Function transfer sensitivity of an electronic filter versus capacitors location on a printed circuit board

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Abstract – For power electronics applications or for power distribution systems, it has been proved that every part of connections between two components is involved in the electrical behavior of the studied structure. Indeed the electrical characteristics of connections can create currents unbalances, additional losses, bad working of switches. For electronics systems such as filters for telecommunication applications, the voltage and current levels are not so high but due to high frequency range, some millimeters of cabling can induce a shift in the resonance frequency and non desire behavior. In this article, a modeling method is presented to point out the influence of cabling and location of components on a filter structure. Results are compared successfully with measurements.

INTRODUCTION

For power electronics applications and for power distribution systems, connections between components inside a single structure or between several equipments can no longer be considered as perfect short circuits. A lot of works have proved their electrical characteristics contribute to currents unbalances, over voltages and supplementary losses [1-3]. And one conclusion of these works is that the position of components as well as the way to connect them is key points during the design process of a structure.

Today for electronics applications, the level of frequency range is increasing. And some electrical aspects which have been neglected before have to be considered now in order to ensure a good working of the structure. Hence, due to high value of frequency, only few millimeters of connections can introduce parasitic characteristics or modify the impedance. So the transfer function of the structure, a filter for instance, can be modified and then the global behavior of the structure is not the expected one.

This paper presents how the influence of cabling can be taken into account while designing an electronics structure through the influence of the position of passive components on the circuit.

First of all, the studied structure is presented as well as the theoretical results.

Then the principles of the adopted modeling method are detailed to focus on the necessary assumptions and the possible simplifications.

Then the results on the studied structure are compared with on one hand theoretical aspects and on the other hand measurements.

THE STUDIED STRUCTURE

The studied structure is a part of a complex printed circuit board. It concerns the output filter of a Switched Mode Power Supply (SMPS) or DCDC converter.

It is constituted by two thin layers of copper, connected themselves at several points in order to ensure a reference potential which is fixed and a "power track" named Vlx. On this track, an inductance is connected as well as two capacitors as shown on figure 1.

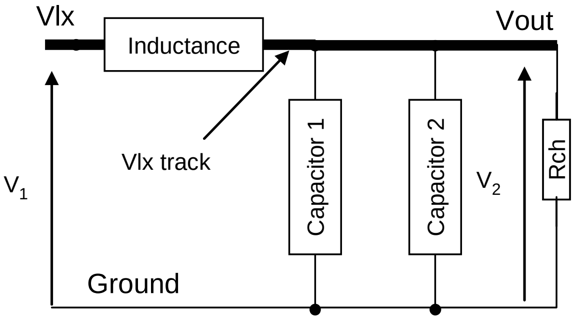

Figure 1: the theoretical filter

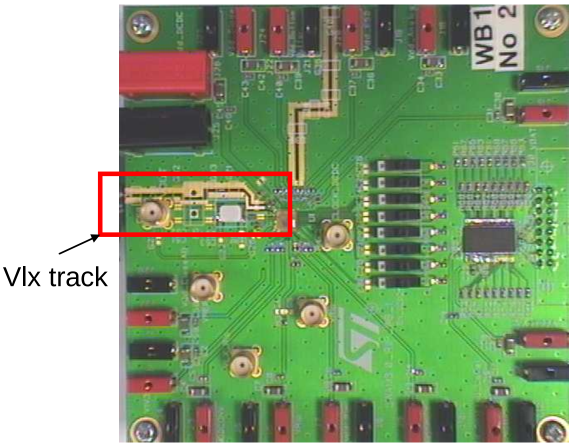

Figure 2: the under test device

The device under test is presented on figure 2. Vlx track has been underlined on this figure in order to appreciate the sizes of the structure.

Several prototypes have been designed with different positions and connections of capacitors on this track. Measurements have shown significant differences between very close configurations upon the transfer function of the filter. Indeed, some investigations have shown that the electrical characteristics of this track are involved in this transfer function. Two extreme configurations will be studied in this paper in order to confirm this fact.

