

# INVESTIGATIONS OF HIGH FREQUENCY PLANAR POWER INTEGRATED MAGNETIC CIRCUITS VIA FINITE ELEMENT METHOD

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**Abstract** – High frequency (HF) magnetic systems are often used in different sorts of devices due to their small construction dimension and high power handling capacity. This paper introduces a new type of a flat structured high power planar integrated magnetic circuit (IMC) developed for a wide range of applications such as DC/DC converters. The paper investigates the differences of a flat and a ‘Top-Up’ IMC version via FEM, introduces the concept of this special combination of inductor, capacitor and HF transformer, and visualizes initial investigations in the field of these kinds of HF high power density magnetic devices.

## I. INTRODUCTION

High frequencies for high power DC/DC converters are essential and necessary to achieve a higher efficiency, and due to less core material usage cost savings can be realised. Hence, the trend is to integrate passive magnetic devices into one single device such as the integration of electromagnetic passive components in DC/DC converters [1-2]. Many techniques for the integration of passive magnetics also include the use of the parasitic capacitances and leakage inductances of the transformer [3]. However, to avoid unwanted impact and more usage variability with one IMC device, whereas it is possible to change frequency and load without changing the values of the passive integrated devices, the inductor, capacitors and transformer are not dependent from each other. The operating frequency range of the 1.5 kW IMCs is between 100kHz to 1MHz, designed for the step-down operation from 400V to 50V, and the normal operational temperature is approximately 80°C and should not exceed 110 °C.

## II. TECHNICAL INFORMATION AND DESIGN CONSIDERATIONS

Two different configurations are employed for the planar integrated magnetic circuit, with F47 core material: The top-up version (Fig. 1), where the inductor for the resonant tank is on the top of a HF faraday-shielded planar transformer, and a parallel flat version of an IMC (Fig.2), where the inductor and capacitances are on the same height level as the transformer. This flat configuration reduces the production costs due to the fact that all devices can be attached to the single PCB layers instead of the top-up configuration, which requires the production of the transformer PCB layers and additional PCB layers for the inductor and capacitor. One of the advantages of the flat version against the top-up IMC is the larger cooling surface, which allows an operation with thermal convection without a heat sink.

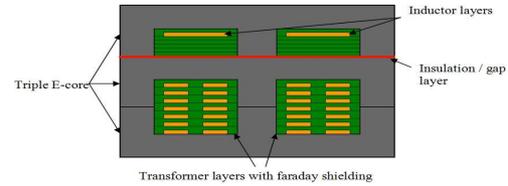


Fig.1: Top-up IMC configuration

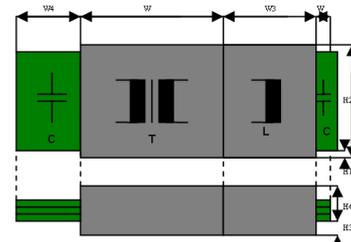


Fig.2: Flat IMC configuration (from left to right: C for rectifier, HF planar transformer part, inductor, and capacitor for the resonance tank)

## III. FEM SIMULATION AND MEASUREMENT RESULTS

The FEM simulations for the two versions of the IMC are conducted with COMSOL Multiphysics, which allows investigating, if the passive devices and the transformer are influencing each other and if a normal operation is employable.

For the top-up IMC version it can be seen, that the shared core in the upper part of the transformer core is highly stressed (Fig.3). The relationship in equation (1), where N is the number of turns, demonstrates that if the effective magnetic area  $A_e$  decreases, the magnetic flux density in the shared core area rises.

$$B = \frac{V_{rms}}{\sqrt{2} * \pi * N * A_e * f} \quad (1)$$

This effect also increases the operating temperature and impacts on the efficiency. Besides, the core can be easily saturated, if the power range is not low enough or the cross section of the transformer core in this area is not adjusted for this application. Finally, the system must be cross-connected; otherwise the magnetic flux will cancel each other (Fig.4).



Fig.3: FEM simulation: Constructive interference of magnetic field (arrows), magnetic flux density (colour) top-up version (close to core saturation)

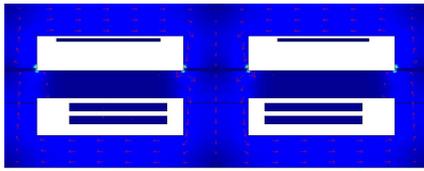


Fig.4: FEM simulation: Destructive interference of magnetic field (arrows), magnetic flux density (colour) top-up version

The FEM simulation of the IMC flat version shows, that the flux of the transformer has no or only a very small impact of the magnetic flux of the inductor cores or vice versa (Fig.5).

