The Benefits of Planar Magnetics in HF Power Conversion

Planar Magnetics (PM): The Technology that Meets the Challenges of HF Switch and Resonant Mode Power Conversion

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I. Introduction

The ever lasting quest for high power density solutions to power conversion systems, has recently yielded intriguing new engineering ideas and conversion topologies. Most if not all of these, hinge on the theoretical prediction that the size of magnetic components and capacitors should decrease as the conversion frequency is increased. Unfortunately, as many designers have learned the hard way, an increase in switching frequency, by itself, will not necessarily lead to higher power density if the conversion efficiency is to be maintained or improved. The benefits of high frequency conversion can be materialized, without compromising losses, only if a multitude of objectives are met. Among theses:

1. Reduction of switching losses
2. Improving the current handling of filter capacitors
3. Combating copper losses due to the 'skin effect'
4. Reducing core losses
4. Improving heat conduction

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Most of the problems encountered, as the switching frequency is increased, are related to the magnetic components: transformers and inductors . Unless the copper and core losses are harnessed, the net size reduction, as the switching frequency is boosted, may be marginal.

The objective of this article is to identify the major obstacles that have to be overcome in the design of magnetic components for modern High Switching Frequency (HSF) conversion systems. As will be shown, the technology of Planar Magnetics (PM) offers cost effective solutions to HSF power conversion. Furthermore a cursory cost analysis suggest that planar magnetics are viable alternatives even at switching frequencies as low as 20kHz - especially in large production quantities.

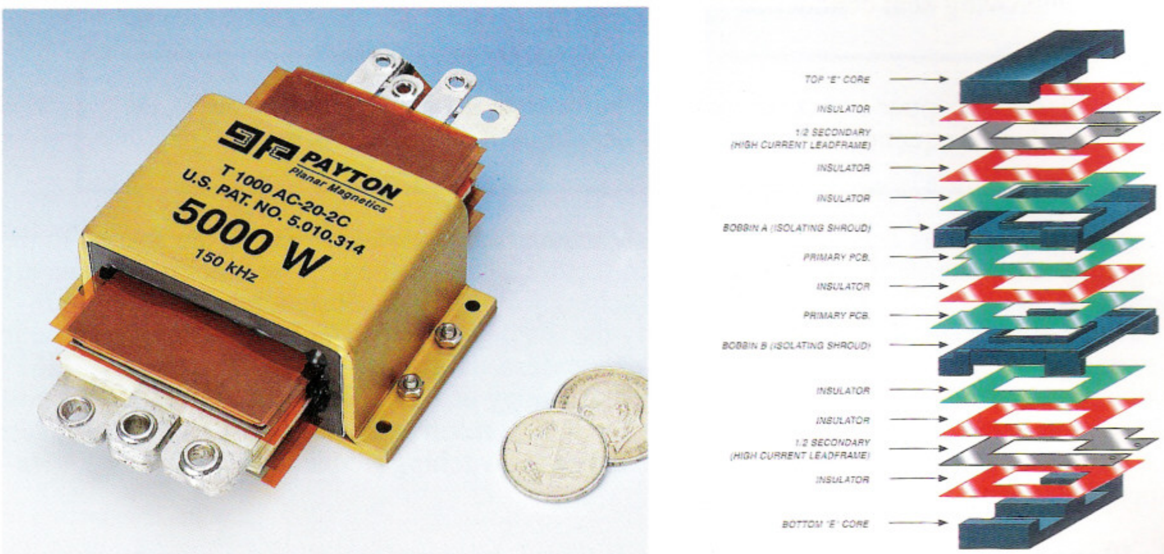
II. Planar Magnetics (PM) Versus Classical Magnetics

The main differences between Planar Magnetics (PM) and conventional magnetic components are related to the geometry of the cores and the structure of the windings (Ref. 1, 6). In classical magnetics, the windings are made of solid or LITZE wires. In PM, (Fig. 1) the windings are made from pre-tooled parts: thin copper foils which are manufactured as flat conductors on Printed Circuit Boards (PCB) or self supported "Lead frames" (LF). These parts (PCB & LF) with precisely defined winding positions, make it possible to predict with high accuracy the geometry of PM magnetic parts and electrical specifications of planar transformers and inductors.

