Optimum design of high current power planar inductors with flat winding

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With deep sadness, the first author, Todor Filchev would like to express his gratitude to Colin Day who passed away recently. He was the founder and the Director (Vice President) of HiMag Planar Magnetics.

Abstract

High current power planar inductor as a key component of high-power Switch Mode Power Supply (SMPS) is presented in the paper. The main advantages of the planar inductor over a conventional wire wound component are discussed. A design process including detailed fringing coefficients for different shape E and ER planar cores is introduced. FEM models with ANSYS®/Maxwell® are investigated, and the results are presented.

1 Introduction

1.1 Planar magnetics

In a planar design, the windings are made using printed circuit boards, copper lead frames, litz wire or flat helical wires. Planar inductors have the main following advantages:

- Efficient cooling - larger surface for a heat sink or cold plate attached; highly efficient heat dissipation and thermal management [1,2].
- Configurations for Switch Mode Power Supply (SMPS) topologies with IGBTs and MOSFETs switches as well as new wide band gap devices - Silicon Carbide (SiC) and Gallium Nitride (GaN) [1].
- Unmatched repeatability: all windings are pre - tooled [2,3,4]

Power planar DC inductors with flat wire are discussed in this paper.

1.2 Proposed Design Flowcharts

The overall design procedure is a combination of analytical design and computer design which is illustrated through the flowchart shown in Fig.1 [5] The sequence of step illustrated through the flowchart enables optimisation of the inductor design.

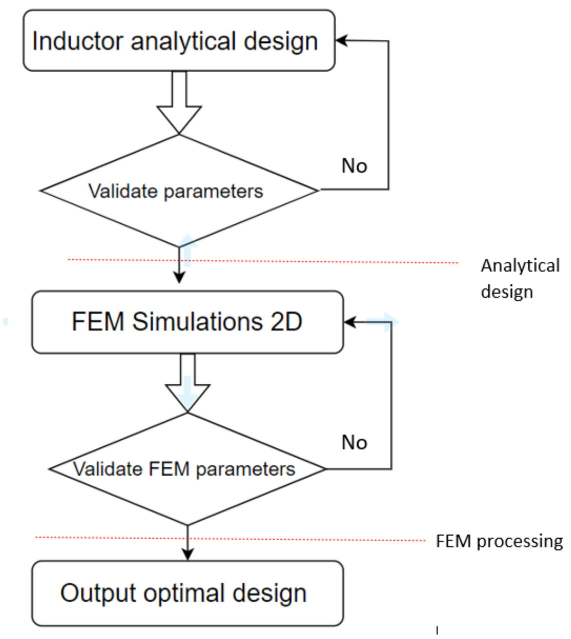


Fig. 1 Optimization flowchart

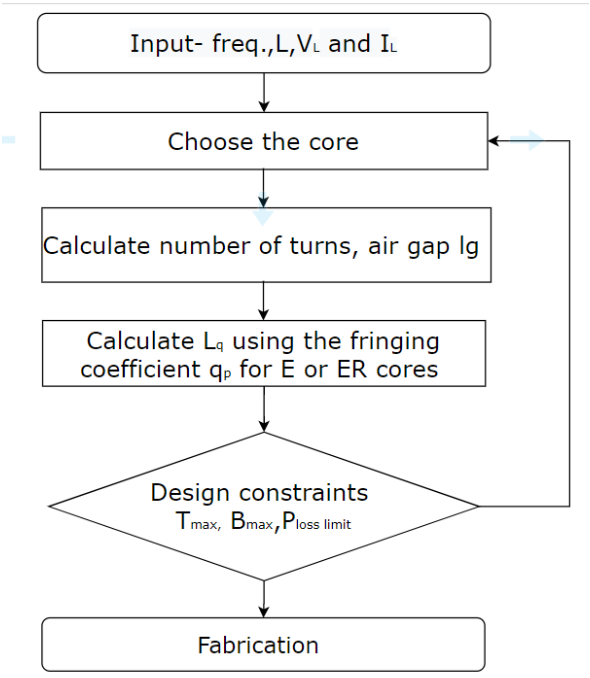


Fig. 2 Analytical design flowchart for planar flat wire Inductors.

