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Planar Power Magnetics

Cost-Effective, Low-Profile Transformer and Inductor Designs

By Ed Bloom, e/j BLOOM associates Inc

This is the second of two articles on the topic of planar magnetics. In this final part, a general overview of the design of planar magnetic components is presented, along with a look at a new multi-chambered planar integrated magnetic construction concept.

Power magnetic components continue to be most expensive and space-consuming parts in the majority of power processing systems today. For the most part, these parts are usually custom-designed, requiring highly labor-intensive manufacturing processes. Recently, new and more efficient packaging methods have been developed for these components, which involves the use of low-profile magnetic core structures and printed-circuit-board (PCB) style windings in lieu of magnet wires and mounting bobbins. Such components are classified as planar in construction because of the "flat" character of their cores and their windings.

FIGURE 1
Planar Magnetics Assemblies
Upper Photo => SMT units courtesy of Pulse Engineering Inc.
Lower Photo => HWT™ Inductors courtesy of the Schott Corporation

Figure 1 contains two photos of two planar magnetic designs being produced today by Pulse Engineering and the Schott Corp. In the upper photo in this figure, these two miniature parts use low-profile SMT-style PQ ferrite cores with PCB windings. In the lower photo, flat PQ cores are also used, but the windings are flat helical spirals of insulated metal. In this latter winding design, window fill factors approaching 80 percent can be achieved.

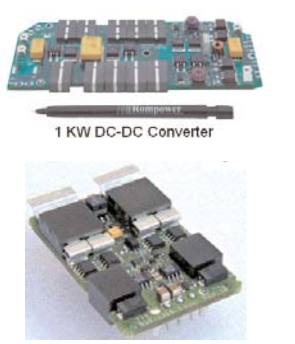

FIGURE 2
High-Density High-Power DC-DC Converter Assemblies Using Planar Magnetics
Upper Photo --- 1KW Battery Charger unit, picture courtesy of Rompower Inc.
Lower Photo --- Model QHS 1.8V, 50A unit, photo courtesy of Celestica™ Inc.)

Planar transformers and inductors can be found in many new power supply designs today. Good examples are DC-DC power converters where unit heights must be low (e.g., less than 0.5 inches for a rack-mounted telecom application) and the power-processing densities must be high to keep power loss at an absolute minimum. Figure 2 contains photos of two such assemblies in production today by the Rompower and Celestica™ corporations, respectively.

Table 1
Planar Magnetic Assemblies

Advantages	Comments
High Power Density	Higher Surface Area to Volume Ratio than Conventional Parts
High Current Capability	200A Per PCB Layer Winding Designs Practical (10 oz CU)
Large Power Capacity	2W - 150kW in a Single Unit
High Efficiency	Typically 98% For Most Medium Power Designs
Good Thermal Conduction	More Surface Area For Thermal Transfer, Lower Unit Temp Rise
Low Profile	Lower Unit Height Than Conventional Designs
Low Leakage Inductance	Interleaving Transformer Primary & Secondary Winding Layers
High Parameter Repeatability	Pre-Tooled, Precise Winding Structures Using PCB Methods
Low EMI Emission Possible	"Closed" Core Designs With Internal Windings Shielded
Application Frequency Ranges	20kHz To 2MHz And Above

Planar magnetics have many advantages over conventional magnetic constructions. Table 1 is a summary of these features. There is no limitation to the power levels that planar magnetics can be used. Practical designs exist today that can handle up to 150 kW of power (e.g., see the UPE design shown in Part 1 of this article).

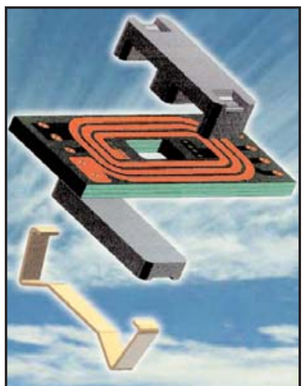

FIGURE 3
Planar E-I Core & PCB Winding Assembly
(Photo courtesy of Ferroxcube Components Inc.)

Pieces of a Planar Design ....

The base elements of a planar magnetic assembly consist of a low-profile core set, thin printed-circuit-board (PCB) windings and mechanical hardware to secure the PCBs in the core set and to hold the core pieces together. Figure 3 is an exploded view of a typical planar transformer using E-I style cores. In this example, the winding PCB is a ten-layer design and contains both primary and secondary windings of the transformer. To keep the leakage inductances small, the primary & secondary turns are "split" and interleaved in the layers of the PCB. Vias are provided in the PCB layers to interconnect the sections of both windings. Via terminals on the outside ends of the PCB provide terminal points for accessing the ends of the windings and their sections. More information about the construction of this board design can be found in reference [7] (see the end of this article for reference identification by [number]).

As shown in Figure 3, the core halves are held together by a small pressure bracket. Other methods for securing the core assemblies include gluing techniques where glue drops are added on the outside mating edges of the side surfaces of the core pieces. Recommended glue types include a two-part Aradite mixture (part number 2011 available from the Vantico Company (http://www.adhesives.vantico.com).

