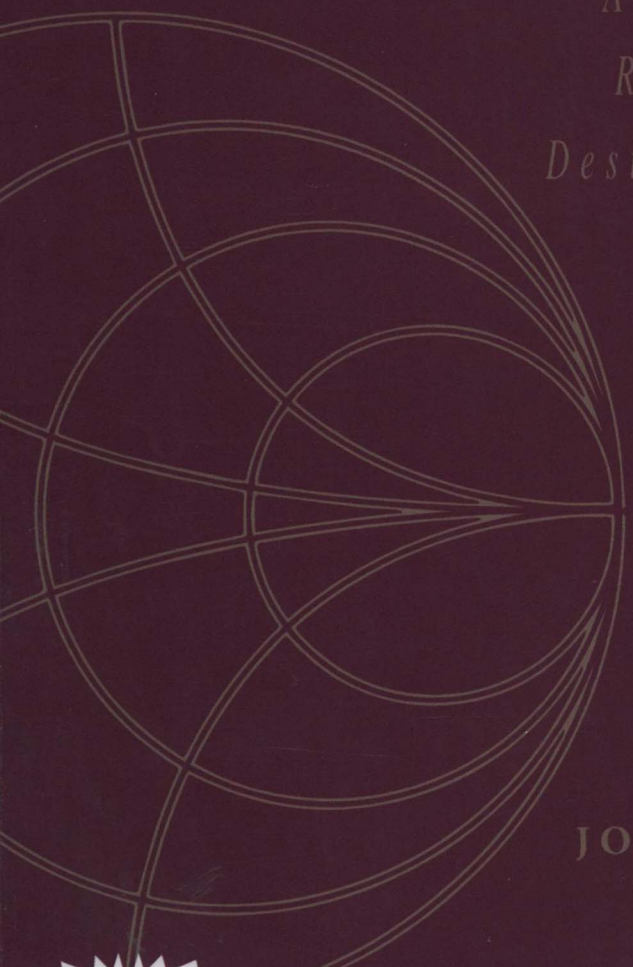
High Frequency Techniques

An Introduction to RF and Microwave Design and Computer Simulation



JOSEPH F. WHITE

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To Linda

PREFACE

Since the initial publication of this book, it has occurred to me that both its content and style may not have been apparent. I intended that the undergraduate electrical engineering student could use the book as an introductory text. However, the book contains much more content and analytical depth than what reasonably can be presented in an introductory course. In fact, the book also can serve as a text and reference for the graduate student or the practicing electronics engineer.

Despite this, all one needs to understand its content are introductory courses in calculus and physics, as would usually be given in the freshman year of an engineering curriculum. A review of the *Table of Contents* or the *Index* will reveal to the reader the thoroughness with which the electrical engineering topics are treated. The book is self-contained, not requiring recourse to other texts, and, therefore, is a completely explanatory text and reference for the interested reader.

Initially, it can be used in a first course to introduce alternating circuit (AC) analysis at the sophomore level. For example, complex number math (Appendix B) and the basis of steady-state AC analysis using complex numbers (Chapters 1 and 2) are treated at the introductory level. The usefulness of AC analysis is illustrated by the *Q matching method* (Section 3.5), a convenient design technique derived from the formulas for series-to-parallel impedance transformations. Other topics include the definition and use of matrix algebra (Chapter 6) to describe two-port networks. This gives details for *y*, *z*, *abcd*, and *s* matrices (the latter also known as *s parameters*).

The *impedance transformation equation* is derived (Section 4.14), which gives the input impedance to a transmission line of arbitrary length when terminated in an arbitrary load impedance. While useful, this equation requires complex calculations to apply, yet it does not provide insight into the locus of impedances to which the load may be transformed. An epic solution to this limitation was the *Smith Chart.*

The Smith Chart is developed in detail. It begins with how the chart was derived from the variation of the reflection coefficient on uniform transmission lines and, then, how it evolved mathematically to the graphical aid we now know. This is followed by illustrative examples of impedance matching using the chart.

The book also can be used at the junior and senior levels, as for example, for the introduction of field analysis using vector calculus (Chapter 7). *Maxwell's equations* are presented and their usefulness demonstrated by the proof that *radio waves propagate through a vacuum and at the speed of light* (see Section 7.20), an astounding discovery credited to James Clerk Maxwell, circa 1863.

Finally, the book can be used as text for a graduate-level course. Advanced topics such as *electromagnetic (EM) circuit simulation, vector potential, retarded potentials,*

Green's functions, and *higher order modes*, advanced filter techniques (*elliptic filters, the Richards transformation*, and *Kuroda's identities*); *statistical design and yield analysis;* and advanced amplifier design (including *noise figure*, nonlinearity, broadbanding, and cascading sections) may be covered.

