RAF TABTRONICS
Technology to the global power

CASE STUDY

Novel Frequency Selective Winding Geometry Significantly Reduces Winding Losses In Boost Inductors, Without Using Litz Wire

Abstract:

RAF Tabtronics was challenged to develop a novel and innovative winding technique to reduce AC dissipation of boost inductors significantly.

Challenge –Develop a novel and innovative winding technique to reduce AC dissipation of boost inductors significantly.

Results–Application of preferential conductors reduced AC dissipation to 3.7 W (54% reduction) with negligible change in DC dissipation.

The Challenge

RAF Tabtronics was challenged to develop a novel and innovative winding technique to reduce AC dissipation of boost inductors significantly.

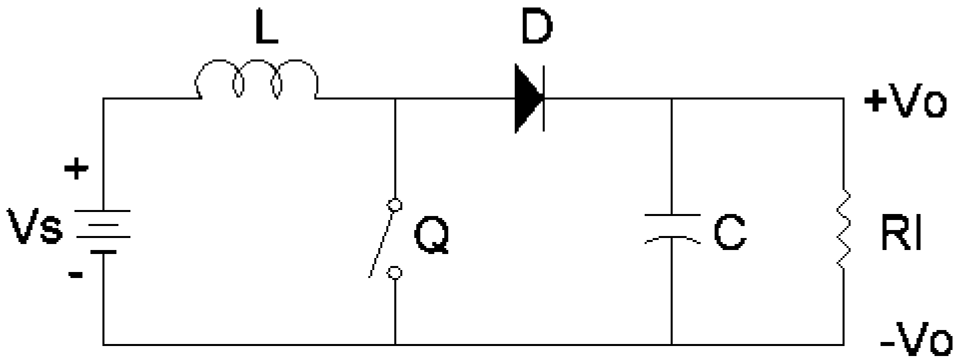
Technical Objective

The technical objective was to reduce inductor AC winding dissipation by 50% without resorting to expensive Litz wire construction while shrinking inductor size.

Background

The Boost converter is a popular power supply topology that is often used to achieve active power factor correction. This topology relies upon an inductor to store energy and increase output load voltage above power supply input voltage. The Boost inductor experiences a combination of DC and AC signals which result in various dissipation components. Frequently, designers resort to Litz wire construction to reduce high frequency eddy currents within the winding. However, Litz wire can be expensive and the benefit of reduced eddy currents must be weighed against diminished window utilization and increased thermal resistance.

Consider the following simplified schematic for a Boost converter:



In this circuit schematic, Vs represents the input supply voltage, L is the Boost inductor, Q is the switching element, D is the rectifier diode, C is the filter capacitor, and Vo is the output load voltage across the load resistance Rl.

When the switching element, Q, is closed, energy is stored in the inductor and the load is sustained by the capacitor C. When Q opens, the capacitor is charged, energy is removed from the inductor, and the load is sustained by the input supply voltage and the inductor. For continuous inductor current mode operation, the inductor current contains a DC bias component and a periodic superimposed triangular ripple current corresponding to the switching frequency.

For steady state converter operation, the energy storage elements operate in a state of input / output energy equivalence. For the inductor, this condition results in a statement of volt - time equivalence. For the capacitor, the corresponding statement of current - time equivalence applies.

Applying these energy principles to the continuous mode Boost converter results in the following relationships between switching duty cycle, *****; input supply voltage, Vs; DC output load voltage, Vo; output load current, Io; and average inductor current, Idc.

$$Idc = \frac{Io}{(1-\delta)} \qquad Vo = \frac{Vs}{(1-\delta)}$$

For PWM control set to give a fixed output voltage (and fixed load current for a constant load resistance), the maximum inductor DC bias current occurs at maximum duty cycle (or at minimum input source voltage).

By evaluating the variation of inductor volt - time as a function of switching duty cycle, it can be shown that the maximum inductor current ripple (and core AC flux density) occurs at 50 % switching duty cycle.

Inductor dissipation can be separated into three primary components: DC winding loss, AC core loss, and AC winding loss.

DC Winding Loss

The DC bias current causes a winding dissipation that is based upon the DC resistance of the winding and the DC inductor current, Idc.

AC Core Loss

The periodic AC voltage across the inductor induces a time varying magnetic field within the core, which gives rise to an AC core loss.

Gap Effects

Inductors carrying DC current are designed so that the core structure provides an effective air gap to limit the DC bias current from excessively polarizing the magnetic material. For cores having discrete gap structures, the fringing AC magnetic field at air gap boundaries may induce excessive flux crowding or excessive eddy currents within adjacent conductors that are exposed to normal surface field components.

AC Winding Loss

For a winding that has frequency invariant resistance, the AC winding loss is given by

$$\text{AC Winding Loss} = \left[Irms(AC)\right]^2 * Rwinding$$

Where *Irms(AC)* is the RMS value of the AC component of the winding current and *Rwinding* is the frequency invariant winding resistance.

For the continuous mode Boost converter, the RMS of the AC winding current is given by

$$Irms(AC) = \frac{\sqrt{3}}{6} * deltaI$$

Where *deltaI* is the peak to peak ripple current.

Fourier harmonic decomposition enables evaluation of AC winding loss for a frequency dependent winding resistance. The prediction of winding resistance for each harmonic frequency will be based upon solving the magnetic field diffusion equation and applying the boundary conditions at the winding conductor surfaces. The boundary conditions are determined by applying Ampere's Law to carefully selected integration paths to facilitate calculation. Unlike the boundary conditions for load current excitation in a transformer, the inductor current generates peak field intensity at the inner surface of the winding, adjacent to the magnetic material boundary.

The Solution

By employing a novel frequency selective winding geometry, preferential conductors can be introduced for the DC and AC current components. These preferential conductors significantly reduce winding loss without resorting to Litz wire construction.

This technique was applied to a 750 W Boost converter operating at 100 KHz. Without preferential conductors, AC dissipation was 8.0 W and DC dissipation was 2.5 W. Application of preferential conductors reduced AC dissipation to 3.7 W (54 % reduction) with negligible change in DC dissipation.

About RAF Tabtronics LLC

RAF Tabtronics creates advanced electromagnetic technologies and cost-effective customized solutions for the world's leading power technology companies. We produce innovative ultra-high power density and high-efficiency components which provide significant competitive advantage to our customers in defense electronics, homeland security, medical electronics, aerospace, data management, and several diverse high technology sectors.

RAF Tabtronics facilities are certified to AS9100 and ISO9001 quality management systems.

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