1.3 Design considerations of a planar inductor

The most widely available and accessible planar ferrite cores are E and ER core [Fig 3], Planar E cores have a very similar effective area as their conventional equivalents, but their lower profile provides a reduced volume of ferrite and an improved thermal management. [6] Planar E cores have larger window area compared to ER cores The window width of ER cores is much narrower than that for a planar E core, resulting in fewer or narrower tracks of flat copper. Therefore, E cores are a better choice for the high current planar inductors. However, the round center leg of ER cores enables the windings to be circular, which results in lower winding DC losses with a reduced inductor length.[6]

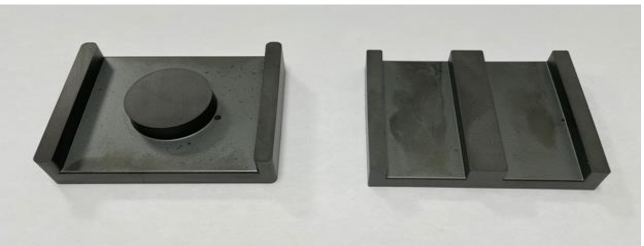


Fig. 3 Ferrites ER64 core and E64 core.

The design considerations are the thickness of the flat is smaller than the skin depth and the windings are in a 'symmetrical' position (Fig.4 and Fig.5).

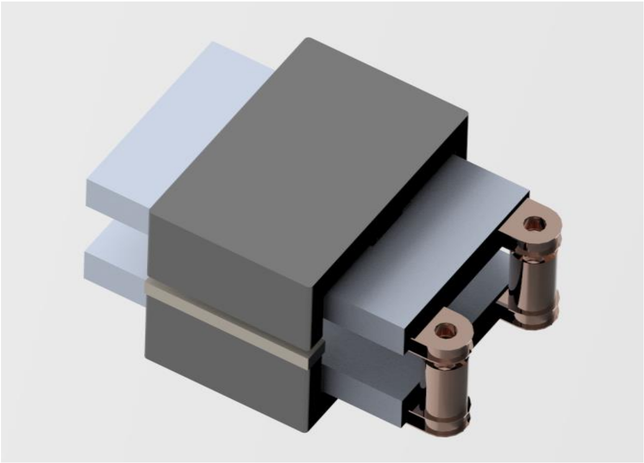


Fig. 4 Planar inductor with EE cores.

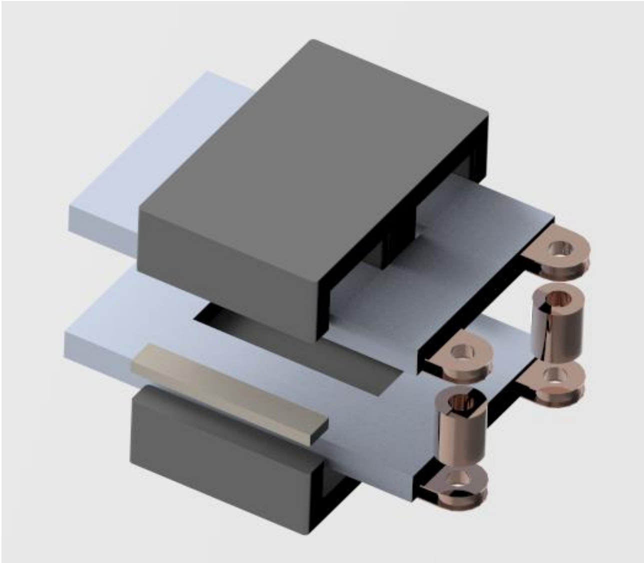


Fig. 5 Planar inductor structure with two parallel windings.

2 Simulation and analytical results

2.1 Simulation results

A 2D physical model simulation results obtained from the Ansys/Maxwell® are used to illustrate and visualize the fringing flux of EE and EI cores (Fig 6). The two groups and four groups' windings shown on Fig. 6 (a) and Fig. 6 (b) are subject to same fringing flux. Each parallel windings is located at equivalent distance at equal distance from the source of the magnetic field [7].