First of all, figure 3 shows the electrical circuit of the filter. It is constituted of a series inductance of 1 µH and two parallel capacitors of 220 nF. The electrical characteristics of these components, such as the ESR or the ESL, are taken into account in this study.

The equivalent impedance from the inputs of such a structure is given by the following equation, considering that the intrinsic characteristics of the two capacitors are the same.

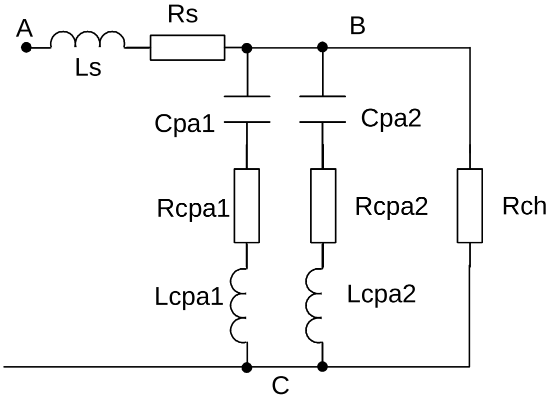

Figure 3: the theoretical filter with intrinsic characteristics of components

$$Z = Zs + \frac{1}{\frac{2}{Zcapa} + \frac{1}{Rch}}$$

$$\text{with} \begin{cases} Zs = Rs + j\omega Ls \\ Zcapa = Rcpa + j\omega\left(Lcpa - \frac{1}{Cpa}\right) \end{cases}$$

The theoretical transfer function T(jω) of this filter can also be evaluated.

$$T(j\omega) = \frac{V_2}{V_1} = \frac{Z_{12} \cdot Rch}{Z_1 \cdot Z_2 + Z_1 \cdot Rch - Z_{12}{}^2}$$

$$\text{with} \begin{cases} Z_1 = Zs + \frac{Zcapa}{2} \\ Z_{12} = \frac{Zcapa}{2} \\ Z_2 = \frac{Zcapa}{2} \end{cases}$$

On figures 4 and 5, the theoretical results are presented, when the load Rch is a 4.7 Ω resistance.

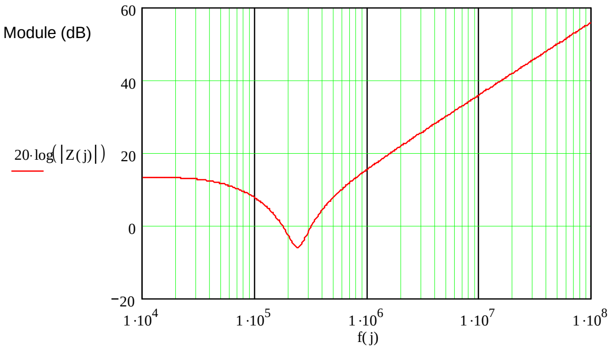

Figure 4: Equivalent impedance of the filter

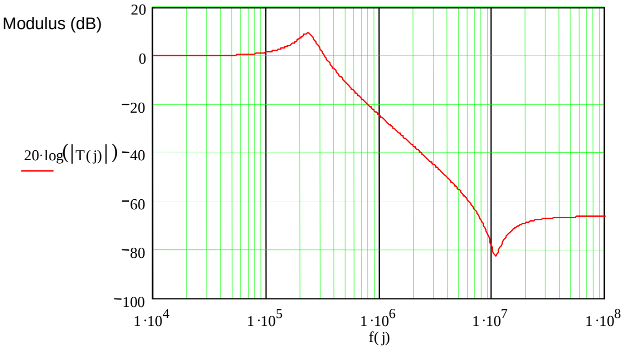

Figure 5: Transfer function of the filter

MODELING METHOD

The adopted modeling method is based on PEEC method (Partial Element Equivalent Circuit) which consists in replacing each straight part of conductor by an electrical equivalent circuit composed of resistance, inductance and mutual couplings [4-5]. The assumptions of this method are a uniform current density in the cross section of conductors and parallel or perpendicular position of conductors. In that case, the values of the components of the equivalent circuit are evaluated using analytical formulations [6].

