Prediction and measurement of The magnetic near field of a static converter

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***Abstract*—Increases of switching levels and frequency make the compliance with radiated EMC standards more and more difficult. A modeling method based on the partial equivalent element circuit (PEEC) formulations, permitting to know the field emitted by the layout of complex power electronic structures, is presented in this paper. The near magnetic field of a buck chopper has been measured and calculated. The comparison of the simulated results with measurements shows the effectiveness of the modeling methods and of the near field acquisition bench.**

I. Introduction

Power electronic structures become more and more powerful and complex. In consequence, switching levels and frequency are increased; multilayer PCBs are commonly used [1] and [2]. Unfortunately, the compliance with radiated EMC standards becomes more and more difficult for many structures. Today, the EMC is an important economical constraint for industrials. It appears that the knowledge of the emitted perturbations before testing a product becomes essential. That is why modeling methods are developed. But the complexity of the PCB layouts is a limitation for many modeling methods. The subject treated in this paper is about the calculation of the near magnetic field using a modeling method based on the partial equivalent element circuit (PEEC) formulations. A buck chopper has been chosen as prototype. A measurement bench has been developed and measurements have been realized at the Ecole des Mines de Douai Laboratory (ENSM). The modeling method has been developed at the Electrical Engineering Laboratory of Grenoble (LEG). The results of measurements and simulations have been compared, validating the two approaches.

II. Measurements

1 Introduction

The aim of our work is to measure the magnetic field radiated by an academic converter (not optimized with industrial constraints but dedicated to understand radiated phenomena) by using a test bench already validated. A three dimensional near field scanner was used to measure the magnitude of the magnetic field within a plane at a given height above the converter. These measurements enable us to locate the switching cell consisted of a capacitor, a diode and a transistor.

2 Experimental setup [3]

The test bench consists of a magnetic near field probe, mechanical 2D robot and EMI receiver: the probe is connected to the EMI receiver and is mounted on a two-axis robot. A computer monitors the probe displacement (along x and y) over the converter and records data provided by the EMI receiver as illustrated in Fig. 1.

Fig. 1. The near-field test bench

The magnetic field radiated by the converters is measured by a calibrated near field probe whose diameter is equal to 10 mm (Fig. 2).

Fig; 2. Near field magnetic probes

3 The converter under test

Figure 3 shows a picture of the studied converter, it is fed by a 50 V DC voltage source, and it provides a 2A current in the output load. The switching signal is a 20 kHz square wave voltage of 6V amplitude, with an offset of 3V and a 50% duty cycle.

The electrical schematic of the model is illustrated in Fig. 3.

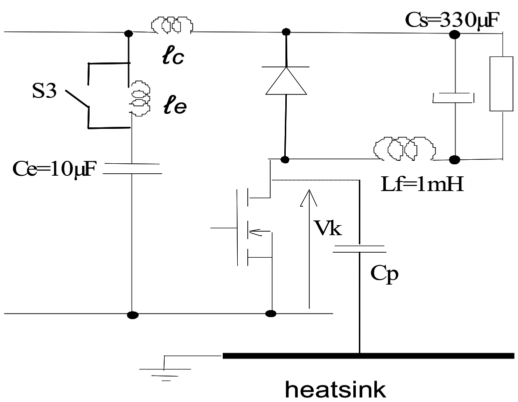

Fig. 3. Electric diagram of the converter

The parasitic elements l_e and l_c which contribute significantly to the disturbances [4] are represented. As illustrated in Fig. 4, the layout is made such a way that a loop is created near the filtering capacitor of the DC bus situated at the input of the structure.

