and intrinsic characteristics have to be taken into account with an appropriated model.

B. Electrical modeling

1. Passive components models

In order to have an accurate electrical model, we must take into account the characteristics of passive components such as capacitors used in the device. Classically, using the data constructor, the electrical characteristics of these components, such as the ESR or the ESL, can be deduced. An equivalent circuit is then associated to each capacitor (Fig. 5).

For example, for the 4.5 µF decoupling capacitors which are included in the studied structure, values of ESL and ESR parameters can be deduced from the resonance frequency given by constructors via measurements (Fig. 6).

From the curve on Fig. 6, the point at the resonance frequency f_r allows the determination of the unknown parameters (1-2). So ESL and ESR are deduced. The procedure is the same for all capacitors used.

$$fr = 1/(2\pi(LC)^{1/2}) = 1.3\ MHz \quad (1)$$
$$ESL = L = 0.09\ \mu H \text{ and } ESR = R = 0.004\ \Omega \quad (2)$$

Concerning the 1µH inductor, datasheet of constructor (Fig. 7) shows that it can be considered as a simple inductance for the studied frequency range.

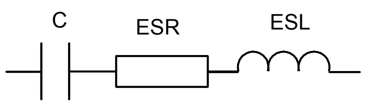

Fig. 5 Equivalent circuit of the capacitor

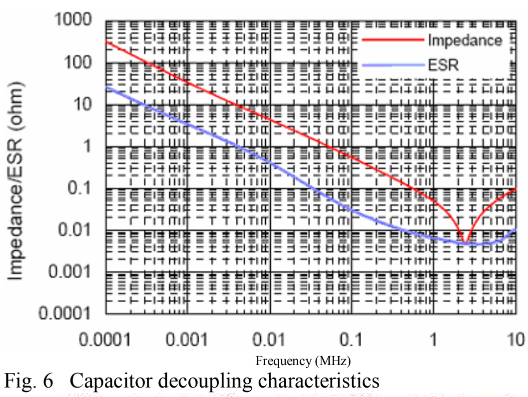

Fig. 6 Capacitor decoupling characteristics

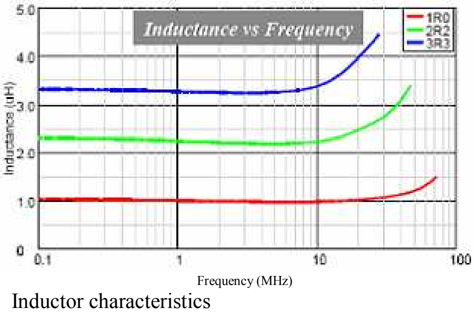

Fig. 7 Inductor characteristics

2. Wiring model

The PEEC method which has been previously presented has been implemented into a software called InCa3D® [9] in order to automatically generate the good meshing (adapted to the selected frequency) and the evaluation of all the RLM parameters of subdivisions. On Fig. 8, a detail of the description of the structure inside this software is presented. The final full model is constituted by a full complex matrix whose size is directly linked to the number of subdivisions.

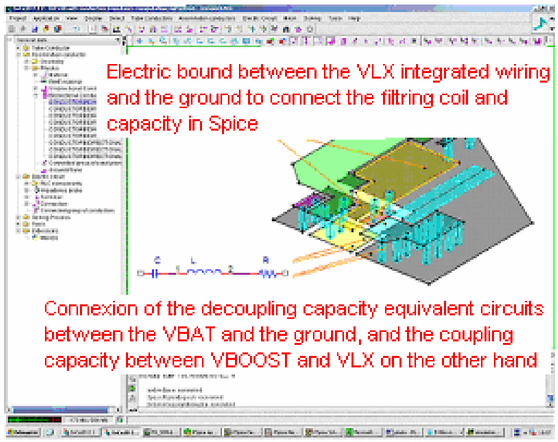

Fig. 8 Geometry description inside InCa3D corresponding to the PCB board

C. Characteristics of the model

1. Impedance evaluation

Using the InCa3D software, all the values of resistances, inductances and mutual inductances of the connections have been evaluated. Considering impedance point of view, these information are too numerous to allow a fine analysis. In fact, what can be interesting is to evaluate the impedance from inputs-outputs of the structure for a frequency range. So first it is necessary to well identify these inputs and outputs points to then calculate the transfer function of the system by reducing for each frequency the full model.

