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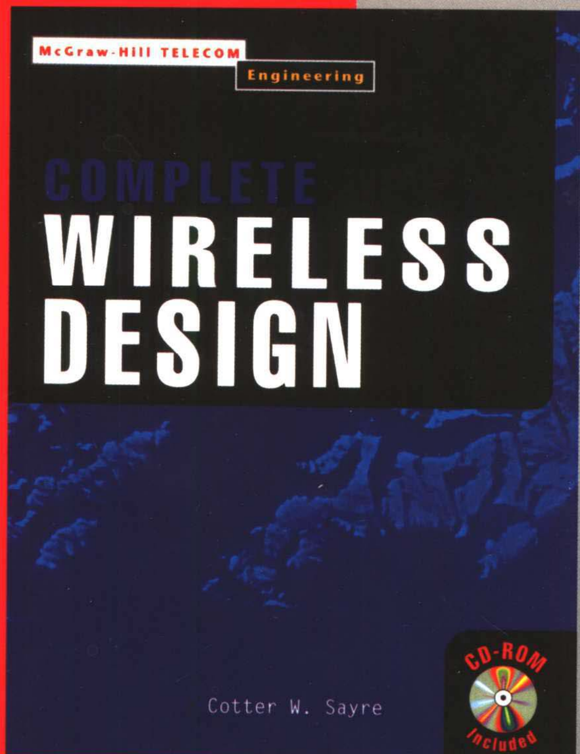
Cotter W. Sayre

完整无线设计



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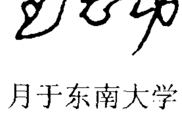
Complete Wireless Design

影 印 版 序

近十多年来，以无线电波为媒体的移动通信、无线局域网等技术和产业呈爆炸式发展。无线系统特别是其中的射频电路设计成为世界范围内炙手可热的专业。一大批电子信息专业学生和技术人员渴求获得无线有关的知识、技术和经验。本书正是为适应这种需求而撰写的全面讨论无线设计的专业书。既可作为本科生的教学参考书，也可作为工程师和业余爱好者的自学教材。

本书分为十章。第一章简单介绍无线电的基本元器件和基础知识。基本元器件包括电阻、电容、电感和变压器等无源元件、二极管和三极管等半导体器件和微带线，基础知识包括传输线、S 参数和电波传播等。第二章介绍幅度调制、频率调制、单边带调制和数字调制，调制器与解调器集成电路设计。第三章讨论各种放大器的设计，包括小信号放大器、大信号放大器、微波单片放大器（MMIC）、宽带放大器、音频放大器与可变增益放大器（VGA）等，讨论了放大器偏置以及放大器的耦合与去耦等问题。第四章讨论压控振荡器（VCO）、LC 振荡器和晶体振荡器的设计。第五章讨论锁相环（PLL）和直接数字频率合成器的设计。第六章讨论集总参数、分布参数、双频、晶体、声表面波（SAW）、有源和可调谐等各种滤波器设计。第七章讨论有源和无源混频器设计。第八章讨论倍频器、射频开关、自动增益控制、衰减器、平衡非平衡转换（Bulun）、分波器 / 合波器，电源和方向耦合器等一系列射频微波系统支持电路的设计。第九章讨论接收机和发射机的设计、链路的性能预算与完整系统的设计。第十章讨论器件与系统噪声、电磁干扰、射频电路底板设计、软件无线电、混合集成电路、直接变换接收机、原型机设计、天线、射频接头，无线设计软件、美国联邦通信委员会（FCC）的无线设备管理法等一系列无线电相关知识以及语音处理、自动频率控制和静噪电路等几种关联电路。本书带有一张光盘，刻录有一种称之为 Puff 的射频电路 CAD 软件。附录 A 给出了 Puff 的使用说明。

本书的特点是：代替众多复杂的数学推导过程，给出了一系列简明的计算公式；避免了纯粹的理论叙述，给出了大量的设计实例；从系统、电路、器件到测试和设计工具，内容全面，通俗易懂。可以相信，这本专著影印本的出版发行对我国移动通信、微波通信、卫星通信和无线局域网等射频电路与系统的人才培养和工程设计都将产生有益的帮助。



2004 年 12 月于东南大学

To my lovely wife Linda, without whom this book would not have been possible.

