Proposal of a PHD topic

Contribution of embedding of magnetic components in PCB core

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The challenges of reducing greenhouse gas emissions and the scarcity of resources are at the heart of current social concerns. The French transport sector alone represents more than 30% of energy consumption and is the main emitter of greenhouse gases (30% of emissions in 2017). As in many other European countries, the process of energy transition has already been launched with, in particular, the banning of the sale of thermal cars from 2035 (Law n°2019-1428 of 24/12/2019). In this sector, power electronics play a key role because they manage the energy exchanges between the battery storage and the drive train. Although these electronics are very efficient, a reduction of the losses they generate remains an essential objective.

In order to increase the efficiency of static converters, designers are using more and more transistors made of large bandgap semiconductor materials, especially GaN. Their switching speed reduces the losses in the converter and their small surface area contributes to the reduction of parasitic currents [1]-[3]. However, the strong current variations that they generate during switching produce overvoltages when the switching mesh is even so slightly inductive. This phenomenon can be reduced by decoupling the DC input bus with a good quality capacitor located in very close distance from the transistors.

In a similar way, the fast variations of the output voltages of the converter induce common mode currents and propagation phenomena in the cables and interconnections between the converter and the load. Just like the decoupling of the input of the converter, the output of the converter must be decoupled from the load by an efficient inductance. The latter must keep its inductive aspect on frequencies ranging from DC to the equivalent frequency of the switching transient. Moreover, to limit the propagation phenomena, the latter must be located as close as possible to the switching cells. To do this, the integration of power functions is a good candidate.

To date, integration technologies allow to reduce the interconnection lengths between chips, thus limiting the inductive effects in the switching mesh, as shown in Figure 1. We propose to address the inductive output filter of switching cells by simultaneously integrating the active components and inductors in the core of the PCB [4]. Figure 2. shows examples of possible implementations. Here, the magnetic circuit is integrated in the insulating substrate of the PCB, the tracks allow the realization of the winding.

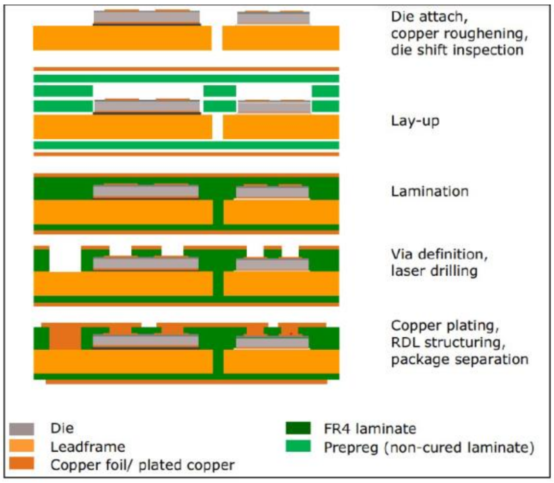

Figure 1 Active components embedding

Figure 2 PCB embedding Inductor

Initially, the PhD student will be in charge of characterizing these inductors in terms of electrical behavior (impedances, parasites, etc.), losses and aging of the components. In parallel, the implementation of multi-physics simulations will allow to understand the phenomena limiting the performances of the components.

With this knowledge, a second part of the work will be devoted to the improvement of the structures of buried magnetic components. One track, to limit the skin effects in the conductors, is to replace the large tracks by tracks reproducing a Litz wire. In addition, the PhD student will have to conduct characterization campaigns of magnetic materials. Indeed, the impact of the thermocompression cycle necessary to the realization of the PCB on the intrinsic characteristics of the material is currently completely unknown. If necessary, we will think about limiting the residual mechanical stresses during the annealing cycle.

Finally, the aging of these components must be characterized. To do this, controlled temperature rise and fall cycles will allow the acceleration of the aging of the components. We will have to define the protocol(s) of aging and we will have to define indicators of aging to specify the health of the component. Indeed, the damage phenomena of PCB integrated converters are currently not well known. Moreover, the components that we propose to realize occupy an important surface (tens of square centimeters) of the substrate compared to the switching cells. This raises questions about aging and electro-thermo-mechanical damage of integrated passive components.

This thesis is part of the ANR TECOCIP program, in which the Ampère, Laplace and Satie laboratories are partners. The 3Dphi platform, available in the LAPLACE laboratory (Toulouse), will facilitate the realizations envisaged in this thesis and will complete the fabrication tools available in the Satie laboratory. The PhD student will work in close collaboration with the 3Dphi platform and will visit it regularly.

Finally, in the framework of this ANR, another PhD student will be in charge of the development of PCB integrated converters. The aging of these stacks must also be studied simultaneously with the inductors. The PhD student recruited on this thesis will therefore also participate in the aging of active components.

Bibliographic reference

[1] A. R. Ekon, M. Petit, F. Costa, F. Bouvet, et E. Dupuy, « Impact of routing on the EMC behavior of a GaN HEMT-based full bridge DC-DC converter », in *2022 International Symposium on Electromagnetic Compatibility – EMC Europe*, sept. 2022, p. 415-420. doi: 10.1109/EMCEurope51680.2022.9900951.

[2] P. B. Derkacz, J.-L. Schanen, P.-O. Jeannin, P. J. Chrzan, P. Musznicki, et M. Petit, « EMI Mitigation of GaN Power Inverter Leg by Local Shielding Techniques », *IEEE Trans. Power Electron.*, vol. 37, nº 10, p. 11996-12004, oct. 2022, doi: 10.1109/TPEL.2022.3176943.

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[4] R. Caillaud, « Integration of a 3.3 kW, AC/DC bidirectional converter using printed circuit board embedding technology », These de doctorat, Lyon, 2019. Consulté le: 27 août 2022. [En ligne]. Disponible sur: http://www.theses.fr/2019LYSEI001

Summary:

The new technologies of large gap transistors are promising for static converters in terms of efficiency. Their implementation requires not only a particular packaging but also a quality decoupling of both the DC bus of the converter and the output from the load. This output decoupling must be done by a wide frequency band inductance which must be as close as possible to the output of the converters. Through this thesis topic, we want to develop a buried inductor technology. The latter will be integrated into the PCB substrate simultaneously with the active components. The PhD student will set up experimental protocols and simulations to understand the impact of the PCB burial of magnetic materials on their intrinsic behavior. In a second part, the PhD student will investigate the electrical behavior of the buried inductors and will try to optimize the topologies of the components. Finally, the reliability of the latter will be addressed through accelerated aging protocols. The doctoral student will also define the indicators of the aging of these components.