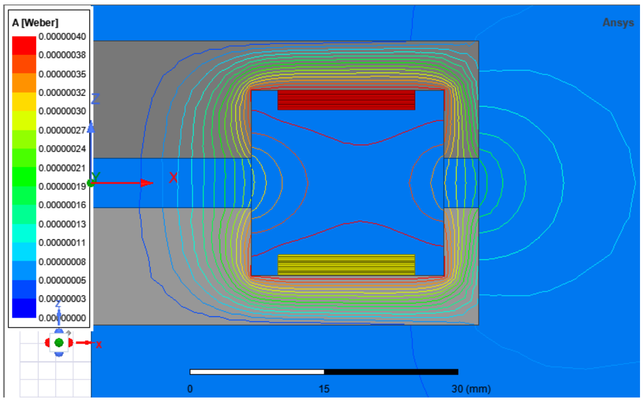


Fig.6 (a) Ansys Multiphysics FEM model of gapped inductors - axisymmetric representation, an EE cores inductor with two parallel windings

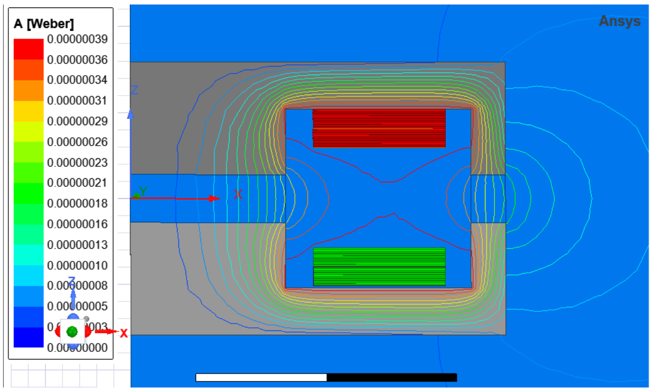


Fig. 6 (b) An EE cores inductor with thicker coper of the two parallel windings

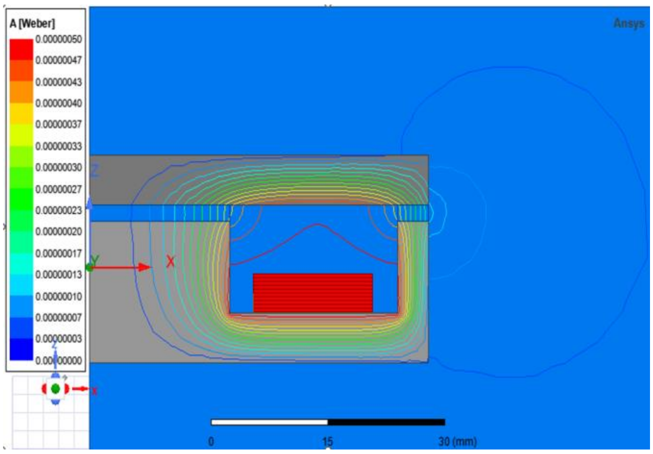


Fig.6 (c) An EI cores inductor with one winding

The distance to the air gap is presented, avoiding too much fringing, FEM model (Fig 6).

2.2 Analytical approximation

The effect of fringing flux has been investigated in several papers [8,9]. An improved and accurate method is suggested in [9]. We discuss a simplified method with a corrective coefficient. An analytical approximation for calculating fringing permeance in gaped inductors is presented. The fringing coefficients [9] are compared and tuned by FEM Ansys/Multiphysics program (Fig 6).

The equation to calculate the inductance [9] using tuning coefficient for round and rectangular cross section and the new coefficient q_p (planar) is adapted for E and ER planar cores:

$$L_q = LX_f\,, \quad X_f = 1 + \frac{q_p l_g}{\sqrt{A_g}} ln\left(\frac{2w}{l_g}\right) \qquad (1)$$

Where,

q_p=1.15 for rectangular E planar cores;
q_p= 0.95 round ER planar cores;
L_q: inductance corrected for fringing;
X_f: fringing factor;
w: total height of the winding; lg: air gap length, A_g: surface of the air gap.