Preface

Complete Wireless Design gives the reader a solid grounding in the latest radio-frequency (RF) design methods and communication circuits employed in today's wireless equipment and systems, and will assist any engineer, technician, or ham, to design—down to the circuit level—anything from a basic two-way radio to the wireless receivers and transmitters of a digital communications system.

Included with the book is a free and complete copy of Caltech's Puff RF/microwave circuit simulation software, along with Sonnet Lite's electromagnetic simulator, Agilent's AppCad RF design software, and National's PLL design programs.

Unlike many wireless books, *Complete Wireless Design* does not simply present predesigned circuits and expect readers to modify them in some haphazard fashion for their own wireless applications, nor does this book present overly complex equations for the design of wireless circuits and systems, which most readers, even engineers, would have difficulty understanding, much less applying. Instead, *Complete Wireless Design* allows the reader, using simple algebra, to design cutting-edge oscillators, amplifiers, mixers, filters, phase-locked loops (PLLs), frequency multipliers, RF switches, microstrip elements, automatic gain control (AGC) loops, power splitters, attenuators, and diplexers easily and quickly. This book will also explain the practical aspects of designing with radio-frequency integrated circuits (RFICs) and monolithic microwave integrated circuits (MMICs); and how to perform all the necessary calculations for impedance matching, perform wireless link analyses, complete a frequency plan, and integrate a complete communications system. The book covers vital high speed and circuit design issues as well.

Cotter W. Sayre

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David Rutledge of Caltech University, along with Richard Compton, Scott Wedge, and Andreas Gerstlauer, for the linear circuit simulator *PUFF*.

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Contents

Chapter

1

Wireless Essentials

A firm understanding of how passive and active components function at high frequencies, as well as a strong grasp of the fundamental concepts of lumped and distributed transmission lines, S-parameters, and radio-frequency (RF) propagation, is essential to successful circuit design.

1.1 Passive Components at RF

1.1.1 Introduction

At radio frequencies, lumped (physical) resistors, capacitors, and inductors are not the "pure" components they are assumed to be at lower frequencies. As shown in Fig. 1.1, their true nature at higher frequencies has undesirable resistances, capacitances, and inductances—which must be taken into account during design, simulation, and layout of any wireless circuit.

At microwave frequencies the lengths of all component leads have to be minimized in order to decrease losses due to lead inductance, while even the board traces that connect these passive components must be converted to transmission line structures. *Surface mount devices* (SMDs) are perfect for decreasing this lead length, and thus the series inductance, of any component (Fig. 1.2), while the most common transmission line structure is *microstrip,* which maintains a 50-ohm constant impedance throughout its length—and without adding inductance or capacitance.

As the frequency of operation of any wireless circuit begins to increase, so does the requirement that the actual physical structure of all of the lumped components themselves be as small as possible, since the part's effective frequency of operation increases as it shrinks in size: the smaller package lowers the harmful distributed reactances and series or parallel resonances.

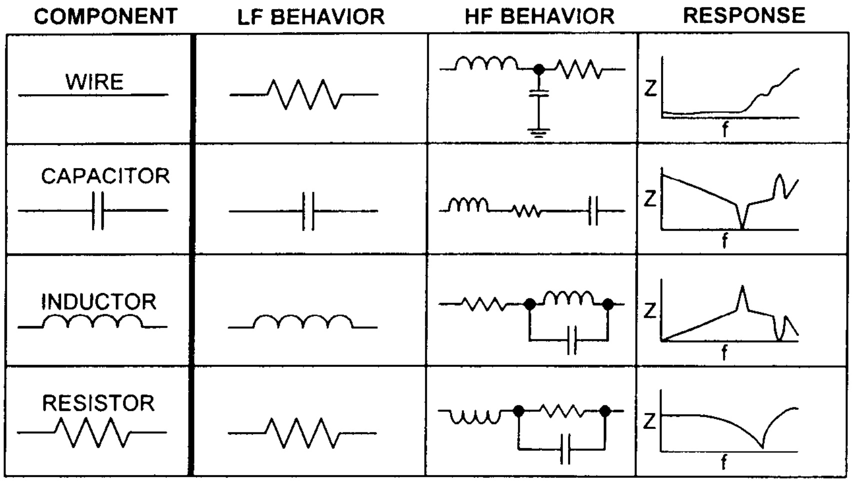

Figure 1.1 A component's real-life behavior at high frequencies (HF) and low frequencies (LF).