For the studied structure, three points, named VBAT, VLX and Ground have been identified (Fig. 4). A very condensed circuit can then be calculated (3).

$$Z = \begin{bmatrix} Z1 & Z12 \\ Z21 & Z22 \end{bmatrix} \text{ with } Z = R + jL\omega \quad (3)$$

The influence of some particular parameters of the structure such as frequency but also geometrical position of some components can be studied on the obtained transfer function [10-11].

In addition this reduced circuit has been automatically exported towards a Spice-like software through a macro-block in the schematic software library Spice. Then, it is just necessary to add in Spice the active components (semiconductors with their appropriated models, loads and other passive components or power sources) to deduce the current and voltage waveforms (Fig. 9).

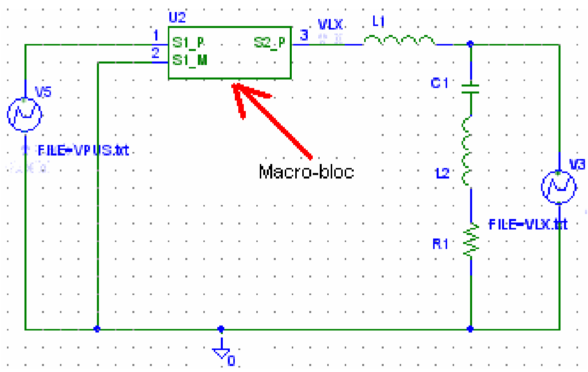

Fig. 9 Pspice equivalent circuit of the studied filter

2. *Current distribution*

After a PEEC resolution at a given frequency, it is also possible to supply the complete electrical equivalent circuit including the model of passive components with an equivalent source representing the mosfets commutations. Then the solving of circuit equations give the current inside each subdivision and then the current distribution can be drawn as it is shown on Fig. 10. Then, we can know the possible hot points from the board and the overloaded conducting parts of the PCB and evaluate the total supplementary losses due to cabling in general or to some connections in particular.

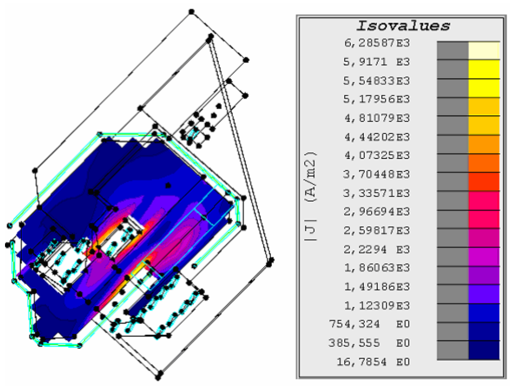

Fig. 10 Current density in the selected conductor

IV. RESULTS

In this section, the results obtained on the studied industrial structure are presented.

A. *Transfer function*

The InCa3D® software gives us an equivalent circuit strongly related to the connections geometry. The result of this modeling can be condensed like previously exposed. From the three defined points, using one as a reference, three impedances can be evaluated: Z1, Z2 and Z12 to each frequency (from 2 MHz to 10 MHz). This corresponds to the transfer function of the structure. In Table I the values are given for a frequency of 2MHz and Fig. 11 shows how frequency dependent is this transfer function for the considered frequency range [12-13]. This is very important information which allows us to estimate the frequency impact on the equivalent circuit.

TABLE I
IMPEDANCES VALUES AT F=2 MHZ

	Real part (Ohm)	Imaginary part (Ohm)
Z1	0.00264	0.0351
Z12	0.00252	0.0189
Z2	0.00623	0.0606

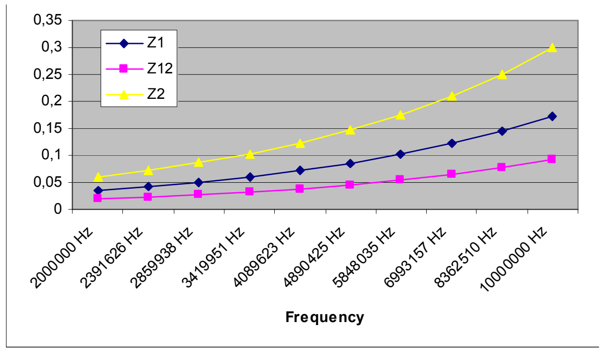

Fig.11 Frequency evolution of Z1, Z12, and Z2 (Ω)

So to evaluate the current density inside the full model, it will be necessary to supply it with an equivalent sinusoidal source at a specific frequency. The value of the equivalent source is deduced from a FFT of the time domain simulation detailed in the next part.

