

# 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 inductor designs, 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

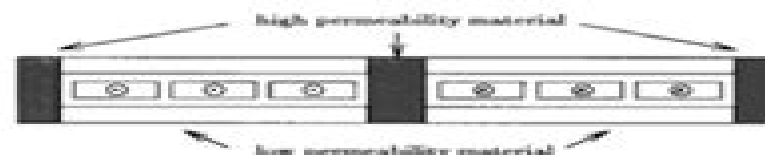


Fig. 1. Cross section of a planar inductor. The low-permeability material acts as a distributed gap. The resulting field distribution controls ac conduction losses in multilayer planar windings.

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

Manuscript received October 26, 1997; revised September 9, 1998. This work was supported by grants from the National Semiconductor Corporation and the University of California Micro Program. Recommended by Associate Editor, J. Szelecsenyi.

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Publisher Item Identifier S 0885-8965/99/050709-06.

# Design Of Microfabricated Inductors Power Electronics

**W.G. Hurley, W.H. Wölfle**



## **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

**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

**Design of Power Management Integrated Circuits** Bernhard Wicht,2024-05-14 Design of Power Management Integrated Circuits Comprehensive resource on power

management ICs affording new levels of functionality and applications with cost reduction in various fields Design of Power Management Integrated Circuits is a comprehensive reference for power management IC design covering the circuit design of main power management circuits like linear and switched mode voltage regulators along with sub circuits such as power switches gate drivers and their supply level shifters the error amplifier current sensing and control loop design Circuits for protection and diagnostics as well as aspects of the physical design like lateral and vertical power delivery pin out floor planning grounding supply guidelines and packaging are also addressed A full chapter is dedicated to the design of integrated passives The text illustrates the application of power management integrated circuits PMIC to growth areas like computing the Internet of Things mobility and renewable energy Includes numerous real world examples case studies and exercises illustrating key design concepts and techniques Offering a unique insight into this rapidly evolving technology through the author's experience developing PMICs in both the industrial and academic environment Design of Power Management Integrated Circuits includes information on Capacitive inductive and hybrid DC DC converters and their essential circuit blocks covering error amplifiers comparators and ramp generators Sensing protection and diagnostics covering thermal protection inductive loads and clamping structures under voltage reference and power on reset generation Integrated MOS MOM and MIM capacitors integrated inductors Control loop design and PWM generation ensuring stability and fast transient response subharmonic oscillations in current mode control analysis and circuit design for slope compensation DC behavior and DC related circuit design covering power efficiency line and load regulation error amplifier dropout and power transistor sizing Commonly used level shifters including sizing rules and cascaded tapered driver sizing and optimization guidelines Optimizing the physical design considering packaging floor planning EMI pinout PCB design and thermal design Design of Power Management Integrated Circuits is an essential resource on the subject for circuit designers IC designers system engineers and application engineers along with advanced undergraduate students and graduate students in related programs of study

**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      **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      *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

[Metallic Films for Electronic, Optical and Magnetic Applications](#) Katayun Barmak,Kevin Coffey,2014-02-13

Metallic films play an important role in modern technologies such as integrated circuits information storage displays sensors and coatings Metallic Films for Electronic Optical and Magnetic Applications reviews the structure processing and properties of metallic films Part one explores the structure of metallic films using characterization methods such as x ray diffraction and transmission electron microscopy This part also encompasses the processing of metallic films including structure formation during deposition and post deposition reactions and phase transformations Chapters in part two focus on the properties of metallic films including mechanical electrical magnetic optical and thermal properties Metallic Films for Electronic Optical and Magnetic Applications is a technical resource for electronics components manufacturers scientists and engineers working in the semiconductor industry product developers of sensors displays and other optoelectronic devices and academics working in the field Explores the structure of metallic films using characterization methods such as x ray diffraction and transmission electron microscopy Discusses processing of metallic films including structure formation during deposition and post deposition reactions and phase transformations Focuses on the properties of metallic films including mechanical electrical magnetic optical and thermal properties