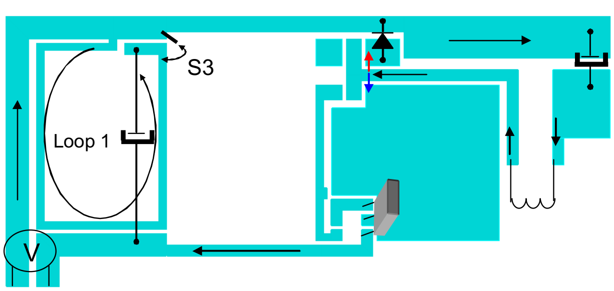

Fig.4. Loop 1 situated at the input of the buck chopper

Using a static switch S3, the value of the parasitic inductance ℓ_e (intrinsic inductance of the layout where the input capacitor is connected) can be modified (0 or 50nH) in order to highlight its influence on the radiated field. The radiated field value change because the corresponding loop areas vary too when S3 is actuated. When S3 is open, the radiation due to ℓ_e dI/dt is maximized

Two other loops are created by the layout. The first one named loop 2 is the loop created by the flowing of the current when the MOSFET, is closed. This loop appears only during the conduction of the MOSFET, that is to say during α.T (α is the duty cycle ant T is the switching period).

As illustrated in Fig. 5, a loop can be created on the other side of the PCB when closing the two switches (S1 and S2).

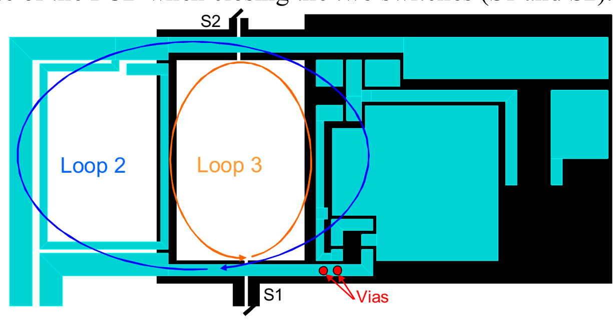

Fig. 5. Loop 2 and loop 3 of the buck chopper

This third loop is generated by induced currents appearing in loop 3. By application of the Lenz law, the induced currents will tend to cancel the source at their origin. The magnetic field created by loop 3 will tend to cancel the magnetic field created by loop 2. These effects will be quantified and analyzed in the paper.

The static converter is represented in Fig. 6 with the three switches. The switching cell is localized in red.

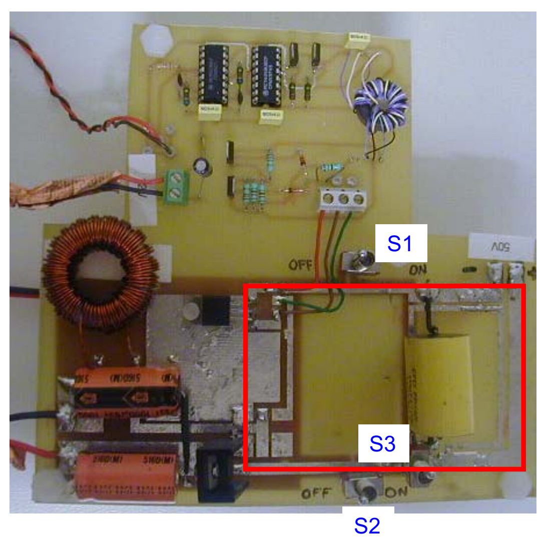

Fig. 6. The buck converter

4 Near field results

The three components of the magnetic field (H_x, H_y and H_z) have been measured at 80 mm height above the plane of the converter with a step of 10 mm at the switching frequency (20 KHz). This measurement was carried out for two cases. First, all the switches are closed and the field is minimized. Second, all the switches are open and the field is maximized. The results presented below show the field emitted when the switches are all open.