But in fact, current density is often non uniform in cross section of conductors due to proximity effect and skin effect.

For the studied application, the frequency is high so skin effect has to be taken into account.

So in order to make it possible to apply the PEEC method, a meshing of geometry has to be adopted [7-9]. It consists in subdividing the cross section of straight conductors into conductors of smaller cross section with a uniform density which is different from one subdivision to the other. This is well adapted for conductors in which current is one direction. A R-L series equivalent circuit is associated to each subdivision. All inductances are coupled with mutual inductances.

For thin layers of conductors, such as return plane, there is no variation of current inside the thickness so a simple 2D meshing can be adopted in order to also take into account the geometrical discontinuities of these layers. So current can flow in two perpendicular directions. The equivalent circuit of an elementary subdivision of this meshing is detailed on figure 6.

These two kinds of meshing are presented on figure 6.

For the studied structure, the 1D meshing has been adopted for the Vlx track and the 2D meshing for the two thin layers which act as a reference plane and to which capacitors are connected.

You can note that for complex geometries or very large frequency range, this meshing can lead to a very high number of subdivisions if no attention is paid to the assumptions which can be done upon the current distribution.

Like for every kind of modeling method, the meshing step is the key point of the accuracy of results.

This modeling method has been implemented in InCa3D® software [10] in order to establish the electrical equivalent circuit of the meshed geometry.

The result of such a modeling is a very big impedance matrix which is necessary to reduce in order to obtain desired equivalent impedance or the transfer function of the filter.

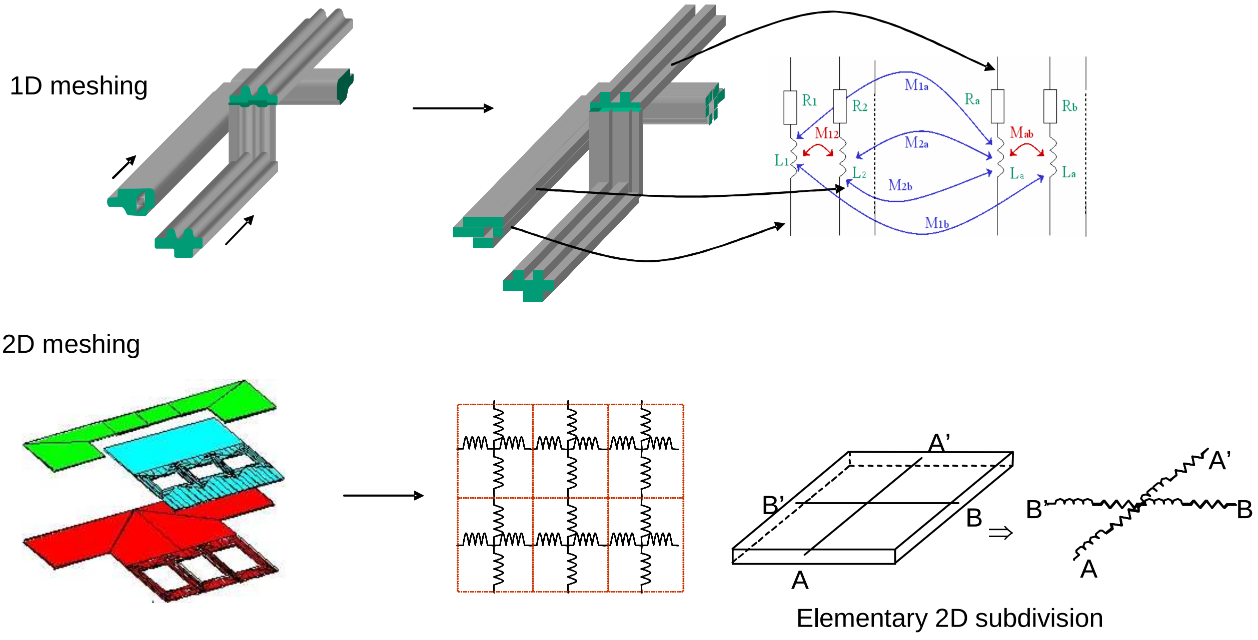

Figure 6: The meshing principle for 1D and 2D conductors

For that, the passive components of the studied structure are added, with all their intrinsic parameters such as ESR, ESL … and the transfer function is evaluated for the frequency range of interest by solving the circuit equations [11].

