# Master project, 2021-2022

## — Virtual Prototyping of Planar Transformers: Adjustment of the leakage inductance for HF isolated DC/DC converter —

**Supervisor:** Dr Xavier Margueron, xavier.margueron@centralelille.fr, L2EP – Centrale Lille Institut
Dr Reda Bakri, reda.bakri@centralelille.fr, L2EP – Centrale Lille Institut
Dr Frédéric Gillon, Frederic.gillon@centralelille.fr, L2EP – Centrale Lille Institut

### Context

Magnetic components (transformers, inductors) play an essential role in power electronic (PE) converters. With improvements made on High Frequency (HF) active components with new materials (SiC, GaN), HF passive components have to be upgraded also to be more efficient and more compact.
Planar components are prevalent solution for the integration of power magnetic devices. Indeed, these components exhibit low profile, high power density and high reproducibility compared to other types of HF magnetic components [1, 2]. They can obviously be found on embedded systems (automotive, avionics) for example.
The leakage inductance of such component is a topic of huge interest. Indeed, due to their low profile, their leakage inductance value is usually supposed to be low [3] while in PE converters high value and controlled/specific ones can be required for soft-switching converters [4] and other specific DC/DC converters.

### Objective

The goal of this work is to use models to tune the leakage of a component as a desired value. Numerous analytical modeling can be found in the literature [5-12]. In [8] A review is performed to compare some models in terms of accuracy and computational efforts. For some years, analytical formulations have been developed at the L2EP to calculate the leakage inductance of planar components [10-12]. Such model enables to compute, before conception of the component, the leakage value for any kind of planar winding with and without leakage layers (also called magnetic shunt). More recently, magnetic equivalent circuit (MEC) modeling have been applied to a HF transformer to estimate the minimal and maximal value of a design, with topology optimization [13].
The present work deals with the further step: Based on these analytical or semi-analytical models and optimization process, how conductors can be placed in a transformer window to ensure a specific value of leakage inductance?
Such inverse-problem is of major interest for PE designers and manufacturers. Indeed, if the leakage is well controlled, expensive prototypes could be avoided or, at least, further reduced. Moreover, a well-tuned leakage inductance can also avoid the use of a supplementary inductor if the leakage value is not sufficient.

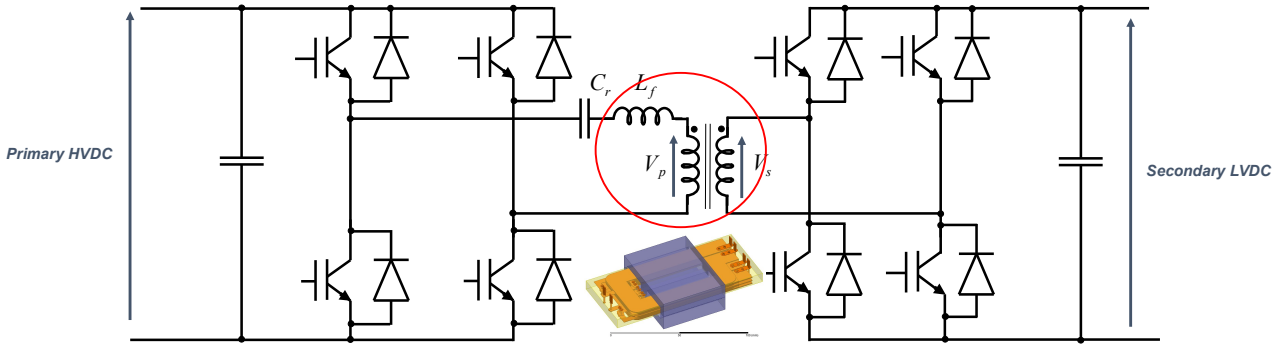


***Figure 1: Isolated DC/DC converter with planar transformer***


*Figure 2: 2.5kW planar transformer*

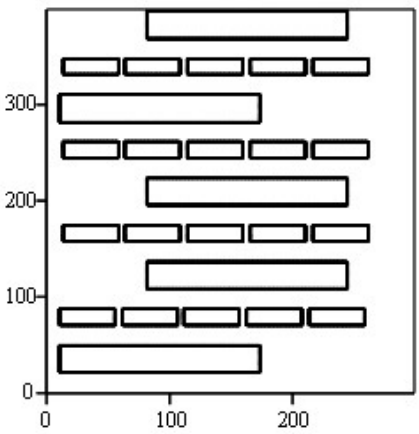


*Figure 3: Example of conductors' placement inside a transformer window for the tuning of the leakage inductance*