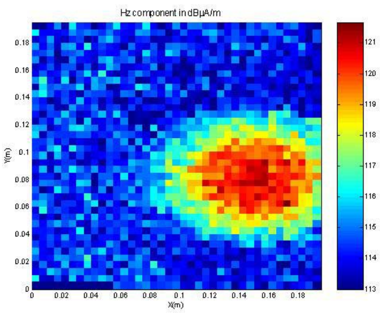

Fig. 7. Hz component in the XY plan

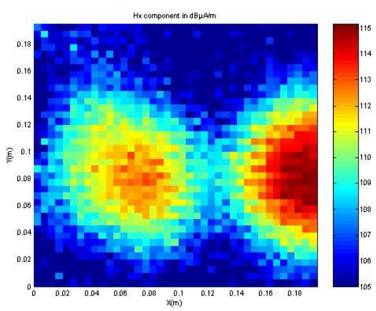

Fig. 8. Hx component in the XY plan

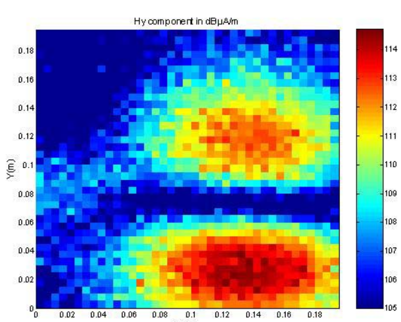

Fig. 9. Hy component in the XY plan

As illustrated by the cartography in Fig. 7, the field is localized above the input capacitor and the switching cell, delimited in solid red in Fig. 6. When the switches S1 and S2 are open, the parasitic inductances are maximum, and then the radiation due to l_edI/dt and l_cdI/dt is very high (see figure 7, 8, 9). When the switches are closed, l_e=0nH, loop 3 is activated and the radiation due to ldI/dt, is decreased by 10dB.

III. Modeling Method

The common mode currents are recycled through capacitances between the tracks and the ground plane. They generate a field which can be measured horizontally, on the side of a device under test. On the other hand, the differential mode currents circulate through the tracks of a structure and generate a field which can be measured above the unit under test. For this study, the capacitance model has not been implemented. The modeling method presented here is taking into account the influence of the differential mode currents. That is why by application of the Biot Savart law; the near magnetic field can be easily deduced if the current density is known in each conductors of the structure. The current density is known if the impedance of the layout is known, that is to say if the intrinsic impedance of the conductors and the couplings are determined.

The localized element method was introduced by A. Ruehli in 1972 [5]. Based on low frequency exact analytical formulations of inductances, it consists in extracting the electric parameters from topology of conductors. The calculation method of the impedance of a system of conductors can be generalized [6]. Firstly, the conductors are meshed. In the very widespread case of big size conductors, the path of the current is not known, so it is necessary to mesh them in two dimensions. Whatever the type of meshing used, the current density is constant in a subdivision of a conductor. The system of conductors linking components can be perceived as a multi-port with current inputs and outputs which can be modeled by the PEEC method. The equivalent electrical scheme of a subdivision of conductor is an inductance in series with a resistance. Coupling terms thus appear between the subdivisions of a conductor. In the same way, macroscopically, for a system with several drivers, induced currents generate couplings with real part (losses) and imaginary part (mutual inductance). The impedance of the system is defined thanks to inductive and resistive matrices. Matrices diagonals are filled with the intrinsic resistance and inductance of the conductors. The other terms of the matrices are the losses generated by the induced currents and the mutual inductances between the conductors.

The method has been applied to determine the magnetic field emitted by a square loop. The dimensions of the loop are 8cm by 8cm with 1cm for the width; it looks like the switching cell of the converter. As illustrated in Fig. 10, by putting a sinusoidal voltage source of 50 volts, 20 KHz, the current density can be determined.

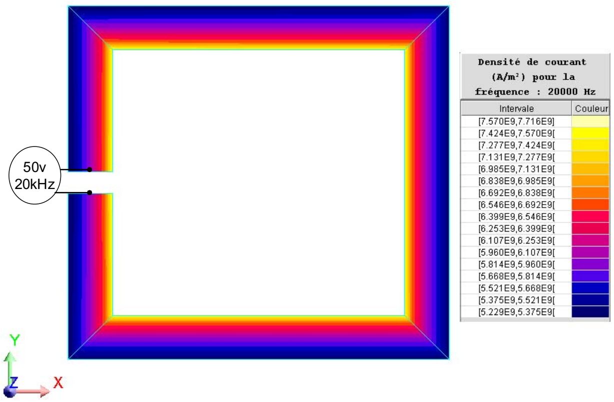

Fig. 10. Current density of a loop using PEEC model

Then, the radiated field is calculated by using the Biot-Savart law:

$$\vec{B}(P) = \frac{\mu 0}{4\pi} * \iiint_{M \in V} \frac{\vec{j} \times \overrightarrow{MP}}{\left\| MP^3 \right\|} dV \qquad (1)$$

Point M is an element of the volume where the current density is known, here the tracks, and P is the field point.

The H field is calculated at 8 centimeters above the loop. The modulus of the magnetic near field is illustrated in Fig. 11.