The use of circuit simulator software is employed throughout the book, and this leads into the design of transistor amplifiers. This analysis, based on *S* parameters, can be readily covered provided the student has access to microwave circuit simulator software, a practical requirement for today's electrical engineering student. Amplifier design criteria are presented, which include gain, impedance matching, and stability (resistance to oscillation). Some firms may make these simulator software available free to engineering schools that apply for it.

Antennas are presented, including wire, aperture, and phased array types. The coverage of antennas, path loss, and propagation (Section 7.3) provides an insightful introduction to the design of wireless (radio) systems.

The presentation of EM simulation (Section 7.34) is illustrative of how EM-based software can provide a more accurate prediction of actual circuit behavior. This is illustrated by a comparison of the performance of a practical transmission line stub as revealed by EM simulation with the predicted performance of an ideal (zero line width) stub.

This book treats many topics that I encountered as a practicing microwave engineer, in a period during which computer aids were evolving.

For example, I found the behavior of backward wave couplers fascinating, and sought to understand them. Questions arose: How could the quarter wave coupler (Chapter 8) be matched at all frequencies, and how could its direct and coupled arm outputs always be 90° out of phase, even for broad bandwidths over which the coupling region departs widely from its 90°, center frequency value? The *even- and odd-mode analysis* for this coupler is complex, a credit to the original researchers who formulated it. But it is presented in its entirety in this book (and in few other texts). Through these equations, one can find and prove the answers.

Rigor has been used throughout the book, with complete mathematical derivations given for all presented formulas (other than those empirically derived, such as Maxwell's equations). Is such thoroughness necessary? I believe so. This developmental rigor provides insight to the engineer on how he or she can develop equations for other circuits that may be encountered in practice. In essence, the basis of this book is the mathematics of electrical engineering, particularly high-frequency engineering. For this reason, I believe the book's content will remain ever applicable, no matter how the technology evolves in the future.

It was a pleasure to write this book. I will be happy to hear from you.

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ACKNOWLEDGMENTS

The *Smith chart* symbolized on the cover and employed within this text is reproduced through the courtesy of Anita Smith, owner of Analog Instrument Company, Box 950, New Providence, New Jersey 07974. I am happy to acknowledge the late Phillip Smith for this remarkable tool, arguably the most profound insight of the microwave field. Numerous Smith chart matching solutions were performed using the software program *WinSmith* available from Noble Publishing Co., Norcross, Georgia 30071.

All of the circuit simulations have been performed using the Genesys software suite provided through the courtesy of Randall Rhea, founder of Eagleware Inc, Norcross, Georgia 30071. My thanks also go to the members of the Eagleware on-line support team, whose assistance improved the many simulation examples that appear in this text.

My gratitude to Dr. Les Besser who encouraged me to begin microwave teaching and shared with me many RF and microwave facts and design methods. I also thank Gerald DiPiazza for his patience and help in critical field theory development in this text.

I gratefully acknowledge Dr. Peter Rizzi, my colleague and friend, who patiently read the manuscript and made numerous suggestions to improve its readability, usefulness, and accuracy. He directly contributed the portions on noise and noise temperature. Dr. Rizzi is the author of *Microwave Engineering and Passive Circuits*, an important, widely used text that is referenced extensively in these notes. He is a professor of microwaves who is loved by his students. No one but I can appreciate the magnitude of his contributions.

Anyone who has written a book knows how much patience his spouse requires. My thanks and love to Eloise.

THE AUTHOR

Joseph White is an instructor and consultant in the RF and microwave community, also known as the "wireless" industry.

He received the BS EE degree from Case Institute of Technology, the MS EE degree from Northeastern University and the Ph.D. degree from the Electrical Engineering Department of Rensselaer Polytechnic Institute with specialty in electrophysics and engaged in semiconductor engineering at

M/A-COM Inc, Burlington, Massachusetts, for 25 years. He holds several microwave patents.

He received the *IEEE Microwave Theory and Techniques Society's* annual Application Award for his "*Contributions to Phased Array Antennas.*"

He also wrote *Microwave Semiconductor Engineering*, a textbook in its third printing since 1977.

He has taught courses on RF and microwave engineering at both the introductory and advanced engineering levels. He has lectured in the United States and internationally on microwave subjects for more than 30 years.

He has been a technical editor of microwave magazines for over 20 years, including the *Microwave Journal* and *Applied Microwave and Wireless.*

He has served as a reviewer for the *IEEE Transactions on Microwave Theory and Techniques*. He is a Fellow of the IEEE and a member of the *Eta Kappa Nu* and *Sigma Xi* honorary fraternities.

Questions, corrections and comments about this book are welcome. Please e-mail them to the author at jfwhite@ieee.org.

CONTENTS