Another major difference between the classical and PM magnetics is the ratio of ferrite to copper volumes. A PM device will typically comprise of a core with a larger cross section area but the windings will normally have smaller number of turns. This tradeoff is possible since the magnetic flux density (B) of a magnetic material is a function of the product (n A_e));

$$B = \frac{e\ K_d}{n\ A_e} \qquad (1)$$

where:
B =magnetic flux density
n = number of turns
A_e = effective core cross section area
e = excitation; V-s (for transformers) or A-H (for inductors)
K_d = dimensional constant



(a) (b)

Fig. 1. (a) Picture of Planar Magnetics (PM) transformer.
(b) Exploded view of a Planar Magnetics (PM) transformer.

That is, an increase in cross section area allows a proportional decrease in the number of turns. Furthermore, for both transformer and inductors the required ' area product" (A_p) is proportional to the power flowing through the magnetic device:

$$A_p = (A_w \cdot A_e) ª K_e \; E \qquad (2)$$

where:

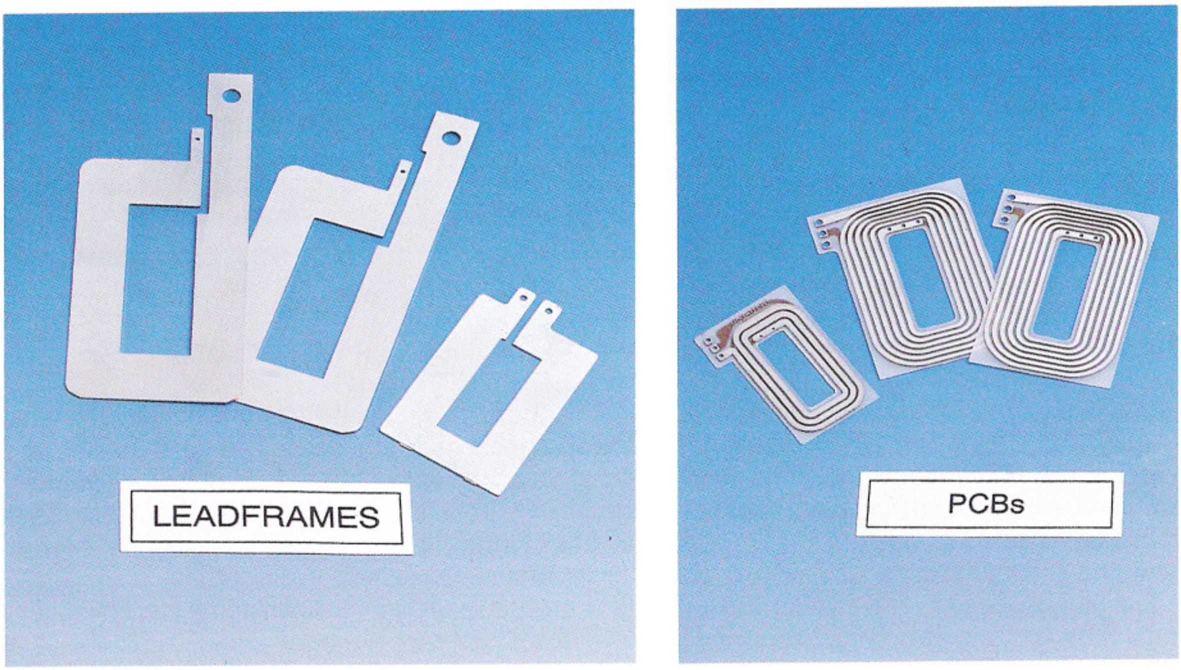
A_p = area product
A_e= effective core cross section area
A_w = winding window area
E= energy handled by the magnetic device
K_e = constant

In planar magnetics,the ratio between the 'effective core cross section' and 'winding window area' (A_w /A_e) is smaller than the ratio in classical core structures (Ref. 2). This geometry implies a smaller number of turns which in turn is highly compatible with technology of foil windings ('lead frames' or PCB).

III. Winding Realization in PM

Two winding structures are employed in PM: 'Lead frame' and PCB windings. The 'lead frame' (Fig, 2(a)) are self supported foil conductors which are shaped to fit the core as a single turn. It is designed to carry heavy currents per the application. It is therefore suitable for low voltage high current applications and can be used as a single or multiple layer winding. The PCB approach (Fig. 2(b)) is more suitable for a high voltage low current winding and can also be applied as a single or multiple layer winding.
The technology of foil conductors applied in PM has many direct and indirect advantages especially in high switching frequency applications.
Some of the advantages are related to copper loss while other are related to magnetic properties of the devices.