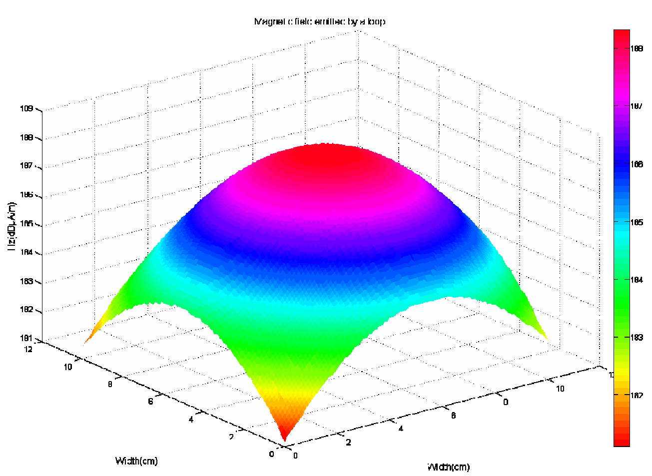

Fig. 11. Modulus of the magnetic field at 8cm above a loop

The most important part of the field is concentrated at the centre of the loop.

In this case, an arbitrary source has been implemented. But in fact, the determination of the source needs some investigations. First, the current going through the printed conductors must be determined thanks to an electrical time domain simulation. The real current is known by taking into account the influence of the PCB, that is to say, the influence of its parasitic inductances. The calculation of the impedance using PEEC method is made possible by using the InCa3D® software. Firstly, the geometry is entered. Then, a macro block containing the differential equations defining the impedance can be extracted. In other words, an electrical simulation taking into account the geometry of a structure is possible [7]. The time-domain simulations are realized by using the SaberSketch software. Then, the current generating the emitted field at a fixed frequency is known by a FFT of the time domain current.

IV. Buck Chopper Modeling

The previously presented buck chopper has been modeled. As presented in the second part of the paper, three different loops can be activated. This structure is simulated in the time domain. The current is known in each printed conductor. The electrical simulation schematic is illustrated in Fig. 12.

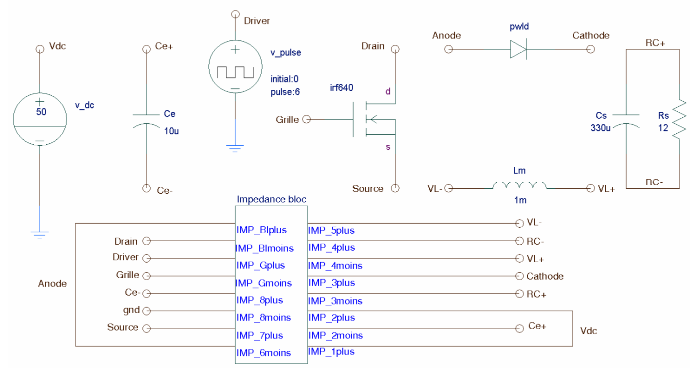

Fig. 12. Schematic of the buck chopper with a macro component

A macro component is added to the electrical schematic. The layout impedance is taken into account in the simulation of the buck. Converter by this macro-component named ‘impedance bloc” as represented in Fig. 12. Electrical components are linked to this macro component. By this way, the current waveforms can be well known in all the tracks of the structure. The current flowing through the MOSFET is described in Fig. 13.

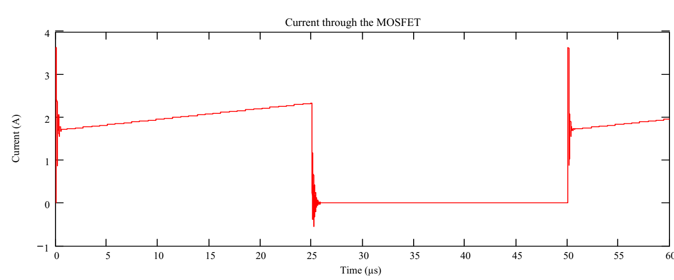

Fig. 13. Current by taking into account the layout

The influence of the layout appears clearly when the switch is opened and closed; oscillations due to the parasitic inductances of the PCB conductors appear at each switching. On the other hand, as shown in Fig. 14, without taking into account the influence of the layout, the ringing on the current disappear.

