

Design of Microfabricated Inductors

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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 inductor 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

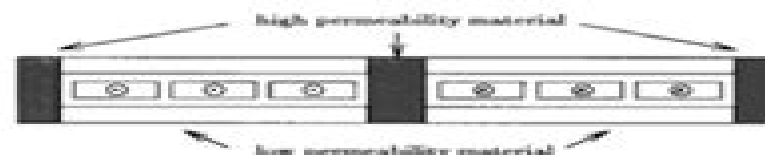


Fig. 1. Cross section of a planar inductor. The low-permeability material acts as a distributed gap. The resulting field distribution controls ac conduction losses in multilayer planar windings.

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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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

Transformers and Inductors for Power Electronics W.G. Hurley, W.H. Wölfle, 2013-02-21 Based on the fundamentals of electromagnetics this clear and concise text explains basic and applied principles of transformer and inductor design for power electronic applications It details both the theory and practice of inductors and transformers employed to filter currents store electromagnetic energy provide physical isolation between circuits and perform stepping up and down of DC and AC voltages The authors present a broad range of applications from modern power conversion systems They provide rigorous design guidelines based on a robust methodology for inductor and transformer design They offer real design examples informed by proven and working field examples Key features include emphasis on high frequency design including optimisation of the winding layout and treatment of non sinusoidal waveforms a chapter on planar magnetic with analytical models and descriptions of the processing technologies analysis of the role of variable inductors and their applications for power factor correction and solar power unique coverage on the measurements of inductance and transformer capacitance as well as tests for core losses at high frequency worked examples in MATLAB end of chapter problems and an accompanying website containing solutions a full set of instructors presentations and copies of all the figures Covering the basics of the magnetic components of power electronic converters this book is a comprehensive reference for students and professional engineers dealing with specialised inductor and transformer design It is especially useful for senior undergraduate and graduate students in electrical engineering and electrical energy systems and engineers working with power supplies and energy conversion systems who want to update their knowledge on a field that has progressed considerably in recent years

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Design and Implementation of Fully-Integrated Inductive DC-DC Converters in Standard CMOS Mike Wens, Michiel Steyaert, 2011-05-10 CMOS DC DC Converters aims to provide a comprehensive dissertation on the matter of monolithic inductive Direct Current to Direct Current DC DC converters For this purpose seven chapters are defined which will allow the designer to gain specific knowledge on the design and implementation of monolithic inductive DC DC converters starting from the very basics

CMOS Integrated Switching Power Converters Gerard Villar Piqué, Eduard Alarcón, 2011-05-20 This book describes the structured design and optimization of efficient energy processing integrated circuits The approach is multidisciplinary covering the monolithic integration of IC design techniques power electronics and control theory In particular this book enables readers to conceive synthesize design and implement integrated circuits with high density high efficiency on chip switching power regulators Topics covered encompass the structured design of the on chip power supply efficiency optimization IC compatible power inductors and capacitors power MOSFET switches and

efficient switch drivers in standard CMOS technologies

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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

Power Systems-On-Chip Bruno Allard, 2016-11-23 The book gathers the major issues involved in the practical design of Power Management solutions in wireless products as Internet of things Presentation is not about state of the art but about appropriation of validated recent technologies by practicing engineers The book delivers insights on major trade offs and a presentation of examples as a cookbook The content is segmented in chapters to make access easier for the lay person

Voltage Regulators for Next Generation Microprocessors Toni López, Reinhold Elferich, Eduard Alarcón, 2010-12-01 This book deals with energy delivery challenges of the power processing unit of modern computer microprocessors It describes in detail the consequences of current trends in miniaturization and clock frequency increase upon the power delivery unit referred to as voltage regulator This is an invaluable reference for anybody needing to understand the key performance limitations and opportunities for improvement from both a circuit and systems perspective of state of the art power solutions for next generation CPUs

High-Frequency Magnetic Components Marian K.

Kazimierczuk, 2011-08-24 If you are looking for a complete study of the fundamental concepts in magnetic theory read this book No other textbook covers magnetic components of inductors and transformers for high frequency applications in detail This unique text examines design techniques of the major types of inductors and transformers used for a wide variety of high frequency applications including switching mode power supplies SMPS and resonant circuits It describes skin effect and proximity effect in detail to provide you with a sound understanding of high frequency phenomena As well as this you will discover thorough coverage on integrated inductors and the self capacitance of inductors and transformers with expressions for self capacitances in magnetic components criteria for selecting the core material as well as core shape and size and an evaluation of soft ferromagnetic materials used for magnetic cores winding resistance at high frequencies expressions for winding and core power losses when non sinusoidal inductor or transformer current waveforms contain harmonics Case studies practical design examples and procedures using the area product method and the geometry coefficient method are expertly combined with concept orientated explanations and student friendly analysis Supplied at the end of each chapter are

summaries of the key concepts review questions and problems the answers to which are available in a separate solutions manual Such features make this a fantastic textbook for graduates senior level undergraduates and professors in the area of power electronics in addition to electrical and computer engineering This is also an inimitable reference guide for design engineers of power electronics circuits high frequency transformers and inductors in areas such as SMPS and RF power amplifiers and circuits

Microfabrication of Magnetic Components for High Frequency Power Conversion Charles Roger Sullivan,1996

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Microfabricated Systems and MEMS VI Peter J. Hesketh, 2002 Microfabricated Systems and MEMS ... , 2000

Power Electronics Technology and Applications II Fred C. Lee, 1997 A sequel to Power Electronics Technology and Applications this text is targeted specifically towards the needs of practicing design engineers The focus is to provide the practicing engineer with up to date technology and emerging applications Transformers Xose M. López-Fernández, H. Bülent Ertan, Janusz Turowski, 2017-12-19 Recent catastrophic blackouts have exposed major vulnerabilities in the existing generation transmission and distribution systems of transformers widely used for energy transfer measurement protection and signal coupling As a result the reliability of the entire power system is now uncertain and many blame severe underinvestment aging technology and a conservative approach to innovation Composed of contributions from noted industry experts around the world Transformers Analysis Design and Measurement offers invaluable information to help designers and users overcome these and other challenges associated with the design construction application and analysis of transformers This book is divided into three sections to address contemporary economic design diagnostic and maintenance aspects associated with power instrument and high frequency transformers Topics covered include Design considerations Capability to withstand short circuits Insulation problems Stray losses screening and local excessive heating hazard Shell type and superconducting transformers Links between design and maintenance Component related diagnostics and reliability Economics of life cycle cost design review and risk management methods Parameter measurement and prediction This book is an essential tool for understanding and implementing solutions that will ensure improvements in the development maintenance and life cycle management of optimized transformers This will lead to enhanced safety and reliability and lower costs for the electrical supply Illustrating the need for close cooperation between users and manufacturers of transformers this book outlines ways to achieve man The International Journal of Microcircuits and Electronic Packaging , 2000

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