Another kind of applications could be a complete solving of circuit equations in order to evaluate the current inside each subdivision and then to obtain the current distribution for all conductors, the supplementary losses involved by induced currents or non uniform current density …

RESULTS AND ANALYSIS

The studied structure has been modeled using this process.

Figure 7 shows an example of meshing; only the electrical nodes have been drawn.

On this figure, the two studied configurations have been underlined. The two capacitors are connected between the red conductor (Vlx track) and the ground plane in green and yellow. Between the two configurations, the distance is only some millimeters. The load Rch is connected at the end of the Vlx track between this track and the ground plane.

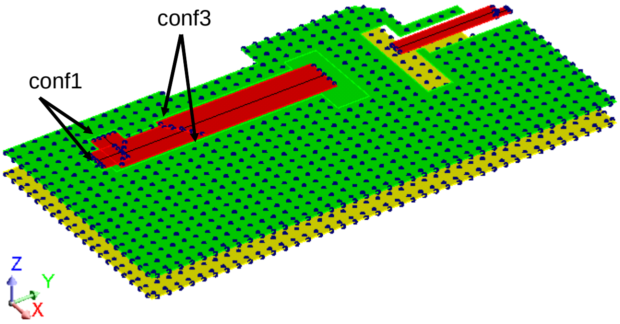

Figure 7: the meshing and the definition of the 2 studied configurations

For the two configurations of capacitors cabling, the equivalent impedance between points A and C of the filter has been evaluated in the frequency range of 10 kHz to 80 MHz. It is compared with theoretical behavior on figure 8.

It can be noted that no significant difference between the theoretical value and the two configurations appear. So one conclusion of this first evaluation is that the position of the two capacitors on the Vlx track has no influence upon the equivalent impedance of the filter with a 4.7 Ω load.

The only difference which appears on this figure is due to a bad frequency vector definition. One evaluating frequency is missing around 200 kHz.

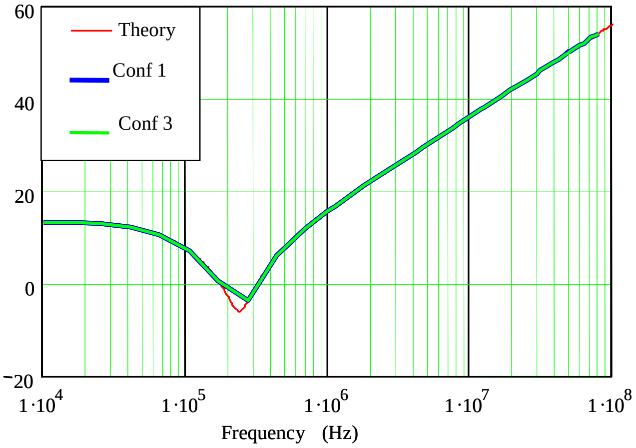

Figure 8: Equivalent impedance using InCa3D

Table 1 sum up the different particular values: low frequency, high frequency and the resonance ferquencies.

