

If you can't explain it simply, you don't understand it well enough.  
Albert Einstein

Why don't you write books people can read?  
Nora Joyce to her husband, James Joyce

## PREFACE

Welcome to “House of Maxwell’s Electrodynamics” or even better, “Kingdom” of Electrodynamics. Like any house, it has a solid foundation made of four “all-inclusive” equations discovered by James Clerk Maxwell in 1861. Over the following 150 years, a universe was erected on this simple basis. It helped to establish the unique relationship between electric and magnetic fields, electromagnetic field interactions with the surrounding world, and the possibility to carry energy and information through space. Maxwell’s equations “govern” the electromagnetic processes in our body, “make” modern computers intelligent, “deliver” the electrical power to our home and elsewhere around the world, and “provide” all satellite, wire, and wireless communications, internet connections, etc. It would not be an exaggeration to say that the current state of civilization is a broad “solution” of Maxwell’s equations.

The primary intent of this book is to help readers reach a deeper understanding of the fundamentals of electrodynamics, show how to use this knowledge in a challenging world of practical engineering and teach the corresponding skills. We are not going to provide a full course of modern electrodynamics, as that would take many and many volumes. Our relatively narrow goal is to give our reader a basic understanding of electrodynamics that makes him/her capable of solving modern engineering problems for a reasonable period of time.

*If you are looking for ideas on how to shorten your way to a practical solution to your engineering problems in a time and money constrained environment or you would just like to get the most out of your study in continuous education – you will see that this book for you.*

### How This Book Is Organized

This book is written by practicing engineers for practicing engineers and university students of all levels planning to incorporate electrodynamics into their professional toolbox. Over many years in the engineering field and teaching electrodynamics, the authors have observed that students and engineers are very results oriented and prefer to avoid extensive mathematical manipulations. ***And they are basically right*** because now the numerical modeling of electromagnetic problems by commercially available and user-friendly software alleviates much of the need for in-depth-mathematical-proficiency. Following this trend, we decided to limit the complexity of the mathematics in this book. We are focused primarily on readers achieving an intuitive grasp of the material through physical analogies, unit dimension analysis, simplified models, etc. We ask our readers to give us some credit for it not judging us severely. There is no doubt that electrodynamics and almost everything connected to electromagnetic concepts is challenging for understanding, but be patient and spend some extra time and efforts to succeed.

The crucial ideas unifying different elements of this book are Danish physicist Niels Bohr’s quotation “Nothing exists until it is measured” and the two fundamental laws of physics: (1) the Charge Conservation Law, which states that charges can neither be created nor destroyed in an isolated system, and (2) the Electromagnetic Energy Conservation law, which that in an isolated system the total amount of any kind of energy can be neither created nor lost. This

approach allows reaching the definition of electromagnetic fields through the energy they carry. In other words, electric and magnetic fields become directly accessible to experimental observation. Moreover, it paves the way to Maxwell's equations with minimal mathematics and subsequently the presentation of Lorentz's force equation and Gauss's conservation laws for electric and magnetic charges.

### **The Contents at a Glance**

We believe that one can learn more from a well-thought-out example than from reading a dozen pages in a book. To make the most out of our book, we advise you to install on your computer, as a minimum, the student version of MATLAB® and CST STUDIO SUITE® tools.

The book is organized into 9 chapters and an appendix with short reference material. It can be conditionally divided into two parts. Part I (Chapter 1, 2, 3, and 4) is preliminary and devoted to the classical and neoclassical theory of electromagnetism. The “raison d'être<sup>1</sup>” of the book is in Part II (Chapter 5, 6, 7, 8, and 9) connecting the theory with engineering applications.

*To be aware of that Electrodynamics is a challenging for study matter, we arrange each chapter into small chunks of 3 - 5 pages with detailed contents at the chapter beginning. We hope that chunking helps the motivated readers identify key words and ideas, develops their ability to paraphrase, and makes it easier for them to organize and synthesize information. We recommend to review and apply the learned material regularly keeping understanding fresh. If you don't use it, you'll forget it sooner.*

Chapter 1, *Basic Equations of Macroscopic Electrodynamics*, provides an introduction to the world of macroscopic electrodynamics and its fundamental principles based on the symmetry in nature and conservation laws. Most of this chapter is devoted to exploring Lorentz's force equation, all four of Maxwell's equations, and building so-called House of Maxwell's Electrodynamics with attic and basement.

Chapter 2, *Neoclassical Theory of Interaction of Electric and Magnetic Fields with Material Media*, covers an important practical aspect of such interactions in the conductive, natural and artificial dielectric, ferro-, and metamaterials, graphene, etc. The analysis is primarily based on neoclassical Drude-Lorentz's models. Chapter constitutes a discussion of boundary conditions, material classification based on their electrical parameters, Kramers-Kronig (K-K) Relations, connected to all of these ideas of remote sensing, and Eddy current.

Chapter 3, *Poynting's Theorem*, is one of the central topics in the book. The objectives of this chapter are to present information you need to formulate electromagnetic problems uniquely and prepare them for analytical or numerical analysis. Particular attention is paid to the association between Poynting's theorem and traditional circuit analysis that allows converting the high theoretical electrodynamics into a powerful and intuitive tool for engineering design.

