Multiphase Voltage Regulator Modules with Magnetic Integration to Power Microprocessors

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(ABSTRACT)

Advances in very large scale integration (VLSI) technologies impose challenges for voltage regulator modules (VRM) to deliver high-quality power to modern microprocessors. As an enabling technology, multiphase converters have become the standard practice in VRM industry. The primary objectives of this dissertation are to develop advanced topologies and innovative integrated magnetics for high-efficiency, high-power-density and fast-transient VRMs. The optimization of multiphase VRMs has also been addressed.

Today's multiphase VRMs are almost universally based on the buck topology. With increased input voltage and decreased output voltage, the multiphase buck converter suffers from a very small duty cycle and cannot achieve a desirable efficiency. The multiphase tapped-inductor buck converter is one of the simplest topologies with a decent duty cycle. However, the leakage inductance of its tapped inductors causes a severe voltage spike problem. An improved topology, named the multiphase coupled-buck converter, is proposed. This innovative topology enables the use of a larger duty cycle

with clamped device voltage and recovered leakage energy. Under the same transient responses, the multiphase coupled-buck converter has a significantly better efficiency than the multiphase buck converter.

By integrating all the magnetic components into a single core, in which the windings are wound around the center leg and the air gaps are placed on the two outer legs, it is possible for multiphase VRMs to further improve efficiency and cut the size and cost. Unfortunately, this structure suffers from an undesirable core structure and huge leakage inductance. An improved integrated magnetic structure is proposed to overcome these limitations. All the windings are wound around the two outer legs and the air gap is placed on the center leg. The improved structure also features the flux ripple cancellation in the center leg and strongly reverse-coupled inductors. Both core loss and winding loss are reduced. The steady-state current ripples can be reduced without compromising the transient responses. The overall efficiency of the converter is improved. The input inductor can also be integrated in the improved integrated magnetic structure.

Currently, selecting the appropriate number of channels for multiphase VRMs is still an empirical trial-and-error process. This dissertation proposes a methodology for determining the right number of channels for the optimal multiphase design. The problem formulation and general method for the optimization are proposed. Two examples are performed step by step to demonstrate the proposed optimization methodology. Both are focused on typical VRM 9.0 designs for the latest Pentium 4® microprocessors and their results are compared with the industry practice.

To my wife

Xiling

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