

Design of Microfabricated Inductors

Luca Daniel, *Student Member, IEEE*, Charles R. Sullivan, *Member, IEEE*, and Seth R. Sanders, *Member, IEEE*

Abstract—Possible configurations for microfabricated inductors are considered. Inductance can be set by adjusting permeability through control of anisotropy of a permalloy core or via a patterned quasi-distributed gap. A design methodology based on a simple model is proposed. A more accurate model and a numerical optimization are also developed. Design examples for 5- and 10-MHz buck converters and 2.5-MHz resonant converter applications are presented.

Index Terms—Anisotropy, application, automatic design, buck converter, code, coil fabrication process, computer program, control of permeability, design, design example, design methodology, distributed gap, eddy currents, efficiency, end turns, fabrication process, hard-baked photoresist, high-frequency power inductors, hysteresis losses, inductance adjustment, inductor geometries, inductors, loss analysis, magnetic thin films, microfabricated inductors, microfabricated inductors design, multilayer core, multilayer windings, numerical simulation, optimization, permalloy, planar inductors, power density, quasi-distributed gap, resonant converter, secondary effects, SEM pictures.

I. INTRODUCTION

RECENT advances in microfabrication of transformers, using thin-film magnetic materials, show much promise for miniaturization of power converters [1]–[10]. Microfabrication techniques can produce fine patterning and thin films, which are advantageous for the control of eddy-current losses. This allows the use of magnetic metal alloys at frequencies in the range of 2–20 MHz. These materials can have high usable flux density and low-hysteresis loss [8]. Although some inductors have been built using similar techniques [11]–[20], many have not been designed for power applications. Through design and optimization specifically for these applications, higher efficiencies and power densities can be achieved.

In this paper, various geometries and fabrication methods for inductors are considered. Design calculations and optimizations for one configuration are developed. Specific results for example designs are presented.

II. INDUCTOR CONFIGURATIONS AND GEOMETRIES

The designer of a magnetic component with a magnetic core, fabricated by deposition of metal or other films on a substrate, faces a basic choice between depositing two layers of magnetic material with a conductor in between, or depositing two layers

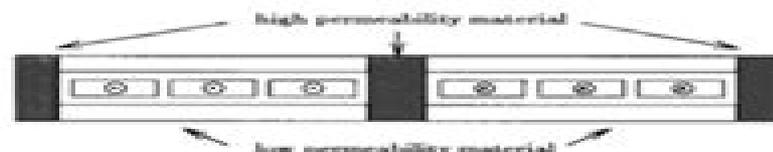


Fig. 1. Cross section of a planar inductor. The low-permeability material acts as a distributed gap. The resulting field distribution controls ac conduction losses in multilayer planar windings.

of conductor with a magnetic core in between. A device that uses two layers of conductor requires low resistance via contacts, and does not allow optimal use of an anisotropic magnetic material. As discussed in more detail in [8] and [21], a configuration using two layers of magnetic material above and below a conductor is preferred for these reasons, and because it generally allows higher power density. This geometry has been applied in [9] and [20].

A high-frequency inductor with substantial ac current requires careful design to avoid high-ac conduction losses. When a material with appropriate permeability is not available, high-permeability materials are generally used, and most designs will require increasing the overall reluctance of the magnetic path by introducing a gap. An air gap can adversely affect the field distribution, causing eddy currents, particularly with planar conductors and multilayer windings.

A series of fine gaps could be used to form a “quasi-distributed gap” to approximate a low-permeability material [8], [22], [23]. However, the scale of patterning that would be required for a typical design, on the order of a few microns, is difficult to achieve with a multilayer core [9].

Discrete gaps would be more easily placed at the “magnetic vias” where the top and bottom core materials connect. This leads to a large vertical field in the winding space, and problems with ac losses in the conductor. Turns that are wide compared to a skin depth, especially in multilayer designs, become problematic. Designs that use single narrow turns, such as in the “meander coil,” are preferred [9], [17], [24].

Perhaps the most elegant solution to the gap problem is the use of a low-permeability magnetic material to act as a distributed gap across the top and the bottom of the conductors, as shown in Fig. 1. In this case, the field lines are nearly horizontal in the winding space, and the ac resistance effects are determined by the height of the conductor, not its width. Additionally, the number of turns does not affect ac resistance as long as the turns accumulate horizontally, rather than vertically [8], [25]. If the permeability required for a distributed gap is achievable, the distributed gap design

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Design Of Microfabricated Inductors Power Electronics

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Design Of Microfabricated Inductors Power Electronics:

Inductors and Transformers for Power Electronics Vencislav Cekov Valchev,Alex Van den Bossche,2018-10-03 Although they are some of the main components in the design of power electronic converters the design of inductors and transformers is often still a trial and error process due to a long working in time for these components Inductors and Transformers for Power Electronics takes the guesswork out of the design and testing of these systems and provides a broad overview of all aspects of design Inductors and Transformers for Power Electronics uses classical methods and numerical tools such as the finite element method to provide an overview of the basics and technological aspects of design The authors present a fast approximation method useful in the early design as well as a more detailed analysis They address design aspects such as the magnetic core and winding eddy currents insulation thermal design parasitic effects and measurements The text contains suggestions for improving designs in specific cases models of thermal behavior with various levels of complexity and several loss and thermal measurement techniques This book offers in a single reference a concise representation of the large body of literature on the subject and supplies tools that designers desperately need to improve the accuracy and performance of their designs by eliminating trial and error

Power Management Integrated Circuits Mona M. Hella,Patrick Mercier,2017-12-19 Power Management Integrated Circuits and Technologies delivers a modern treatise on mixed signal integrated circuit design for power management Comprised of chapters authored by leading researchers from industry and academia this definitive text Describes circuit and architectural level innovations that meet advanced power and speed capabilities Explores hybrid inductive capacitive converters for wide range dynamic voltage scaling Presents innovative control techniques for single inductor dual output SIDO and single inductor multiple output SIMO converters Discusses cutting edge design techniques including switching converters for analog RF loads Compares the use of GaAs pHEMTs to CMOS devices for efficient high frequency switching converters Thus Power Management Integrated Circuits and Technologies provides comprehensive state of the art coverage of this exciting and emerging field of engineering

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The International Journal of Microcircuits and Electronic Packaging, 2000

Design and Optimisation of Micro-fabricated Inductors for High-frequency Power Converters Ronan Thomas Meere, 2010 Trends in the miniaturisation of electronic products especially in the portable products area has sparked considerable interest in the miniaturisation of the energy processing electronics i e the power conversion circuits such as the switched mode power supply SMPS Unlike digital electronics which have benefited from miniaturisation and integration in microelectronics power conversion electronics have not significantly reduced in size This is directly due to the fact that power conversion requires energy storage components such as inductors and capacitors The value of the inductors and capacitors required can be reduced if the switching frequency of the power converter is increased In order to miniaturise the power converter the switching frequency must be increased so that passive components can be miniaturised and integrated Traditionally the inductive components have been difficult to integrate on chip This work focused on the design and fabrication of integrated inductors on silicon for very high frequency power conversion 20 u2013 100 MHz Initially an analytical model for micro inductors which was developed in previous work was used to design inductors for operation up to 20 MHz The designs selected for fabrication had a footprint area between 5 u2013 9 mm² and a predicted device efficiency of 90% and above These models were validated by finite element analysis before fabrication The fabricated prototypes displayed a low loss of inductance to 20 MHz and current handling ability to 0.5 A The micro inductors were then interfaced with a high frequency dc/dc converter 20 u2013 100 MHz developed by NXP Semiconductor and achieved an inductor efficiency of 93% at 20 MHz The maximum converter efficiency with the micro inductor was measured to be 78.5% which to date is highest quoted inductor on silicon device efficiency in a converter application at 20 MHz Circuit equivalent lumped element models of the micro inductor for use in circuit simulation software were also developed This equivalent circuit model includes elements such as capacitance which are not accounted for in the previously developed analytical model The initial micro inductor devices performance was found to be comparable to commercial chip inductors for inductor efficiency when used in a converter However if the micro inductor technology is to

compete as a viable alternative to commercial devices it needed to reduce its footprint area dramatically This was achieved by using an optimisation software engine to find the inductor designs with maximum efficiency for a given footprint area The footprint of these optimised devices ranged from 0.5 to 2.5 mm² for a range of inductances to 200 nH A range of optimised devices were fabricated and the measured optimised devices displayed a low loss of inductance to tens of MHz and good current handling capability However measured dc resistance was found to be substantially higher than design due to issues in the fabrication process The fabricated inductors also highlighted the trade offs that are introduced in micro inductor performance vs footprint area This design trade off was also reflected in micro inductor performance in a converter An optimised 2.5 mm² area device was tested in a dc dc converter at 20 MHz which resulted in a slightly lower peak micro inductor efficiency of 90.5% than the previous larger devices The fabricated optimised micro inductors achieve an inductance density inductance per unit area ranging from 66 to 110 nH/mm² and display current handling ability of 500mA for the 2.5 mm² 250mA for the 1.3 mm² and 150mA for the 0.5 mm² area device For inductors aimed at power conversion applications this work shows a significant improvement to what is reported in literature in high frequency operation to tens of MHz inductance density and current handling

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Unveiling the Magic of Words: A Overview of "**Design Of Microfabricated Inductors Power Electronics**"

In a world defined by information and interconnectivity, the enchanting power of words has acquired unparalleled significance. Their ability to kindle emotions, provoke contemplation, and ignite transformative change is truly awe-inspiring. Enter the realm of "**Design Of Microfabricated Inductors Power Electronics**," a mesmerizing literary masterpiece penned with a distinguished author, guiding readers on a profound journey to unravel the secrets and potential hidden within every word. In this critique, we shall delve into the book's central themes, examine its distinctive writing style, and assess its profound impact on the souls of its readers.

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