Chapter 4, *Solution of Basic Equations of Electrodynamics*, is entirely a math saturated and introduces the reader to the world of Maxwell's equations solution. Don't fear – we will try to avoid unnecessary rigor wherever possible. The central topic of this chapter is the theory of electromagnetic potentials in space-time and space-frequency domain that opens the door to the concept of electromagnetic wave radiation and propagation. The obtained solutions are applied to the family of such elementary radiators as electric, magnetic, and Huygens'. The electric and

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<sup>1</sup> The “raison d'être” may be translated from French as the most important reason or purpose for existence ([https://en.oxforddictionaries.com/definition/raison\\_d%C3%AAtre](https://en.oxforddictionaries.com/definition/raison_d%C3%AAtre)).

magnetic fields induced by them are illustrated by manifold three-dimensional images that give a clear view of their radiation pattern formation in space. The chapter concludes with a discussion of the skin effect in highly conductive materials and its engineering aspect like the impact of surface roughness on the attenuation factor.

Chapter 5, *Antenna Basic*, continues the study of EM wave radiation and devotes to such topics as EM wave polarization including twisted waves, a broad range of antenna parameters and their impact on system advance, pattern analysis and synthesis of a different type of antennas, beam steering, and focusing techniques, planar and conformal arrays. Section 5.3.6 is devoted to currently “hot topic” of massive MIMO for 5G (fifth-generation) wireless network.

Chapter 6, *Feed Line Basic*, emphasizes the engineering aspect of a broad range of open and closed feed lines starting from their elementary theory and fundamental characteristics. The discussion includes the different types of transition between lines, ferrite devices, and many other topics of engineering importance.

Chapter 7, *Discontinuity in Feed Lines*, and Chapter 8, *More Complicated Elements of Feed Lines*, present the ancillary material necessary for engineering design of a wide variety of microwave components like power combiners/splitters, filters, limiters, multiplexers, etc. The particular attention is paid to their applications.

Chapter 9, *Approach to Numerical Solution of Electrodynamics Problems*, is a short introduction to the modern world of computer analysis.

### **What You Need to Know**

The book is suitable for first-year graduate or senior undergraduate students, and can also be used by practicing engineers who want a quick review covering most of the basic concepts in electromagnetics and includes many application examples. This is not a book for beginners. We assume that the reader had a knowledge of the basics of classical mechanics, fundamentals of electric and magnetic phenomena and completed a basic course on linear electrical circuit analysis. Basics of Calculus is also essential.

### **‘Aha!’ moment in Electrodynamics**

For the last two centuries, numerous books and almost infinite number of papers have been written on the different aspects of the electromagnetic theory. Electromagnetic theory tests the boundary of our imagination the same way as music, abstract painting and sculpture do.

What kind of enjoyment can be found in highly theoretical electromagnetic science?

Students studying electromagnetic phenomena at schools and universities are sometimes confused and overwhelmed. Did I miss or misunderstand something critical and significant? Where is my ‘Aha!’ moment of the *extraordinary*? Do not worry. The beauty of Maxwell’s equations is that they are simple, and we will help you learn and understand them. In the 20<sup>th</sup> century, the major *engineering* discoveries and ‘Aha!’ moments shifted to unique solutions for engineering problems, innovations, and design of superior to existing products. Plenty of easy-to-use commercial software packages transforms electrodynamics into a user-friendly engineering tool for the numerical solution of everyday tasks. Modern computers enormously intensify our intellectual power and permit us to check and validate at first glance crazy ideas and bring them to life.

## **How to Use This Book**

You can use this book any way that you please. If you choose to read it from cover to cover, be our guest. Experienced readers can skip around, picking up useful tidbits here and there. If you are faced with a challenging task, you might try the contents and index first to see whether the book specifically addresses your problem.

Research has shown that roughly half of the human cerebral cortex that facilitates our learning, creates thought, expression, and behavior is solely devoted to visual processing. We are all visual learners and to us “seeing is believing” because a picture may tell a thousand words. So to foster active learning, we extensively used a wide variety of images and diagrams including 3D plots for illustration purposes and as a source of new information. The most of this graphic material is original, but we reproduced a lot of images from the Internet and are grateful to numerous individuals and companies for their permission to reproduce specific figures acknowledged in the book. Please forgive us if we missed some references and do not judge us strictly.

We will be delighted to get your opinion, suggestions, and comments that let improve any future edition. If you have some queries, do not hesitate and send email through our website *<http://www>*.

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We are indebted to Dr. Martin Timm, Computer Simulation Company (CST, a Dassault Systèmes company), who provided a free license for CST STUDIO SUITE® that helps us to realize the multiple computer-oriented simulation data included in the book. We hope to continue our cooperation developing CD-ROM containing various projects based on CST STUDIO SUITE®. Such CD-ROM will be sent for free to our readers who bought the book and registered on our website. Besides, all material and textbook electronic version (eBook) will be put at <http://www.EMwavebook.com>.

**Have fun reading and a good time while learning!**