B. *Current and voltage waveforms*

The previous reduced equivalent circuit given by InCa3D is directly transferred into Spice as an electrical macro-block. It can then be simulated in the time domain. For that it is necessary to insert the semiconductors with their appropriated switching model. If this model is not available, it is possible to extract from measurements on a real structure the time varying voltage. Then the semiconductors can be replaced by a voltage source that reproduces accurately the switching of the MOS device. For example, the potential at point VLX can then be visualized on Fig. 12.

Therefore, other forms of power sources can be considered to determine their impact through the wiring on the critical points of the device.

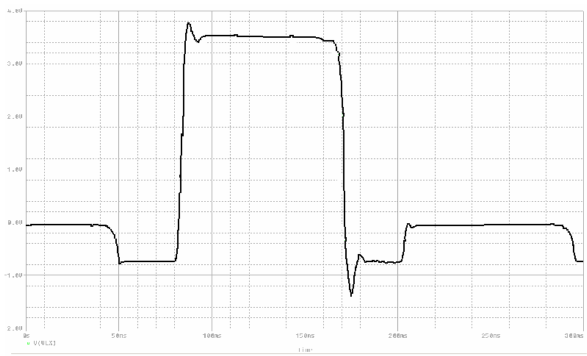

Fig. 12 VLX voltage as a function of time

C. Current density

Once the time domain simulation is completed, we can know the global current level at the input of the device. Since the transfer function is frequency dependent as previously mentioned, the complete equivalent circuit in InCa3D can be supplied by a sinusoidal equivalent source whose value is deduced from a FFT of time result. And the current density in each element of the meshing can be deduced and visualized for each layer of the PCB (Fig. 10).

This last result is very important to conclude upon possible hot points on the circuit or to evaluate the losses due to conducting parts and the global magnetic field radiated by such a structure.

D. Parameters analysis

The modeling process presented in the previous sections can allow answering some designers' questions and help us to choose the best structure.

1. Position of passive component

Indeed, for this application, one question concerns the best position of some discrete components on the PCB. Two configurations have be experimented using the modeling process and are presented on Fig. 13. Table II gives the maximum value of current density in the considered layer for the two configurations. For configuration 1, current level seems to be higher. For health consideration, designers should prefer configuration 2 because radiated magnetic field should be lower.

It can be seen that, position of components is very important for this application, even if only some millimeters are involved (in that case 1.5mm).

The same way, for example for a given value of decoupling capacitor, the question could be should it be better to put one or two capacitors in parallel. Geometrical symmetry is very important for this kind of structure.

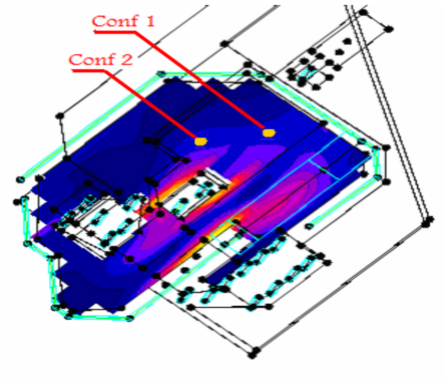

Fig. 13 Two different configurations for component position

TABLE II
MAXIMUM CURRENT DENSITY (A/M²) BASED ON TWO FREQUENCIES AND TWO CONFIGURATIONS TO CONNECT COMPONENT

	2 Mega	5 Mega
Conf 1	6.2	6.32
Conf 2	5.6	5.68

2. Position of intermediate layer

Another designers' question concerns the intermediate layer and its position between the top and bottom layers, close to the top or close to the bottom layer of the PCB [14]. It can act as a shielding plane. So this position has been defined as a geometrical parameter that can vary between some limits, two configurations have been tested and are presented on Fig. 14.

On Fig. 15 and Fig. 16, the current density inside this intermediate layer is drawn. Some differences can be observed on this distribution as well as on the maximum values reached. This can allow the designer choosing the best configuration regarding the desired performances of the structure.