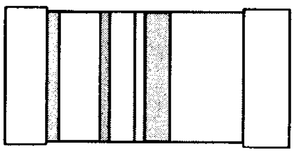

Figure 1.2 A surface mount resistor.

1.1.2 Resistors

As shown in Fig. 1.3, a resistor's actual value will begin to decrease as the frequency of operation is increased. This is caused by the distributed capacitance that is always effectively in parallel with the resistor, shunting the signal around the component; thus lowering its effective value of resistance. As shown in the figure, this distributed capacitance is especially problematic not only as the frequency increases, but also as the resistance values increase. If the resistor is not of the high-frequency, thin-film type, a high-value resistor can lose much of its marked resistance to this capacitive effect at relatively low microwave frequencies. And since the series inductance of the leads of the surface-mount technology resistor are typically quite low, the added reactive effect is negligible in assisting the resistor in maintaining its marked resistance value.

1.1.3 Capacitors

Capacitors at RF and microwave frequencies must be chosen not only for their cost and temperature stability, but also for their ability to properly function at these high frequencies. As shown in Fig. 1.1, a capacitor has an undesired lead inductance that begins to adversely change the capacitor's characteristics as

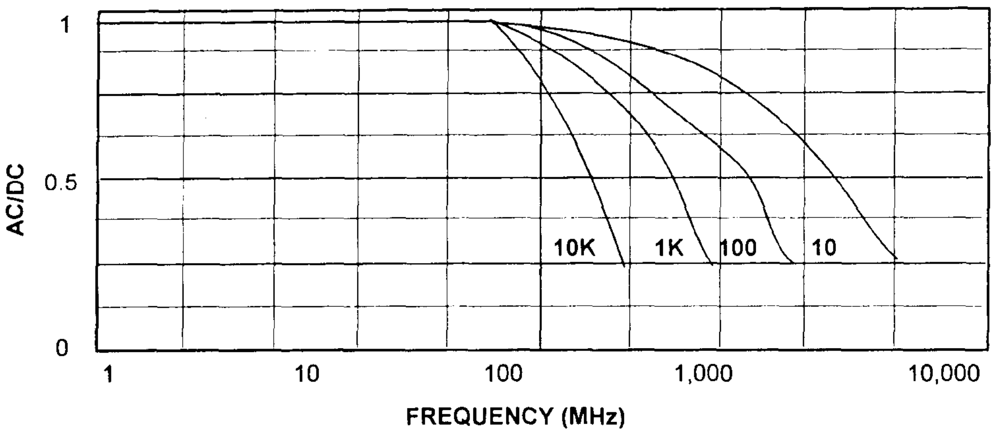

Figure 1.3 Ratio of an SMD resistor's resistance at DC to its resistance at AC for increasing frequencies.

the frequency is increased. This effect is most pronounced if the lead inductance resonates with the capacitance of the physical capacitor, resulting in a series resonance—or a total reactance of nearly *zero* ohms (resonating a capacitor can also be purposeful: a *j0 capacitor* is the type that becomes series resonant at the frequency of interest by resonating its own parasitic inductance with its own small value of marked capacitance, which creates a very low series impedance, perfect for coupling and decoupling at very high frequencies). Above this series resonant frequency the capacitor itself will actually become more inductive than capacitive, making it quite important to confirm that the circuit's design frequency will not be over the series resonance of the capacitor. This is vital for coupling and decoupling functions, while a capacitor for tuned circuits should have a series resonance comfortably *well above* the design frequency. The higher the value of the capacitor, the lower the frequency of this series resonance—and thus the closer the capacitor is to its inductive region. Consequently, a higher-value capacitor will demonstrate a higher inductance, on average, than a smaller value capacitor. This makes it necessary to compromise between the capacitive reactance of the capacitor in coupling applications and its series resonance. In other words, a coupling capacitor that is expected to have a capacitive reactance at the frequency of interest of 0.1 ohm may actually be a much poorer choice than one that has a capacitive reactance of 5 ohms—unless the capacitor is chosen to operate as a *j*0 type.

Only certain capacitor classifications are able to function at both higher frequencies *and* over real-life temperature ranges while maintaining their capacitance tolerance to within manageable levels. The following paragraphs discuss the various capacitor types and their uses in wireless circuits:

Electrolytic capacitors, both aluminum and tantalum, are utilized for very low frequency coupling and decoupling tasks. They have poor *equivalent series resistance* (ESR) and high DC leakage through the dielectric, and most are