



# High Frequency Techniques

*An Introduction to  
RF and Microwave  
Design and Computer  
Simulation*

JOSEPH F. WHITE



**IEEE PRESS**

**WILEY**

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Joseph F. White  
JFW Technology, Inc.

  
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## **HIGH FREQUENCY TECHNIQUES**



*To Linda*



## PREFACE

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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, broad-band, 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  $90^\circ$  out of phase, even for broad bandwidths over which the coupling region departs widely from its  $90^\circ$ , 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.

JOSEPH F. WHITE  
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## ACKNOWLEDGMENTS

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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

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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

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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](mailto:jfwhite@ieee.org).

## CONTENTS

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<b>Preface</b>	<b>xv</b>
<b>Acknowledgments</b>	<b>xvii</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Beginning of Wireless	1
1.2 Current Radio Spectrum	4
1.3 Conventions Used in This Text	8
Sections	8
Equations	8
Figures	8
Exercises	8
Symbols	8
Prefixes	10
Fonts	10
1.4 Vectors and Coordinates	11
1.5 General Constants and Useful Conversions	14
<b>2 Review of AC Analysis and Network Simulation</b>	<b>16</b>
2.1 Basic Circuit Elements	16
The Resistor	16
Ohm's Law	18
The Inductor	19
The Capacitor	20
2.2 Kirchhoff's Laws	22
2.3 Alternating Current (AC) Analysis	23
Ohm's Law in Complex Form	26
2.4 Voltage and Current Phasors	26
2.5 Impedance	28
Estimating Reactance	28
Addition of Series Impedances	29
2.6 Admittance	30
Admittance Definition	30

	Addition of Parallel Admittances	30
	The Product over the Sum	32
2.7	LLFPB Networks	33
2.8	Decibels, dBW, and dBm	33
	Logarithms (Logs)	33
	Multiplying by Adding Logs	34
	Dividing by Subtracting Logs	34
	Zero Powers	34
	Bel Scale	34
	Decibel Scale	35
	Decibels—Relative Measures	35
	Absolute Power Levels—dBm and dBW	37
	Decibel Power Scales	38
2.9	Power Transfer	38
	Calculating Power Transfer	38
	Maximum Power Transfer	39
2.10	Specifying Loss	40
	Insertion Loss	40
	Transducer Loss	41
	Loss Due to a Series Impedance	42
	Loss Due to a Shunt Admittance	43
	Loss in Terms of Scattering Parameters	44
2.11	Real RLC Models	44
	Resistor with Parasitics	44
	Inductor with Parasitics	44
	Capacitor with Parasitics	44
2.12	Designing <i>LC</i> Elements	46
	Lumped Coils	46
	High $\mu$ Inductor Cores—the Hysteresis Curve	47
	Estimating Wire Inductance	48
	Parallel Plate Capacitors	49
2.13	Skin Effect	51
2.14	Network Simulation	53
<b>3</b>	<b><i>LC</i> Resonance and Matching Networks</b>	<b>59</b>
3.1	<i>LC</i> Resonance	59
3.2	Series Circuit Quality Factors	60
	$Q$ of Inductors and Capacitors	60
	$Q_E$ , External $Q$	61
	$Q_L$ , Loaded $Q$	62
3.3	Parallel Circuit Quality Factors	62
3.4	Coupled Resonators	63

Direct Coupled Resonators	63
Lightly Coupled Resonators	63
3.5 $Q$ Matching	67
Low to High Resistance	67
Broadbanding the $Q$ Matching Method	70
High to Low Resistance	71
<b>4 Distributed Circuits</b>	<b>78</b>
4.1 Transmission Lines	78
4.2 Wavelength in a Dielectric	81
4.3 Pulses on Transmission Lines	82
4.4 Incident and Reflected Waves	83
4.5 Reflection Coefficient	85
4.6 Return Loss	86
4.7 Mismatch Loss	86
4.8 Mismatch Error	87
4.9 The Telegrapher Equations	91
4.10 Transmission Line Wave Equations	92
4.11 Wave Propagation	94
4.12 Phase and Group Velocities	97
4.13 Reflection Coefficient and Impedance	100
4.14 Impedance Transformation Equation	101
4.15 Impedance Matching with One Transmission Line	108
4.16 Fano's (and Bode's) Limit	109
Type A Mismatched Loads	109
Type B Mismatched Loads	112
Impedance Transformation Not Included	113
<b>5 The Smith Chart</b>	<b>119</b>
5.1 Basis of the Smith Chart	119
5.2 Drawing the Smith Chart	124
5.3 Admittance on the Smith Chart	130
5.4 Tuning a Mismatched Load	132
5.5 Slotted-Line Impedance Measurement	135
5.6 $VSWR = r$	139
5.7 Negative Resistance Smith Chart	140
5.8 Navigating the Smith Chart	140
5.9 Smith Chart Software	145
5.10 Estimating Bandwidth on the Smith Chart	147
5.11 Approximate Tuning May Be Better	148
5.12 Frequency Contours on the Smith Chart	150
5.13 Using the Smith Chart without Transmission Lines	150
5.14 Constant $Q$ Circles	151
5.15 Transmission Line Lumped Circuit Equivalent	153