## Work steps

This work is suitable with master thesis: bibliographical project, scientific project and master thesis. The work will be divided in some steps:

1. Bibliographical review on HF planar transformer and their use in isolated DC/DC converters.
2. Design of a planar transformer based on a converter specification.
3. Analytical calculation of leakage inductance value. Comparison of different models.
4. Coupling between models and optimization tools to tune a specific value, acting on conductors' position in the transformer window.
5. Estimation of the transformer losses (copper and core ones) for the obtained configurations.
6. Development of prototypes based on ferrite cores and Printed Circuit Boards (PCB).
7. Small signal characterization of the prototypes.
8. Validation inside a HF DC/DC power converter.

## Keywords

Planar magnetics, Power electronics, Modeling, Leakage inductance, Optimization, MEC

## Localization

The work will take place at the L2EP laboratory in ESPRIT building (Campus for Science – Villeneuve d'Ascq).

## Skills

General knowledge on power electronics, MATLAB programming, experimental skills

## References

[1] Z. Ouyang, M. A. E. Andersen, "Overview of Planar Magnetic Technology Fundamental Properties," *IEEE Trans. Power Electron.*, vol.29, no.9, pp.4888-4900, Sep 2014.
[2] J. S. Ngoua Teu Magambo *et al*., "Planar Magnetic Components in More Electric Aircraft: Review of Technology and Key Parameters for DC–DC Power Electronic Converter," in *IEEE Transactions on Transportation Electrification*, vol. 3, no. 4, pp. 831-842, Dec. 2017
[3] B.W. Carsten, "The low leakage inductance of planar transformers; fact or myth?," *Proc. Sixteenth Annual IEEE Applied Power Electronics Conference and Exposition (APEC)*, vol.2, pp.1184-1188, 2001.
[4] J. M. Cho, B. J. Byen, Y. J. Lee, D.-H. Han, H,-S Kho and G.-H. Choe, "Design of leakage inductance in resonant DC-DC converter for electric vehicle charger," *IEEE Trans. Magn*, vol. 48, no. 11, pp. 4417-4420, Nov. 2012.
[5] P. L. Dowell, "Effects of eddy currents in transformer windings", *Proc. IEE*, vol. 113, no. 8, Aug. 1966.
[6] Z. Ouyang, J. Zhang and W. G. Hurley, "Calculation of leakage inductance for high-frequency transformers," *IEEE Trans. Power Electron*, vol. 30, no. 10, pp. 5769-5775, Oct. 2015.
[7] Ziwei Ouyang, William Gerard Hurley, Michael A.E. Andersen, "Improved Analysis and Modeling of Leakage Inductance for Planar Transformers," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vo l. 7, no. 4, pp. 2225-2231, 2019.
[8] R. Schlesinger and J. Biela, "Comparison of Analytical Models of Transformer Leakage Inductance: Accuracy vs. Computational Effort," IEEE Trans. on Power Electronics, vol. 36, no. 1, pp. 146–156, 2021
[9] R. Schlesinger and J. Biela, "Leakage Inductance Modelling of Transformers: Accurate and Fast Models to Scale the Leakage Inductance Per Unit Length," *in Proc. of European Conf. on Power Electronics and Applications (EPE ECCE Europe)*, Lyon, 2020.

[10] X. Margueron, J. Keradec and D. Magot, "Analytical Calculation of Static Leakage Inductances of HF Transformers Using PEEC Formulas," in *IEEE Transactions on Industry Applications*, vol. 43, no. 4, pp. 884-892, July-aug. 2007.
[11] X. Margueron, A. Besri, P-O. Jeannin, J-P. Keradec and G. Parent, "Complete Analytical Calculation of Static Leakage Parameters: A step toward HF Transformer Optimization," *IEEE Trans. on Ind. Appl.*, vol. 46, No. 3, May/June 2010, pp.1055-1063.
[12] W. Tan, X. Margueron, L. Taylor, N. Idir, "Leakage Inductance Analytical Calculation for Planar Components with Leakage Layers", *IEEE Transactions on Power Electronics*, in press
[13] O. Bouchakour, V. Martin, F. Gillon, X. Margueron, "Topology optimization for the tuning of HF transformer leakage inductance" *2020 16th International Workshop on Optimization and Inverse Problems in Electromagnetism (OIPE 2020)*, Szczecin, Poland, September 6-8 2021.