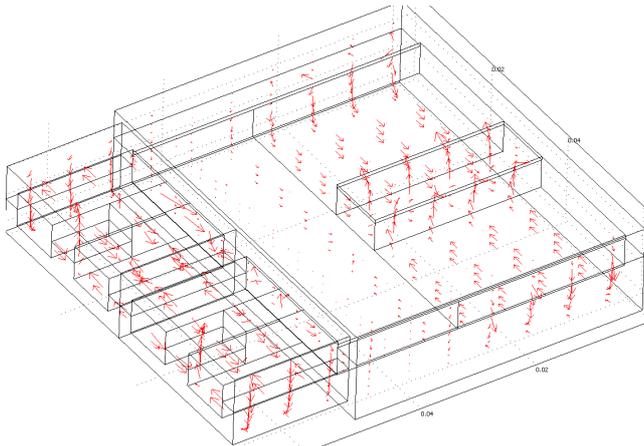
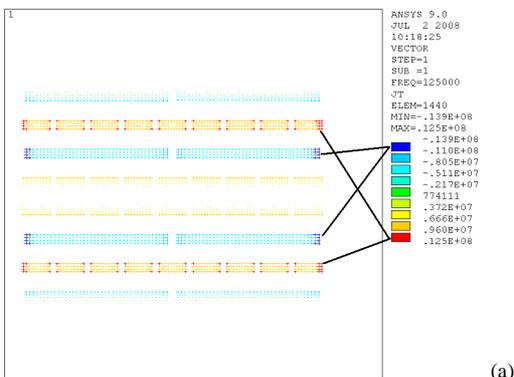


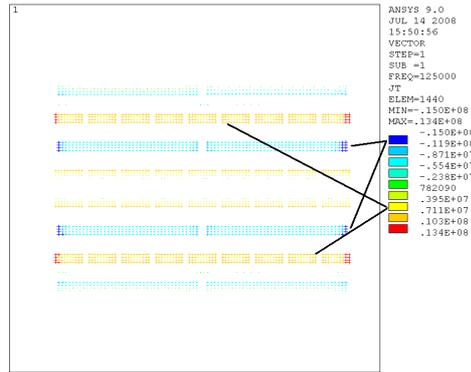
Fig.5: 3D-FEM simulation: Flat IMC (transformer core left, inductor cores right, red arrows: Magnetic flux)

#### IV. FURTHER IMPROVEMENTS IN INTEGRATED MAGNETICS

Although the flat IMC showed good results in the magnetic flux simulations and the devices only disturb each other slightly, parasitic inter-winding capacitances and other coupling factors as unwanted leakage inductance can cause physical parasitic effects such as skin effects and proximity effects. The efficiency of the circuit can be risen by inserting a faraday shield inside the IMC. The shielding method is a very successful technique to reduce eddy currents for coaxial transformers [4]. The FEM simulation of the planar transformer visualizes that the eddy current, induced from the one winding to the other, is smaller with the inserted Faraday shield (Fig.6).



(a)



(b)

Fig.6 (a) Eddy current distribution without shielding, (b) Eddy current distribution with shielding

In figure 7 it can be seen, that after inserting the shield, the coupling capacitances are splitting off to smaller capacitances, which are directly connected to the ground. The gap for the capacitances between the primary and secondary windings and the shield is smaller than the gap between the two windings without the shielding. As a result, the value of the coupling capacitance drops down, if the shield is connected to the ground and this decreases the parasitic effects caused by the inter-winding capacitances.

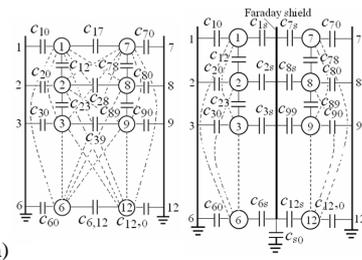


Fig.7 The parasitic capacitance network model of HF transformer for HF noise analysis, (a) without Faraday shield, (b) with Faraday shield.

#### V. CONCLUSION

Two versions of integrated magnetic circuits have been discussed and the FEM investigations visualized the advantages of the parallel flat structure of the IMC. The benefits of the parallel structure are the more affordable and faster one-step production of the IMC, which includes the transformer, inductor and the capacitances for the primary and secondary side on single PCB layers. Finally, the first investigations of inserting a faraday shield were conducted and visualized in FEM simulations.

#### REFERENCES

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