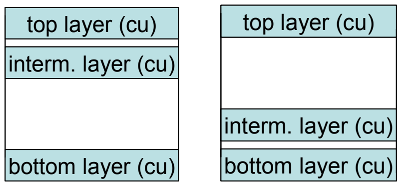

Fig. 14 Two different configurations for intermediate layer

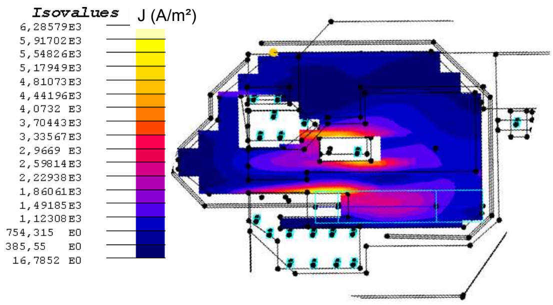

Fig. 15 Intermediate layer close to the top one

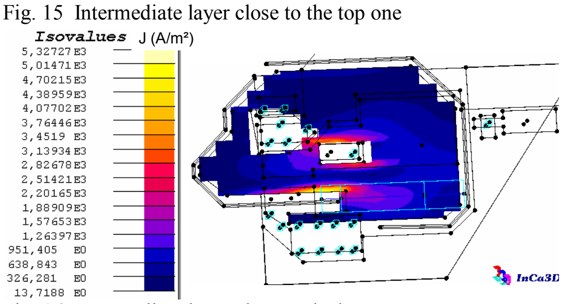

Fig. 16 Intermediate layer close to the bottom one

The influence of this position can also be evaluated upon global data such as the supplementary losses induced by the electrical characteristics of cabling. In that case, the impact of this geometrical parameter is negligible.

Moreover, the reduced model or transfer function has been evaluated for the two positions of the layer. On Fig. 17 the results are presented on the values of Z1, Z2 and Z12. As expected, no effect on Z1. This is linked to its definition. Nevertheless there is an influence on the other values of the equivalent impedance.

So on this global data, the influence of this parameter has to be evaluated.

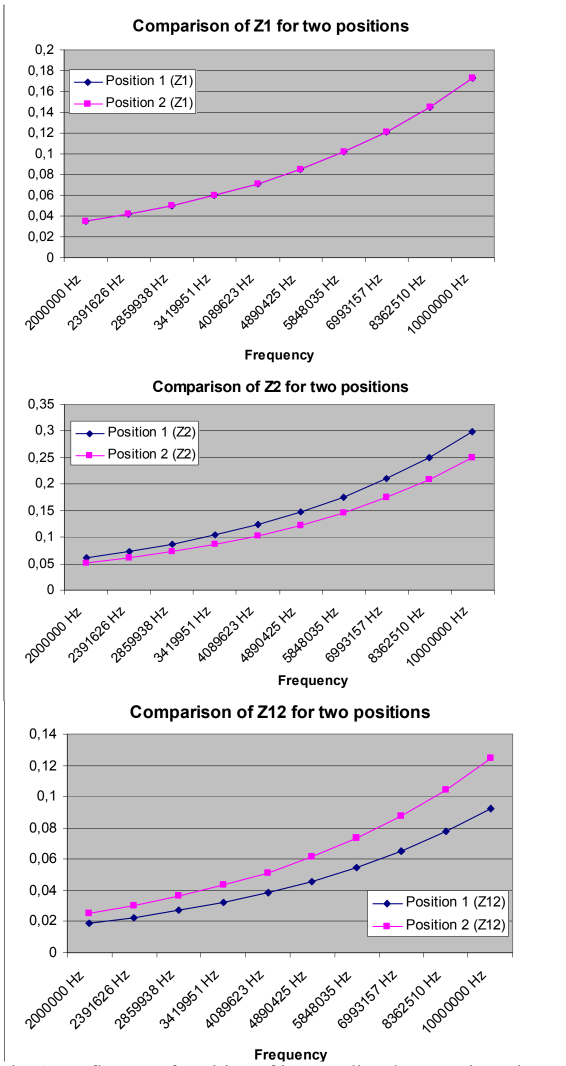

Fig. 17 Influence of position of intermediate layer on impedance values

3. Conclusions

Knowing that the electrical equivalent circuit is closely related to the geometry of the wiring, the modeling process presented in this article is a good way to evaluate the impact of wiring. It also indicates the right position of passive components on an electronic circuit to answer the specification. The results are dependent on the evaluated data. In fact the impact is not the same according the current density or the losses. This modeling process is a good way to limit the number of prototypes and so the design costs.