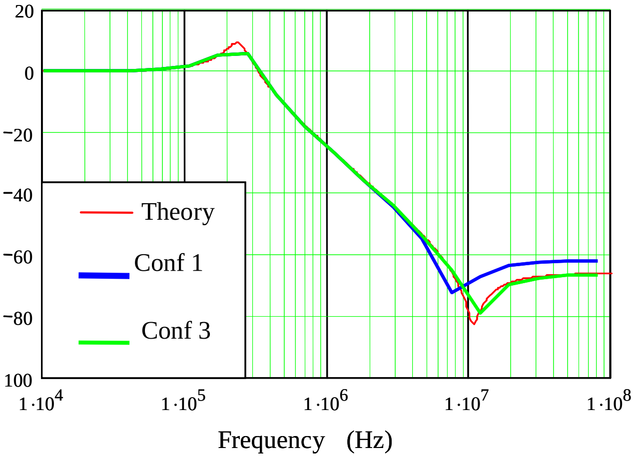

Figure 9: transfer function using InCa3D

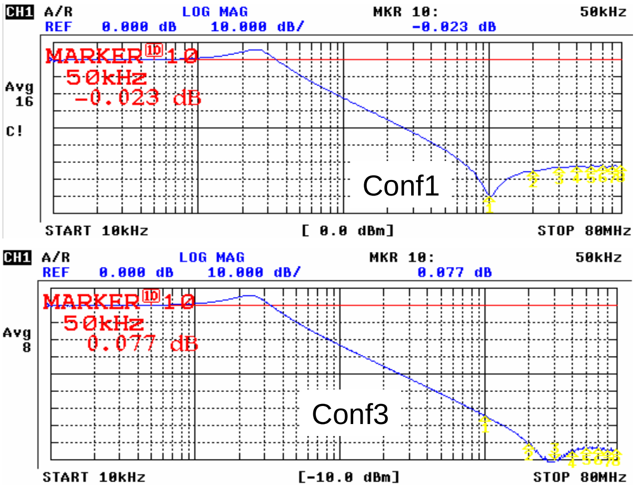

Figure 10: measurements of the transfer function for the two configurations

	10 kHz	233 kHz	Lowest value	80 MHz
Theory	- 0.06	9.2	- 83	- 66
Conf 1	- 0.073	9.03	- 75	- 62
Conf 3	- 0.073	9.06	- 80	- 67

Table 1: Modulus of transfer function in dB - Comparison between evaluated values for the configurations and the theoretical behavior

By the same time, the transfer function of the filter has been evaluated in the same frequency range and compared with theoretical behavior (figure 9) and measurements (figure 10).

Contrary to the previous result, differences between the two configurations and theoretical behavior appear on the modulus of the transfer function figure 9).

And we can see on figure 10 that the same kind of difference between the two configurations has been observed on measurements.

As expected, for low frequencies, the impact of cabling can be neglected. Indeed, some millimeters of connections act as perfect short circuits when frequency is below 100 kHz. Connections are so shorts that their electrical equivalent circuit is near zero.

Whereas when frequency increases, the value of resonance frequency differs from one configuration to the other.

Once again, we can see on figure 9 that one frequency evaluation is missing around 200 kHz that is why there is this difference between InCa3D evaluations and theory.

On figure 9, the same trend of behavior is observed compared to measurements. But there are some differences. The value of resonance frequency as well as the level of transfer function are a little bit different.

Indeed, the trend is respected. That is to say, resonance frequency for configuration 1 (10 MHz) is lower than the one of configuration 3 (30 MHz). By the same time, level of transfer function for high frequency is higher for configuration 1, -62 dB compared to -84 dB.

There are several explanations in order to understand these differences.

The most important error is due to the description and the meshing of the problem. Indeed, just a part of the studied structure has been modeled, the Vlx track and the planes around. These copper layers have been cut. In fact there are bigger. All other passive components have been cut off excepted the inductance and the two capacitors connected to the VlX track.

Moreover, in order to limit the sizes of the impedance matrix as well as the computational time, the meshing has not been as dense as necessary. And the number of connecting points between the two layers has been limited in order to reduce the description time.

So the modeling of the structure can be improved.

Nevertheless, this study has shown that according the geometrical position of capacitors upon the electrical circuit, the transfer function of the filter is not the same. And the observed difference can have an influence on the global performances of the structure.

So the modeling process which is presented in this paper is a good way to evaluate the impact of cabling. It offers a good solution to find the right position of passive components upon an electronic circuit in order to answer the specifications which allows to limit the number of prototypes and so the design costs.

CONCLUSIONS

In this paper, the influence of the cabling position of capacitors upon the transfer function of an electronic application is presented.

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

Two geometrical configurations have been investigated and modeling results are in good agreement with measurements.

It appears that the geometrical position of passive components can no longer be the result of a PCB design tool but must include other rules in order to obtain the best solution for components routing answering to specifications.

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