Copper losses. A major source of loss at high switching frequency is due to the uneven current distribution in current carrying conductors. Consequently, the 'AC resistance' could be appreciably higher than the 'DC resistance' . The deviation is due to two major effects: the skin effect' and 'proximity effect'. Both are caused, in the final analysis, by the interaction of the electrical current and the magnetic fields associated by it. The 'skin effect' reflects the influence of the magnetic field of a current carrying conductor on itself. The 'proximity effect' is due to electromagnetic interaction between two neighboring conductors. Both will push the current toward the surfaced and hence reduce the effective cross section of round inductors. The foil inductors technology, applied in PM, helps to alleviate these problem by realizing conductors with large surface area as compared to the width.
Leakage inductance. Leakage inductance represents the coupling imperfection between primary and secondary windings in transformers. In many applications (e.g. Flyback converters) ,the energy stored in this uncoupled inductor is lost, reducing thereby the overall efficiency. The remedy to this problem is a reduction of the distance between the primary and secondary windings. Hence, one would expect that the reduced number of turns and the foil structure of the windings in PM will help to minimize the leakage inductance. Indeed, PM transformers will have, in some cases, up to ten fold lower leakage than classical transformers.



(a) (b)

Fig. 2 ' Lead Frame ' (a) and PCB winding (b)

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IV. Core Losses

Core losses of magnetic material are mainly due to eddy currents and hysterisis losses. For ferrites and powder cores, which are the economical solutions in modern switch and resonant mode power conversion systems, the eddy losses are normally negligible small. This is due to the fact that these magnetic materials exhibit a high volume resistivity. The hysterisis losses per unit volume (P_{hys}) are found to be a non-linear function of the magnetic flux swing (DB) and switching frequency (f_s) (ref. 4, 5):

$$P_{hys} = K_c (DB)^m (f_s)^n \quad (3)$$

where:
P_{hys} =hysterisis losses per unit volume
DB = magnetic flux density swing
f_s = switching frequency
m = a constant in the range 2...3
n = a constant in the range 1...2
K_c = core loss constant

The conventional interpretation of this relationship is that as the frequency is increased the magnetic flux swing (DB) must be reduced to keep the same loss level. The reduction of DB calls for an increased cross section (A_e) if the same number of turns are to be maintained (equation 1). On the other hand, an increase of (A_e) implies a larger core volume (V_o) which will increase the total core loss (P_{hys} is defined per unit volume). One would therefore prefer cores which exhibit a large cross section area but a relatively small volume. In PM, the ratio of effective cross section to core volume (A_e/V_o) is the largest (as compared to most conventional cores, Ref. 2), making it advantageous in high switching frequency applications.

V. Heat Dissipation

Thermal conduction between the 'hot spot' of the magnetic component will eventually determine the useful power level of the device. Poor thermal conduction will cause unsafe temperature rise and eventually a failure. In PM, the geometry leads to short thermal paths and is characterized by large surface area which helps to dissipate the heat. Consequently, PM designs are more economical since they allow a relatively higher power handling as compared to classical magnetics. The power handling can be enhanced by choosing high temperature electrical isolation material and by applying heat sinks. The large surface area of PM can be conveniently and efficiently be connected to large surfaces with or without a fan. All these can appreciably increase the power density of PM transformers.

VI. Availability.

The idea of PM magnetics and foil windings is not new and the benefits that it can be offered have long been appreciated . However, application of this technology in production lines has been hampered till now due to the lack of commercial availability of PM devices. This is now changing. Multisource Technology Co.,(Boston, USA) and Payton Industries Ltd. (Rishon-Lezion, Israel) are now offering a line of PM products covering the range of few watts to 20 kW and a frequency range of 20kHz to 1MHz. Considering the many benefits of PM, this product availability is bound to convert the PM technology to a viable and economical alternative in many designs.

Planar Magnetics could be beneficial and cost effective in the 20kHz to 1MHz range of conversion frequencies - especially in large production quantities.

