Optimal thermal managment of planar magnetics in high frequency SMPS

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Abstract: This paper focuses on the effectiveness of different mountdown methods to reduce "hot spot" temperatures in planar transformers at rated power dissipation. Methods compared include metal-loaded adhesives, simple bar clamps, clamps with vestigial fins for top-surface cooling, and "omega" shaped brackets that conduct and radiate heat away from three sides of the core at the same time. Cooling the windings separately with metal spacers trapped between windings and sink is also evaluated. Further measurements compare the effects of interface fillers such as thermal grease, dry-to-the-touch waxy compounds, thermally-enhanced polymers, anisotrophic graphite sheets, and "phase-change" coated aluminium foils. These latter are solid and mess-free when cold, but liquefy when hot to expel air from the joints. Because interface enhancement is most effective when surfaces mate badly, this latter work is done with the transformer mounted on a crude stamped metal chassis.

Introduction: Planar transformers and inductors for high frequency converters differ radically from conventional magnetics in that they do not use magnet wire. Instead, windings are copper foil lead frames or flat copper spirals laminated onto thin dielectric substrates. These windings are stacked on flat low profile ferrite "E" cores that are glued together with fine grain epoxy. Thin mylar, Kapton or high-temperature Nomex films provide the necessary inter-winding insulation.

The main benefits of planar technology are:

- Suitable for power levels from a few watts up to 20kW
- Low package profile, only 60mm high for 20kW
- Very efficient high frequency operation, 98-99% to 1MHz and above
- Excellent repeatability thanks to pre-tooled components
- Low leakage inductance
- Easily terminated multiple windings
- Minimum skin effect
- Standard outlines compatible with application-specific custom designs
- Usable in both square- and sine-wave topologies
- Lend themselves to sophisticated thermal management

While core losses in ferrite-cored transformers suitable for operation above 100kHz are lowest when core "hot-spot" is about 100°C, it is uneconomic to operate at this temperature. A maximum of about 130°C is usually dictated by winding-insulator limitations, although higher temperature materials are available at increased cost. These same hot spot criteria apply to all ferrite core designs. Copper losses, on the other hand, are less troublesome in planar than in round-wire designs. Due to skin effects, losses are concentrated on the surface of wafer-thin wide flat conductors so there is little copper wastage. Because adjacent layers are stacked tightly together like pages in a book, cooling is not difficult. By contrast, the same skin effects in round-wire designs waste copper, while minimal line contact between adjacent wires hampers heat extraction. For these reasons, raw materials are better used in planar designs, yielding smaller size and lower cost.

Most efficient heat extraction is achieved by conduction rather than by convection (radiation) cooling, that is by mounting the transformer onto a heatsink or equipment chassis. The low profile flat nature of a planar design provides an ideal large-area mounting surface for conduction cooling the core. The flat spiral-wound copper winding layers also lend themselves to conduction cooling, via metal spacers clamped between the outer winding layers and the heatsink.