<b>6</b>	<b>Matrix Analysis</b>	<b>161</b>
6.1	Matrix Algebra	161
6.2	Z and Y Matrices	164
6.3	Reciprocity	166
6.4	The <i>ABCD</i> Matrix	167
6.5	The Scattering Matrix	172
6.6	The Transmission Matrix	177
<b>7</b>	<b>Electromagnetic Fields and Waves</b>	<b>183</b>
7.1	Vector Force Fields	183
7.2	E and H Fields	185
7.3	Electric Field E	185
7.4	Magnetic Flux Density	187
7.5	Vector Cross Product	188
7.6	Electrostatics and Gauss's Law	193
7.7	Vector Dot Product and Divergence	194
7.8	Static Potential Function and the Gradient	196
7.9	Divergence of the B Field	200
7.10	Ampere's Law	201
7.11	Vector Curl	202
7.12	Faraday's Law of Induction	208
7.13	Maxwell's Equations	209
	Maxwell's Four Equations	209
	Auxiliary Relations and Definitions	210
	Visualizing Maxwell's Equations	211
7.14	Primary Vector Operations	214
7.15	The Laplacian	215
7.16	Vector and Scalar Identities	218
7.17	Free Charge within a Conductor	219
7.18	Skin Effect	221
7.19	Conductor Internal Impedance	224
7.20	The Wave Equation	227
7.21	The Helmholtz Equations	229
7.22	Plane Propagating Waves	230
7.23	Poynting's Theorem	233
7.24	Wave Polarization	236
7.25	EH Fields on Transmission Lines	240
7.26	Waveguides	246
	General Waveguide Solution	246
	Waveguide Types	250
	Rectangular Waveguide Fields	251
	Applying Boundary Conditions	252
	Propagation Constants and Waveguide Modes	253

Characteristic Wave Impedance for Waveguides	256
Phase and Group Velocities	257
TE and TM Mode Summary for Rectangular Waveguide	257
7.27 Fourier Series and Green's Functions	261
Fourier Series	261
Green's Functions	263
7.28 Higher Order Modes in Circuits	269
7.29 Vector Potential	271
7.30 Retarded Potentials	274
7.31 Potential Functions in the Sinusoidal Case	275
7.32 Antennas	275
Short Straight Wire Antenna	275
Radiation Resistance	279
Radiation Pattern	280
Half-Wavelength Dipole	280
Antenna Gain	283
Antenna Effective Area	284
Monopole Antenna	285
Aperture Antennas	286
Phased Arrays	288
7.33 Path Loss	290
7.34 Electromagnetic (EM) Simulation	294
<b>8 Directional Couplers</b>	<b>307</b>
8.1 Wavelength Comparable Dimensions	307
8.2 The Backward Wave Coupler	307
8.3 Even- and Odd-Mode Analysis	309
8.4 Reflectively Terminated 3-dB Coupler	320
8.5 Coupler Specifications	323
8.6 Measurements Using Directional Couplers	325
8.7 Network Analyzer Impedance Measurements	326
8.8 Two-Port Scattering Measurements	327
8.9 Branch Line Coupler	327
8.10 Hybrid Ring Coupler	330
8.11 Wilkinson Power Divider	330
<b>9 Filter Design</b>	<b>335</b>
9.1 Voltage Transfer Function	335
9.2 Low-Pass Prototype	336
9.3 Butterworth or Maximally Flat Filter	337
9.4 Denormalizing the Prototype Response	339
9.5 High-Pass Filters	343
9.6 Bandpass Filters	345



9.7	Bandstop Filters	349
9.8	Chebyshev Filters	351
9.9	Phase and Group Delay	356
9.10	Filter $Q$	361
9.11	Diplexer Filters	364
9.12	Top-Coupled Bandpass Filters	367
9.13	Elliptic Filters	369
9.14	Distributed Filters	370
9.15	The Richards Transformation	374
9.16	Kuroda's Identities	379
9.17	Mumford's Maximally Flat Stub Filters	381
9.18	Filter Design with the Optimizer	384
9.19	Statistical Design and Yield Analysis	386
	Using Standard Part Values	386
	The Normal Distribution	387
	Other Distributions	391
<b>10</b>	<b>Transistor Amplifier Design</b>	<b>399</b>
10.1	Unilateral Design	399
	Evaluating $S$ Parameters	399
	Transistor Biasing	400
	Evaluating RF Performance	403
10.2	Amplifier Stability	405
10.3	$K$ Factor	409
10.4	Transducer Gain	413
10.5	Unilateral Gain Design	416
10.6	Unilateral Gain Circles	422
	Input Gain Circles	422
	Output Gain Circles	424
10.7	Simultaneous Conjugate Match Design	428
10.8	Various Gain Definitions	431
10.9	Operating Gain Design	433
10.10	Available Gain Design	437
10.11	Noise in Systems	442
	Thermal Noise Limit	442
	Other Noise Sources	444
	Noise Figure of a Two-Port Network	445
	Noise Factor of a Cascade	447
	Noise Temperature	448
10.12	Low-Noise Amplifiers	450
10.13	Amplifier Nonlinearity	455
	Gain Saturation	455
	Intermodulation Distortion	456