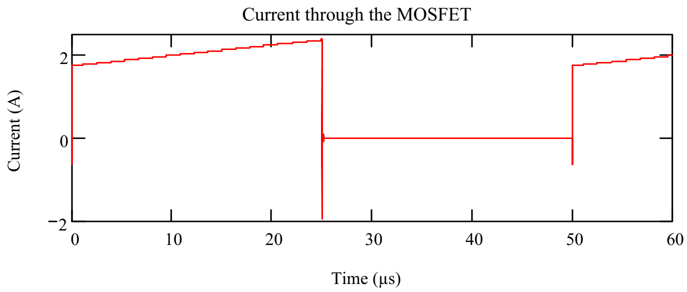

Fig. 14. Current without taking into account the layout

So, it is important to take into account the influence of the layout.

Two cases will be treated hereunder and compared to measurements presented before. The first one is the worst case regarding the magnetic field emitted. This occurs when all the switches are open; loops 1 and 2 are activated. To know the current density of this configuration, two current sources must be added as described in Fig. 15.

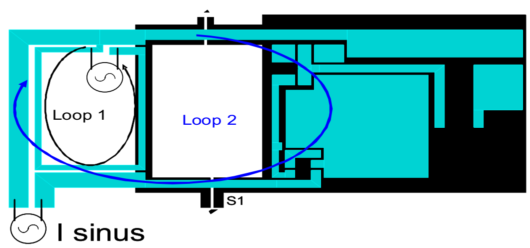

Fig. 15 Connection of the current sources in the worst case

The first source is determined by knowing the current in the printed conductors of the switching cell. This source generates loop 2. The second is determined by knowing the current in the printed conductors of loop 1 that is to say by knowing the current going through capacitor Ce when the layout is taken into account. Then, the map of current density can be extracted; it is shown in Fig. 16.

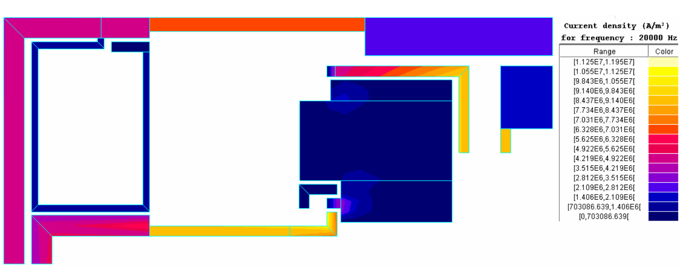

Fig. 16 Current density of the loops 1 and 2

For the switching cell, the influence of the width of the printed conductors appears clearly. The less the width, the greater the current density is.

The magnetic field is calculated at 8 cm above the structure and the result is shown in Fig 17.

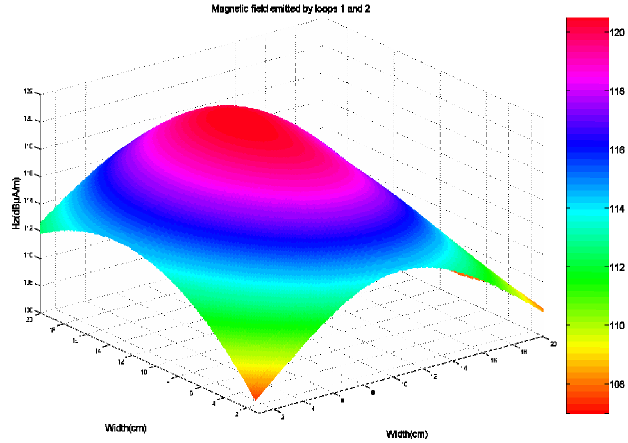

Fig. 17 Magnetic field emitted by loops 1 and 2

As expected, the field is more important at the centre of the switching cell. The comparison between the measurement and the model shows in Fig 18 that the two approaches are similar. The curve shows a cut of the 3D card of the modulus at 8 cm above the converter. Beyond 13 cm, the field measured is at the level of the noise. Between 0 and 12 cm, the field measured is those one along the switching cell.