**Power Electronics Handbook** Muhammad H. Rashid,2023-09-27

Power Electronics Handbook Fifth Edition delivers an expert guide to power electronics and their applications The book examines the foundations of power electronics power semiconductor devices and power converters before reviewing a constellation of modern applications Comprehensively updated throughout this new edition features new sections addressing current practices for renewable energy storage transmission integration and operation as well as smart grid security intelligent energy artificial intelligence and machine learning applications applied to power electronics and autonomous and electric vehicles This handbook is aimed at practitioners and researchers undertaking projects requiring specialist design analysis installation commissioning and maintenance services Provides a fully comprehensive work addressing each aspect of power electronics in painstaking depth Delivers a methodical technical presentation in over 1500 pages Includes 50 contributions prepared by leading experts Offers practical support and guidance with detailed examples and applications for lab and field experimentation Includes new technical sections on smart grid security and intelligent energy artificial intelligence and machine learning applications applied to power electronics and autonomous and electric vehicles Features new chapter level templates and a narrative progression to facilitate understanding

[Beyond-CMOS](#)

Nanodevices 1 Francis Balestra, 2014-06-02 This book offers a comprehensive review of the state of the art in innovative Beyond CMOS nanodevices for developing novel functionalities logic and memories dedicated to researchers engineers and students It particularly focuses on the interest of nanostructures and nanodevices nanowires small slope switches 2D layers nanostructured materials etc for advanced More than Moore RF nanosensors energy harvesters on chip electronic cooling etc and Beyond CMOS logic and memories applications Proceedings of the Fifth International Symposium on Magnetic Materials, Processes, and Devices Lubomyr Taras Romankiw, 1999 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 *IWIPP*, 2000

The Top Books of the Year Design Of Microfabricated Inductors Power Electronics The year 2023 has witnessed a noteworthy surge in literary brilliance, with numerous compelling novels captivating the hearts of readers worldwide. Lets delve into the realm of bestselling books, exploring the fascinating narratives that have captivated audiences this year. The Must-Read : Colleen Hoover's "It Ends with Us" This heartfelt tale of love, loss, and resilience has captivated readers with its raw and emotional exploration of domestic abuse. Hoover expertly weaves a story of hope and healing, reminding us that even in the darkest of times, the human spirit can prevail. Uncover the Best : Taylor Jenkins Reids "The Seven Husbands of Evelyn Hugo" This spellbinding historical fiction novel unravels the life of Evelyn Hugo, a Hollywood icon who defies expectations and societal norms to pursue her dreams. Reids absorbing storytelling and compelling characters transport readers to a bygone era, immersing them in a world of glamour, ambition, and self-discovery. Design Of Microfabricated Inductors Power Electronics : Delia Owens "Where the Crawdads Sing" This captivating coming-of-age story follows Kya Clark, a young woman who grows up alone in the marshes of North Carolina. Owens weaves a tale of resilience, survival, and the transformative power of nature, entrancing readers with its evocative prose and mesmerizing setting. These top-selling novels represent just a fraction of the literary treasures that have emerged in 2023. Whether you seek tales of romance, adventure, or personal growth, the world of literature offers an abundance of compelling stories waiting to be discovered. The novel begins with Richard Papen, a bright but troubled young man, arriving at Hampden College. Richard is immediately drawn to the group of students who call themselves the Classics Club. The club is led by Henry Winter, a brilliant and charismatic young man. Henry is obsessed with Greek mythology and philosophy, and he quickly draws Richard into his world. The other members of the Classics Club are equally as fascinating. Bunny Corcoran is a wealthy and spoiled young man who is always looking for a good time. Charles Tavis is a quiet and reserved young man who is deeply in love with Henry. Camilla Macaulay is a beautiful and intelligent young woman who is drawn to the power and danger of the Classics Club. The students are all deeply in love with Morrow, and they are willing to do anything to please him. Morrow is a complex and mysterious figure, and he seems to be manipulating the students for his own purposes. As the students become more involved with Morrow, they begin to commit increasingly dangerous acts. The Secret History is a masterful and suspenseful novel that will keep you guessing until the very end. The novel is a warning tale about the dangers of obsession and the power of evil.

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