Magnetics Text Is Deepest And Most Comprehensive, Yet Very Accessible

High-Frequency Magnetic Components, Second Edition, Marian K. Kazimierczuk, Wiley, 2014, 729 pages, hardback, $93.95 U.S. retail price; ISBN 978-1-118-71779-0.

Reviewed by Dennis Feucht, Innovatia Laboratories, Cayo, Belize

This is a new edition of a book on power magnetics by an electrical engineering professor and IEEE Fellow at Wright State U. in Dayton, Ohio. What sets this book apart from previous magnetics books recently reviewed in *How2Power Today* is its depth of coverage, especially of topics that are hard to analyze such as winding resistance caused by the skin and proximity effects, and parasitic winding capacitances. Kazimierczuk—I'll call him "Kaz" for short, as Apple co-founder Steve Wozniak is called "Woz"—has worked out in sufficient detail the mathematical derivations of design equations that usually appear in the literature as either given (or else ignored entirely) rather than derived.

The book begins logically enough with magnetics fundamentals (chapter one) and magnetic core material properties (chapter two), including core shapes. Passing coverage of nanocrystalline materials and superconductors leads to core hysteresis power loss. And then the fields equations begin to appear in earnest, with eddy-current loss in cores.

The modified Steinmetz equation is presented (with a footnote on Steinmetz, an ethnic German born in Poland.) Complex permeability, which is found more prominently in the magnetics data of European or Japanese core manufacturers, is covered in some detail. The chapter ends with a nod to "Cooling of Magnetic Cores." This chapter, and the others, all end with extensive bullet-item summaries for the time-challenged (or equation-challenged) reader, extensive references, and some textbook problems.

Already in the second chapter, topics such as eddy-current losses in core material signal Kaz's forte for fields analysis of magnetics. It is the main feature of the book. The next three chapters are superb in their coverage of winding resistance, one of the difficult yet important topics in magnetics design.

While power electronics books typically might go as far as to present, and maybe even outline the derivation of Dowell's equation for frequency-dependent resistance (and inductance), it is but a starting point in Kaz's book. Derivations are given for different shapes and spacings of wire and foil, and layering—essentially all of the common geometric configurations found in magnetics devices. The optimum thickness of foil is derived, for instance.

Kaz gives an approximation for Dowell's equation (with the derivation given in the appendix at the end of chapter five.) Wire bundling (*Litz wire*) appears later in chapter five and optimum strand diameter is derived. Winding loss from waveform harmonics is given a long section. Chapter five concludes with some considerations of thermal effects on winding resistance and a simple thermal model of inductors.

Chapter six on laminated cores finishes this related group of chapters. Laminations are used mostly with low-frequency transformers or inductors yet have high-frequency limits, which Kaz reveals in some derivations.

The next two chapters leave winding details behind to consider transformers (chapter seven) and "integrated inductors" (chapter eight.) The basic obligatory development of the transductor as a circuit element, with equivalent transductor circuit models, measurement of model inductances (leakage, magnetizing or mutual), and interleaving is followed by a substantial section on the design of current transformers.

These are transformers, named for their function more so than their structure, which have a low-resistance sense resistor across their secondary so that they present a near-short on the primary side. A tiny primary-to-secondary turns ratio refers a small sense resistance to the primary as a negligible resistance so that the measured current loop is least interfered with.

Again, Kaz's emphasis is on frequency effects. Plenty of integrals appear but in the end, some algebraic design formulas result that can be used by engineers who do not need to be convinced of their validity. Yet many derivations throughout the book are given and this is a remarkable benefit of the book for those who want to understand the theoretical basis for design formulas. A quick reminder of thermal modeling comes and goes at the end of chapter seven.

Chapter eight returns to the topic of skin effect, though with a contemporary emphasis on planar magnetics. This chapter is broader than power electronics in that those who design RF inductors will also find it relevant. Various inductance approximation formulas attributed to Bryan, Wheeler, Greenhouse, Grover, Rosa and others are given, indicating the empirical nature of some inductor design. Near the end of chapter eight, we return to power inductors with a brief coverage of "PCB Inductors."

Chapter nine is titled "Self-Capacitance" and goes where many magnetics books fear to tread, in trying to model that elusive parasitic capacitance that nevertheless has such an important effect on converter behavior. Switching from magnetic to electric field equations, Kaz starts on the familiar ground of parallel-plate capacitors as a warm-up exercise. The plot thickens with derivation of the capacitance of two parallel wires with nonuniform charge density, single layer inductor self-C, then multi-layer C. Measurement of winding capacitance is given a short but useful section, followed by "Inductor Impedance" which reveals the frequency limits of inductors as inductances.

Chapters ten and eleven finish the book with the design of inductors (chapter ten) and transformers (chapter eleven.) The two design procedures presented are the core area-product method and the K_g method. These are the traditional methods, with some variations that also appear, for which Kaz offers their theoretical basis, then applies them in practical examples. The design procedures are given in enough detail so that the reader is not left wondering about gaps between steps, and this accounts for most of the pages in chapter ten.

The K_g method is found much earlier in the classic book on *Fundamentals of Power Electronics* (Kluwer) by Erickson and Macsimović, and has been around for decades. Although it has an established theoretical basis, I do not use it because it is a "high-entropy" method of design, lacking in intuitive insight. (See my articles on magnetics design optimization at How2Power for an alternative.)

Despite the limitation in the K_g method, this book offers no major innovations in design methods, instead sticking with the traditional techniques. Even so, Kaz remains true to form in working out in clear and convincing mathematics the theoretical basis for both the area-product and K_g methods. Chapter eleven orients the methods to transformer and coupled-inductor (DCM flyback) design.

The book has an adequate index. Besides the many graphs, the other illustrations are conceptually clear and well-drawn. Paging casually through this book, what meets the eye are a mix of mostly equations and graphs. The graphs are as common as the equations and they visually explain the equations for those not as fluent in the language of math. Even if you skip the equations in this book, it still has much to tell about magnetic components.

Kaz's coverage in this new edition is up-to-date in including some of the major, relatively recent advances made by others such as Charles Sullivan and his researchers at Dartmouth College. Among the magnetics books recently reviewed in *How2Power Today*, this is the most in-depth and complete, yet it is readily accessible to power engineers of intermediate skill level. Despite the dense concentration of equations, they are presented most clearly. Anyone with the ability to read math should be able to follow the logic and sequencing of the many insightful derivations.

If you are a beginner in power electronics or are weak on vector calculus (the mathematical foundation of modern fields theory) your eyes will probably glaze over for about half of this book. Yet it stakes a clear long-term goal to work toward in understanding magnetics, and having a copy can provide that guidance. For the price (which for technical books nowadays is rather "ascendant"), it is still worth the investment as an exchange of devaluing monetary paper for book paper revealing enduring knowledge that will retain its value. As you learn more and more, the book will continue to yield a return on investment.

And if you are an experienced engineer driven to excel in the field and do not want to have any gaping "holes" in your knowledge of magnetics, this book is simply a must-have. It will continue to stand as a "book of reference" and a "classic" on magnetics, mainly for power applications and also for RF communications. The author has won my respect; this book is evidence of why he deserves his IEEE Fellow status.

About The Author

Dennis Feucht has been involved in power electronics for 25 years, designing motor-drives and power converters. He has an instrument background from Tektronix, where he designed test and measurement equipment and did research in Tek Labs. He has lately been working on projects in theoretical magnetics and power converter research.

To read Dennis' reviews of other texts on power supply design, magnetics design and related topics, see How2Power's Power Electronics Book Reviews.