If the planar magnetic is to be mounted to a user motherboard with other electronics, it often becomes very cost-effective to place the windings of the magnetic in the layers of the motherboard rather than an external multi-layer PCB to house the windings. The motherboard PCB is then designed to have access holes around the internal windings for mating the core halves. In this integrated packaging example [7], gluing methods of core halves are usually employed rather than mechanical clips.

In many planar magnetic designs, several double-sided PCBs are often used to make up a winding, rather than using a multi-layer PCB. The PCBs are stacked in the window of the core and interconnected by external wiring added to via holes in each PCB. In many cases, this is a more cost-effective method for PCB windings than multi-layer designs, and is often used in production situations where quantities of the finished planar magnetic are small.

Using externally connected two-sided PCBs is also recommended in the initial design stage of a planar magnetic. This permits easy interleaving of winding sections to find the best interleaving method for reducing parasitics, such as leakage inductance in a transformer component.

FIGURE 4
Examples of Low-Profile RM, E and I Cores
(Upper photo courtesy of EPCOS AG Inc.)
(Lower photo courtesy of Ferroxcube Components Inc.)

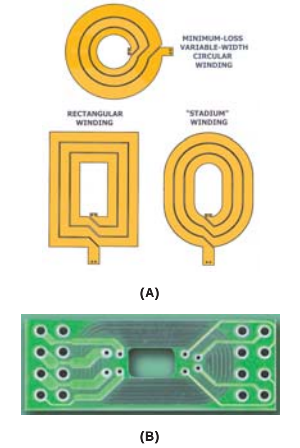

FIGURE 5
(A) Typical Planar Windings Styles
(B) Top View of a Multi-Layer "Stadium" PC Winding Board
(Lower photo courtesy of Ferroxcube Components Inc.)

Planar Core Styles....

The primary materials of choice today for planar magnetic cores are power ferrites. Over the past five years, a number of off-the-shelf planar core designs have become available from a number of major magnetic material manufacturers. The current list of vendors include well-known companies like Magnetics Inc., Ferroxcube, EPCOS AG, TDK/MH&W International and MMG-Neosid. Figure 4 contains some examples of two of the core styles available. An new dimensional standard (IEC 61820) was recently issued by the International Electrotechnical Commission for low-profile E, I, ER and RM cores, and many of these companies are now making core sets that conform to this standard.

Often as not, the core sizes or styles available off-the-shelf will not be adequate for a planar transformer or inductor design. An alternative approach in this instance would be to use one-half of a standard core set and a lid of similar magnetic material to make up the core structure. This 50 percent solution is a very cost-effective way to make a low-profile core structure. Most magnetic manufacturers will grind down a standard core half to produce a lid of material at minimal cost. Many high-frequency ferrite lids of various shapes and sizes can be purchased from Ceramic Magnetics Inc. (http://www.cmi-ferrite.com) in the USA, and they also offer custom planar core fabrication and prototype grinding services.

About Planar Windings....

Unlike magnetic wire, the turns of a planar winding can be designed to vary their widths as functions of lengths, which can be very advantageous from a copper loss standpoint. The resin and base materials used for the insulation laminate of the PCBs is typically epoxy-glass, NEMA grade FR4. This inexpensive laminate type has reasonably large temperature range and dielectric strength capabilities. Other NEMA laminate grades are available with increased capabilities beyond that of FR4, such as NEMA grade GT (Teflon-glass) for high-frequency winding designs where the layer capacitance of the laminate must be minimized.

The form factors of PCB windings are as varied as the number of core styles available today. Figure 5A shows three forms found in many current planar designs, while Figure 5B is a close-up view of the rectangular multi-layer PCB shown earlier in Figure 3. The rectangular form is used in many off-the-shelf E-E or E-I planar components, while the circuit form is suited for core structures with round center posts (e.g., RM, PQ and DS styles). A hybrid form is the stadium winding, which has turns with round circular corners and straight rectangular patterns much like the rectangular form mentioned earlier.

Of these three forms, for identical winding areas, the circular winding will have a smaller overall resistance than the others, particularly if the winding turn widths are increased in a logarithmic manner from the innermost turn to the last outside turn. Using this design technique, the resistance of every turn in the circular winding can be made to be the same. This same width-varying technique can also be used in designing rectangular or stadium-style windings. The circular winding shown in Figure 5A is also considered an optimum winding approach when other power loss factors are considered (e.g., high-frequency losses due to flux entrant effects between turn patterns in rectangular designs).