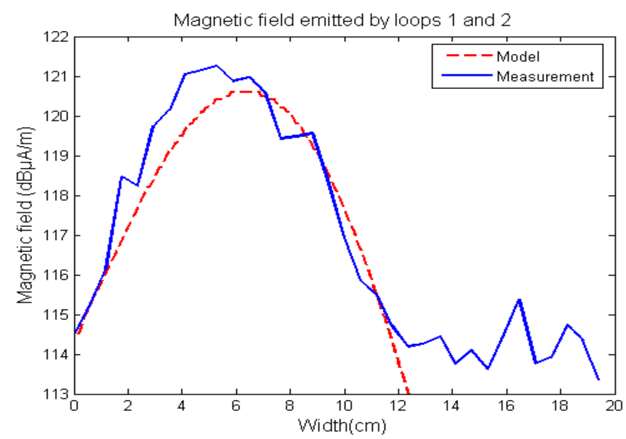

Fig. 18 Comparison between measurement and simulation

The results are good and show that the modeling method is effective. The magnetic near field measured and simulated are close. Beyond 13 cm, only some noise is measured which simulation cannot predict.

The second case treated is when all the switches are closed. Induced currents appear in the printed conductors at he back side of the PCB as illustrated in Fig 19.

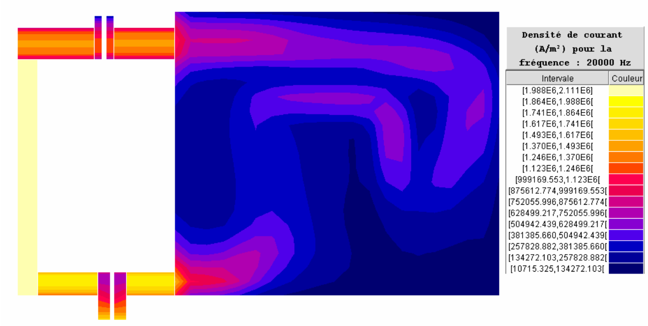

Fig. 19 Induced currents in the back-side loop

In this case, there is no influence of loop 1 anymore. Only loops 2 and 3 are activated. The calculation of the field emitted by loop 2 alone has shown that the maximum at the center of the switching cell is equal to 116 dBμA/m. This value has been confirmed by measurement. Measurements have also shown that this value is reduced by loop 3 to 111 dBμA/m. The result of the magnetic field calculation using the modeling method shows a maximum of 110.9dBμA/m and is illustrated in Fig 20.

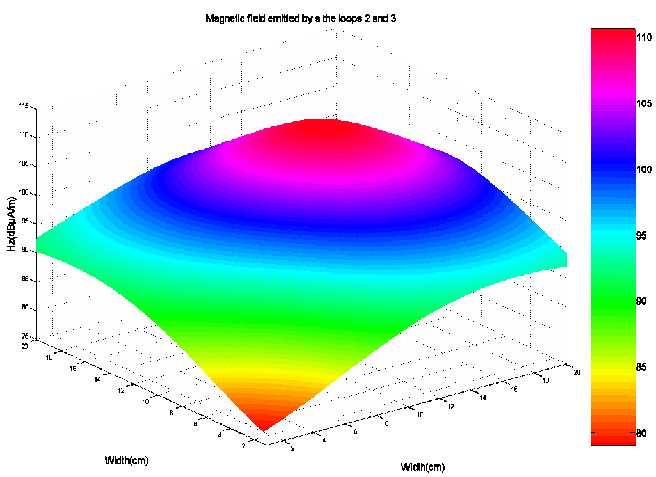

Fig. 20 Magnetic field emitted by loops 2 and 3

The field is clearly reduced at the centre of the switching cell where is localized the back-side loop.

The two cases have shown that measurements and modeling exhibit very similar results.

V. Conclusion

The objective of this study has been to demonstrate the effectiveness of our approach in order to predict the magnetic near field emitted by a static converter. In this way, the radiation of an "academic" buck chopper has been studied. Using static switches in order to control the current flowing in the structure, several loops have been created and their influence have been quantified by measurement and modeling. The method implemented, based on PEEC formulations has shown that structures with complex geometries could be modeled and their magnetic near field could be easily determined, this is the goal of our future works.

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