The adapted equation with fringing coefficient q_p does make a difference between air gap with rectangular and round cross-section Fig.3 and it is limited to small gap Fig.6(c).

Fig.7(a) Prototypes of the inductors with flat wire;- A planar inductor with flat coper and ceramic blocks.

Inductors with flat copper enable good contact with a heatsink or cold plate through the ceramic blocks

Fig.7 (a). This leads to very good thermal performance [11].

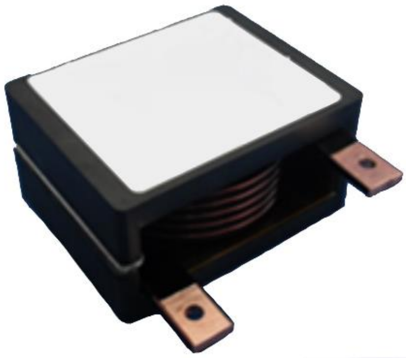
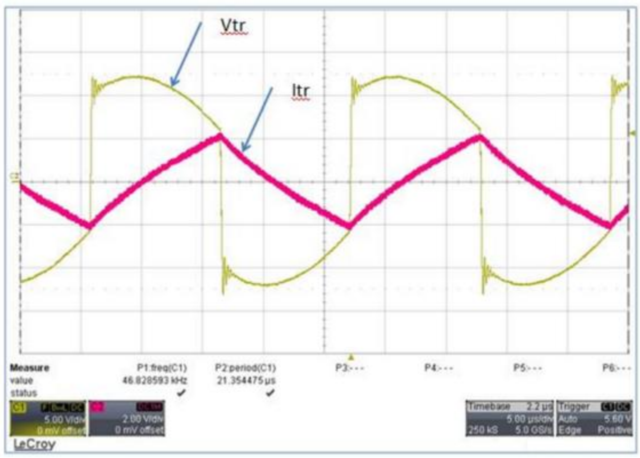


Fig.7(b) A planar inductor with a helical coil

3 Experimental results

The voltages V_{tr} have been measured with a differential voltage probe and the current I_{tr} has been measured with 'toroid' current probe [9].



(a)

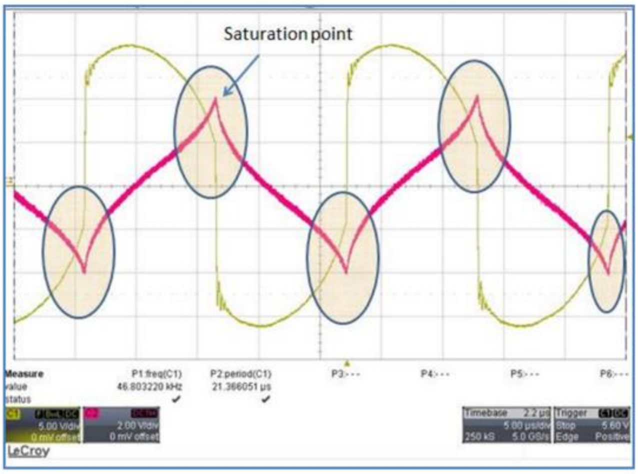


Fig.8 Experimental waveforms (a) Output voltage and current (b) Output voltage, current and saturation points.

As the voltage increases, a point is reached where the inductor is saturated Fig.8(b).

Disadvantage of planar inductors is parasitic capacitance, more specifically self-capacitance [10]. There are methods applied by leading companies to decrease this parasitic capacitance up to 4-5 times by using specific insulation materials and special flat copper construction [12,13].

Fig.9 Setup for the 15uH inductor test measurement with Ed-k choke tester.

The high current inductor which is investigated with a special choke tester Ed-k® is shown in Fig.9.

4 Conclusion

In the present paper an improved process for design of planar inductors with flat copper taking into account the shape of the ferrite cores is suggested. The coefficient *q* used for conventional inductors is used for planar inductors and it is denoted as q_p in the present publication. This coefficient enables using 2D FEM models instead of 3D models which is very time consuming to design without decreasing the accuracy.

Practical measurements using state of the art equipment enable to check analytical and simulation results from the presented methodology.

5 References

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