Spacing between turns of a planar winding is usually determined by the peak voltage gradient posed by the application. Guidelines for spacing amounts can be found in most PCB standard design guides. One particular useful commercial guide for conductor spacing is document IPC-D-275 published by the Institute for Interconnecting and Packaging Electronic Circuits. For military designs, MIL-STD-275 is suggested for spacing guidelines. The latest versions of either of these guides can be obtained from most document centers in the USA that offer copies of commercial standards and specifications. Both of these guides also contain information on selecting the conductor widths to be used in a winding design, giving RMS

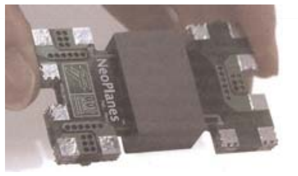

FIGURE 6
NeoplanesTM Prototyping PC Windings for Planar EE Cores
(Photo courtesy of the MMG-Neosid Company)

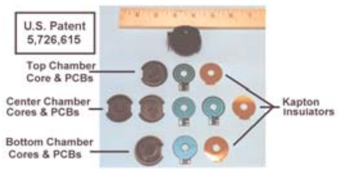

FIGURE 7
Three-Chambered Planar Integrated Magnetic Assembly
(Photo courtesy of e/j BLOOM associates Inc.)

current levels, copper weight of the patterns and allowed temperature rise.

When developing a new planar magnetic design of the E-E or E-I variety, prototyping PCB windings can be used to check out the design before it is committed to production. Here, the costs of designing and fabricating a prototype of the actual PCB at this point in the design cycle can be eliminated. Figure 6 is a photo of a completed E-E planar assembly using these prototyping boards (NeoplanesTM) which can be purchased directly from MMG-Neosid (http://www.mmg-neosid.com). These patented prototyping boards are available as user-selectable winding variants with 1, 2, 4, 6, 8, 10, 12 or 16 turns. They have been designed to fit planar E core structures defined in IEC standard 61860. Up to two isolated high-current primary and two isolated high-current secondary windings can be formed for high-power transformer designs. These prototyping PCBs are also accompanied by support software for quick design of any winding arrangement and/or combination.

New PIM Assembly Methods….

It is possible to design a planar magnetic assembly to contain more than one magnetic function. These assemblies have been classified as planar integrated magnetic (PIM) constructions. An example of a circular PIM structure is shown disassembled in Figure 7. This particular PIM has been designed to house two power inductors and the transformer of a switch-mode DC-DC power converter circuit. This three-chambered structure uses only four core pieces. The windings of these three magnetic elements are also placed in the chambers of the PIM in a manner so that there is minimal magnetic interaction between any of them. The estimated weight and volume savings achieved by this PIM design was on the order of 30 percent when compared to a conventional converter design where three separate magnetic components would be required. More information behind this kind of PIM construction can be found in reference [1] below.

To Learn More….

The ten references shown below are recommended to those readers interested in more of the details behind the practical design and development of planar magnetics assemblies.

[1] G. E. Bloom, "Planar and Integrated Magnetics Design", MODERN POWER MAGNETICS DESIGN TECHNIQUES, SEGMENT TWO COURSE NOTES, e/j BLOOM associates Inc., Educational Division, San Rafael, CA, May 2002.

[2] D. Grafham, "Optimal Thermal Management of Planar Magnetics in High Frequency SMPS" , Eight-page paper reprint available by email request to Alex Estrov, Payton America USA, at aestrov1@bellsouth.net.

[3] K.D.T. Ngo & R. S. Lai, "Effect of Height on Power Density in Spiral-Wound Power-Pot-Core Transformers", IEEE Transactions on Power Electronics, Vol. 7, No. 3, July 1992, pp. 601-606.

[4] D. van der Linde et. al., "Design of A High-Frequency Planar Power Transformer in Multilayer Technology", IEEE Transactions on Industrial Electronics, Vol. 38, No. 2, April 1991, pp. 135-141.

[5] A. Estrov, "Integrating Planar Magnetics in High-Density Power Converters", POWERTECHNICS Magazine, October 1990 Issue, pp. 18-21.

[6] Xu Huang, K.D.T. Ngo & G. E. Bloom, "Design Techniques for Planar Windings with Low Resistances", 1995 IEEE Applied Power Electronics Conference Proceedings, Volume 2, March 1995, pp. 533-539 (ISBN 0-7803-2482-X).

[7] Ferroxcube Components Inc. Application Note, "Design of Planar Power Transformers", Document Number 9398 083 39011, February 2001.

[8] Magnetics Inc. Technical Bulletin, "Designing with Planar Cores", Bulletin Number FC-S8, 2001 (Download from web site at http://www.mag-inc.com).

[9] Sam-Ben Yaakov, "The Benefits of Planar Magnetics in HF Power Conversion", Seven-page paper reprint available by email request to Alex Estrov, Payton America USA, at aestrov1@bellsouth.net.

[10] E. Brown, "Planar Magnetics Simplifies Switchmode Power Supply Design and Production", Power Conversion International Magazine, July 1992, pp. 46-52.

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Correction & Credit

In Part I of the Planar Power Magnetics article in the Summer issue of Magnetics magazine, figure 4b was sent courtesy of UPE, not UPC as incorrectly listed in the caption and article.

Also, the planar winding picture, inset, on the cover of the Summer issue was sent courtesy of Signal Transformer, Inc.