VII. Summary of PM Benefits

Advantage	Comments
High power density	Up to 3 times as compared to conventional transformers
High current capability	Up to 200A per winding layer
Large power capacity	Up to 20kW per single unit
High Efficiency	Up to 98% without volume increase
Good thermal conduction	Short thermal path, lower temperature rise
Good Heat Dissipation	By attaching to chassis or heat sink
Low Profile	Suitable for Telecom applications
Low leakage inductance	About 0.2% of primary inductance
High parameter repeatability	Fixed, pre-tooled winding structure
Low EMI emission	Efficient core shielding
Large operating frequency range	From about 20kHz to 1MHz
Availability	Available as samples and in production quantities

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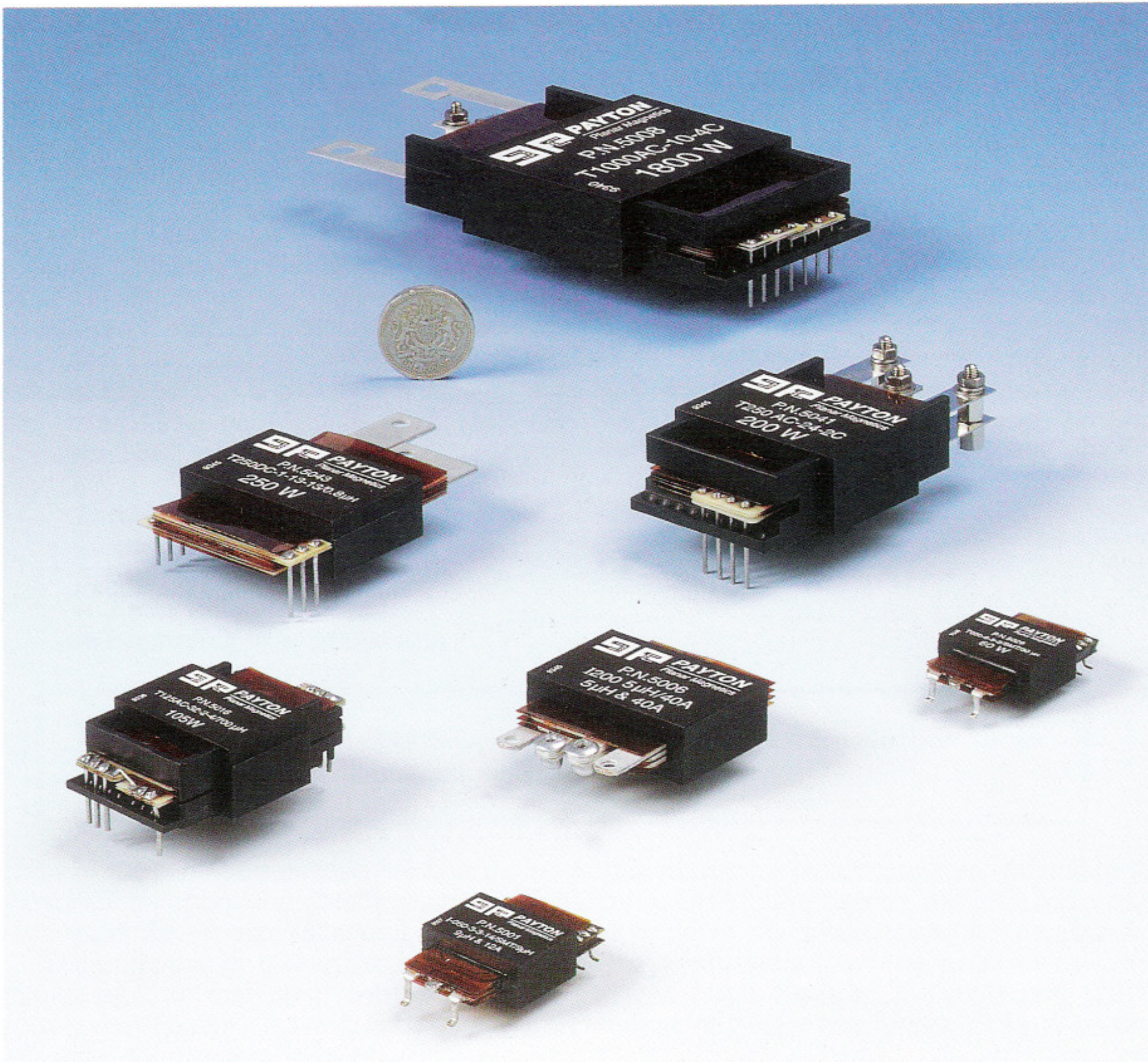
PAYTON
Planar Magnetics
P.N.5008
T1000AC-10-4C
1800 W
PAYTON
Planar Magnetics
P.N.5041
T250 AC-24-2C
200 W
PAYTON
Planar Magnetics
P.N.5043
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P.N.5016
105W
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Planar Magnetics
P.N.5006
I200 5μH/40A
5μH & 40A
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60 W
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