V. CONCLUSION

In this paper, the influence of electrical characteristics of cabling of an electronic PCB is presented. The transfer function or the current density is evaluated according variation of several parameters. A modeling process to answer to the designers concerning the best position for passive components upon the PCB structure is detailed and evaluated upon a real device.

It appears that electrical characteristics of cabling can no longer be neglected even for some millimeters of conductors for high frequency range.

At this stage of the study, electrical modeling using the InCa3D® software coupled with Spice like tool is determined as an equivalent circuit with lumped-constant (R, L and M) taking into account proximity and skin effects.

Furthermore, the characteristics of passive components have been identified from data constructors and added to this model.

This model is then used to obtain the transfer function of the device.

Time domain simulations allow concluding concerning possible over-voltage, global current and waveforms in general.

Therefore it is possible to evaluate current distributions; different geometrical parameters have been taken into consideration and their influence on the performance of the card.

REFERENCES

[1] P.O. Jeannin, J.L. Schanen, E. Clavel, *"Original cabling conditions to insure balanced Current during Switching Transitions between Paralleled Semiconductors"*, IEEE – Transactions on Industry Applications, Jan/Feb 2002, pp 181 - 188.

[2] E. Clavel, C. Prémont, *"Function transfer sensitivity of an electronic filter versus capacitors location on a printed circuit board"*, IEEE 2EMC, Oct. 2007.

[3] Piotr Musznicki , Jean-Luc Schanen, Bruno Allard, Piotr J Chrzan, *"Accurate modeling of layout parasitic to forecast EMI emitted from a DC-DC converter"*, IEEE Power Electronics Specialists Conference, PESC'04, 3-7 October, Seatle USA, vol. 1, pp.278-283, 2004.

[4] A. E. Ruehli, *"Equivalent Circuit Models for Three-Dimensional Multiconductor Systems"*, IEEE Transactions on Microwave Theory and Techniques, 1974.

[5] A. E. Ruehli, A. Cangellaris, *"Progress in the methodologies for the electrical modelling of interconnect and electronics packages"*, Proceeding of IEEE, Vol. 89, N°5, May 2001, pp 740-771.

[6] C. Hoer, C. Love, *«Exact Inductance Equations for Rectangular Conductors With Applications to More Complicated Geometries»,* Journal of Research of the National Bureau of Standards C, Engineering and Instrumentation, Vol 69C N°2, April-June 1965, pp127-137.

[7] Wollenberg C., Gurisch A., "Analysis of 3-D interconnect structures with PEEC using SPICE", Electromagnetic Compatibility, IEEE Transactions on, Volume 41, Issue 4, Nov. 1999 Page(s):412 – 417

[8] G. Antonini, *"Full wave analysis of power electronic systems through a PEEC state variables method"*, IEEE 2002, pp 1386-1391.

[9] InCa3D: Inductance calculations software, CEDRAT, http://www.cedrat.com/.

[10] J-L. Schanen, E. Clavel, J. Roudet, *"Modeling of low inductive connections: the planar busbar structure"*, IEEE - Industry Applications Magazine Sept./Oct. 1996, pp 39 – 43.

[11] J-P. Gonnet, E. Clavel, V. Mazauric, J. Roudet, *"PEEC Method dedicated to the design of electrical systems"*, PIERS04, Pise, Italy, 28-31Mars 2004.

[12] Hung-I Hsieh, Jhong-Shu Li, Dan Chen, "Effects of X Capacitors on EMI Filter Effectiveness," IEEE Trans. on Industrial Electronics, vol. 55, no. 2, pp. 949-955, Feb 2008

[13] Modeling of connections taking Into Account Retum Plane: Apllication to EMI Modeling for Railway. Clavel Edith, TIE March 2009 678-684.

[14] Archambeault B., Ruehli A.E., "Analysis of power/ground-plane EMI decoupling performance using the partial-element equivalent circuit technique", Electromagnetic Compatibility, IEEE Transactions on, Volume 43, Issue 4, Nov. 2001 Page(s):437 – 445