Electromagnetics for High-Speed Analog and Digital Communication Circuits

Modern communications technology demands smaller, faster, and more efficient circuits, the design of which requires a good understanding of circuit theory and electromagnetics. This book reviews the fundamentals of electromagnetism as applied to passive and active circuit elements, highlighting the various effects and potential problems in designing a new circuit. The author begins with a review of the basics: the origin of resistance, capacitance, and inductance, from a circuit and field perspective; then progresses to more advanced topics such as passive device design and layout, resonant circuits, impedance matching, high-speed switching circuits, and parasitic coupling and isolation techniques. Using examples and applications in RF and microwave systems, the author describes transmission lines, transformers, and distributed circuits. State-of-the-art developments in Si-based broadband analog, RF, microwave, and mm-wave circuits are also covered. With up-to-date results, techniques, practical examples, many illustrations, and worked examples, this book will be valuable to advanced undergraduate and graduate students of electrical engineering and practitioners in the IC design industry. Further resources for this title are available at www.cambridge.org/9780521853507.

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Preface

Why another EM book? There are virtually thousands of books written on this subject and yet I felt the urge to write another one.

The idea for this book germinated in my mind on a long and uneventful drive from Berkeley to San Diego. I had just completed my first year of graduate school at Berkeley and had started a research project on analyzing spiral inductors. It occurred to me that studying electromagnetics as a circuit designer was a lot easier than studying it as an undergraduate at UCLA. Even though I took many EM courses during my undergraduate education, very little of it actually stuck with me. Much like all those foreign languages we learn in high school or college, without any practice, we quickly lose our skills. When we find ourselves at that critical moment in a foreign country, our language skills fail us. While EM is the foundation of much of electrical engineering, somehow it's treated as a foreign tongue, spoken only by the few learned folks in the the field. But learning EM should not be like learning Greek or Latin!

That summer I spent many weekends in San Diego visiting my family. During these trips I'd take my EM books down to the beach and study. I'd plant myself on the beach at La Jolla or Del Mar and work my way through my undergraduate EM text. This time around, things were making a lot more sense, since I had an urgent need to actually learn electromagnetics. But I observed that having a circuits background was somewhat equivalent to speaking a related derived tongue. I realized that many people out there also missed the boat on learning EM, since they learned it without any background, desire, or need to learn it. But many of those same people, after taking a lot of high-frequency electronics courses, feel they need to relearn this important subject. If you're one of those people, this book is written for you!

When I was an undergraduate student, EM courses were a required part of every EE student's education. No matter how painful, you had to work your way through two or three courses. But today the situation has changed dramatically. Many schools have made this an optional course and, much to our horror, many students simply skip it! Even though they do take EM as part of their physics education, the emphasis is on fundamentals, with no coverage of important engineering topics such as transmission lines or waveguides. Today, more than ever, this seems like a tragedy. High-speed digital, RF, and microwave circuits abound, necessitating the training of engineers in the art and science of electronics, electromagnetics, communication circuits, antennas, propagation, etc.

With the availability of high-speed 64-bit microprocessors, server farms, Gb/s networks, and mass storage, many practical problems are now computationally tractable. Workers in the field of high-speed electronics are increasingly turning to commercial electromagnetic solvers to tackle difficult problems. As powerful as EM solvers are today, it still takes a lot of skill to set up and run a problem. And at the end of a long five hour simulation, can you trust the results? Did you actually set up the problem correctly? Are the boundary conditions appropriate? Is the field accuracy high enough? These are difficult questions and can only be answered by observing the currents, voltages, and electric and magnetic fields with a trained eye.

The focus of this book is the application of electromagnetics to circuit design. In contrast to classical analog integrated circuit design, passive components play an integral role in the design of RF, microwave, and broadband systems. Most books dedicate a section or at best a chapter to this all important topic.

The book begins with the fundamentals – the origins of resistance, capacitance, and inductance. We spend a great deal of time reviewing these fundamental passive elements from a circuit and field perspective. With this solid foundation, the book progresses to more advanced applications. A chapter on passive device design and layout reviews state-of-the-art layout techniques for the realization of passive devices in an integrated circuit environment. Important circuit applications such as resonant circuits and impedance matching are covered extensively with an emphasis on the inner workings of the circuitry (rather than a cookbook approach) in order to uncover important insights into the insertion loss of these circuits. Next, the book moves to active two-port circuits and reviews the co-design of amplifiers with passive components. Two-port circuit theory is used extensively to understand optimal power gain, stability, activity, and unilateral gain. Transmission lines, transformers, and distributed circuits form the core of the advanced circuit applications of passive elements. These topics are taught in a coherent fashion with many important examples and applications to RF and microwave systems. The time-domain perspective is covered in a chapter on high-speed switching circuits, with a detailed discussion of the transient waveforms on transmission lines and transmission line dispersion. Parasitic coupling and isolation techniques are the topic of an entire chapter, including discussion of package, board, and substrate coupling. An introduction to the analysis and design of passive microwave circuits is also covered, serving as a bridge to an advanced microwave textbook.

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