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editor

MULTIBAND INTEGRATED ANTENNAS FOR 4G TERMINALS

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For a listing of recent titles in the *Artech House*
Antennas and Propagation Series, turn to the back of this book.

This book is dedicated to Matthew Steven, Daniel William, Katherine Mary, Gregory Reginald, Harriet, George, Isobel, Weiwei, Jowita Magdalena, Paulina Elzbieta, Jaroslaw Wojciech, Miguel, Lucía, Mario, Bruno, Irene, Marina, Emil, Søren, Mille, Lærke, Lykke and Liv, our current breed, and to Mary Caroline, Sarah, Shan Yan, Elzbieta, Ángel, José, José Manuel, Marien, Sylvia, Marina, Henriette and Ane, our mates. All of them had to spend less time with us so that we could write this book, and still remain unpaid for that.

Foreword

The worldwide communication technology thirst and demands in bringing digital information to widespread end users have revived the usage of small antennas on handsets and mobile units. Architectures of future wireless communication systems are gradually coming to the realization that antennas play a vital role in the optimal and effective performance of their mobile and personal units. It is now anticipated that the design of antennas and their implantations will be given more attention at the outset of the unit's design instead of waiting to the last minute. This is particularly becoming more critical due to the needs in operating in several frequency bands and at the same time occupying a very limited available area. Additionally, constant demands in increasing information capacity have attracted utilization of multiple antennas either in diversity or MIMO operational modalities.

This book attempts to address some fundamental issues concerning small antenna designs and provide relevant representative recent developments. The seven chapters of the book are written by international experts from academia and industry who present a balanced approach among various important technical topics pertinent to small antennas. Clearly there is no single antenna design that addresses all the needs of various users and diverse variations in mobile unit's architectures and form factors. Nevertheless, there are ample recent developments discussed in this book that should provide useful guidelines for the antenna designers working in these areas.

One thing is clear that the system engineers need to lower their expectations in terms of realistic operational performance of these small antennas. There is no room for a large ground plane, there are interaction issues with other components, there is interaction with the user, and so forth. Therefore, one should not expect to achieve −10-dB return loss in the entire frequency bands of interests nor one can expect pure polarization performance and clean radiation patterns. In some applications depolarization could help the overall unit performance.

In the past, one antenna operating at one frequency band was typically the design objective. Today, there are several frequency bands and multiple antennas are required to respond to the needed information capacity and complex environmental and propagation manifests. Fortunately, advanced and powerful simulation tools have allowed the antenna researches and designers to explore the possibilities of utilizing designs that were not even dreamed of in the rather recent past. Advanced global optimization techniques have also helped in this endeavor; however, there still is a need to understand the underlying physics of this class of antennas. Various chapters of this edited book should provide a good starting point for practitioners and researches in these evolving and complex design paradigms.

I strongly believe that we are in the era that antennas for wireless communications applications are manufactured in billions. Moreover, we must remember that at no time in history have antennas come so close to the human. It is our responsibility to design effective, power-efficient, and radiation-safe devices. Antenna engineers play an important role in this digital information technology age and will influence its successful future!

Yahya Rahmat-Samii
Distinguished Professor
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July 2008

Preface

An enormous amount of research papers are available in the scientific literature for MIMO systems. Despite initial quasi-utopist ergodic capacities being considerably reduced by real implementation prototypes, MIMO techniques are foreseen as the key for solving current capacity and coverage problems of mobile communications systems. 3G bottlenecks have already been identified, and the highly efficient proposed 4G technologies will certainly make use of MIMO techniques to further reduce interference and provide for the extra capacity required in future applications, particularly at downlink. However, this will most probably require multiple antennas at both ends of the link, which highlights the importance of handset MIMO. Unlike his elder conventional MIMO brother, handset MIMO has not received as much attention. The challenges for the antenna designer are certainly astonishing in handset MIMO. While in current mobile handset designs less and less volume is made available for the antenna, at the same time this radiating element has to be able to operate on an increasingly larger number of frequency bands, corresponding to the diverse number of wireless systems typically combined in a handset. Miniaturization, integration, multiband operation, and final performance were real challenges in early designs. A few years ago acquiring the bandwidth requirements for multiband handsets with relatively relaxed VSWR and integration within the handset case was just about the only petition to handset antenna designers. Extraordinarily quickly developed multiband techniques, some of which will be described in this book, soon made multiband handsets a commercial reality. In addition, computing capabilities of handset on-board processors, mainly aimed at the need for real-time video monitoring, vectorial-game-processing, or functional wideband access to Internet, have increased considerably due to market demands. This has conveniently helped space-time processing (STP) algorithm development, which is currently being beta tested for handsets. Surprisingly, smart MIMO multiband handset antenna engineering has not received as much attention, although this tendency is rapidly changing. While antenna designers are ready for new challenges, the need for handset MIMO is currently market-driven, but information is scarce and rarely shared at commercial level. In consequence, the aim of this book is to provide the advance reader with a conjunction of the recently developed multiband techniques for handset antennas and their inherent possibilities and limitations in handset MIMO, conveniently jointly studied and congruently united in a single book by several experts in the field.

The book begins with an introductory chapter (Chapter 1) covering multiband antenna theory and size reduction techniques. There are specific issues to be addressed when reducing the size of an antenna and the performance of small antennas and small antenna theory will help the reader understand the rest of the book. Chapter 2 is devoted to antenna designs capable of both multiband and multisystem operation. While wideband is a commonplace need for fixed wireless communications, the requirements for multiband integrated antennas may have relaxed a little in comparison. VSWR or radiation patterns may not need to be as good as when the antenna is not integrated. However, multiband techniques making use of the available volume are not simple, and are inherently dressed up with some drawbacks that will be highlighted in this chapter. Among the diverse multiband techniques, there has been some discussion about the trade-offs of using wirelike or patchlike antennas for handset antenna design. In Chapter 3, planar wire antennas will highlight the benefits of a hybrid solution. In contrast, Chapter 4 will concentrate on the benefits of printed fractal techniques on handset antenna design. Particular emphasis is placed on the multiband properties and capabilities of these antennas. PIFA-like slotted patch antennas will be reviewed in Chapter 5, as well as some innate practical aspects of miniaturization, such as the effect of the chassis, on final performance. With all previous multiband antenna designs in mind, the antenna engineer faces the further challenges of the future advent of 4G. MIMO techniques are a hot research line since they are part of 4G systems, but the specific aspects of MIMO techniques when employed in a reduced-volume such as the handset are yet to be fully addressed. Chapter 6 is aided to identify the effects of radiation and mismatch efficiency, inherently critical when antennas are integrated in a handset, on final MIMO capacity or diversity gain figures. This includes the effect of the presence of the user on final handset MIMO performance. Likewise, novel MIMO techniques to be specifically ideal for handset design, such as the true polarization diversity (TPD), are explained and compared to more conventional spatial, pattern, or polarization diversity techniques. Finally, Chapter 7 is aimed to identify the current role of antenna design in 4G handset production when evaluated in terms of communications performance, and it also serves as the conclusion. Chapter 7 reviews the most important parameters when evaluating communications performance and highlights the role of the antenna system and its effect on these parameters. This last chapter is very helpful for identifying key design parameters since the impact on final performance results is deeply analyzed. The importance of an adequate antenna system design and construction is clearly reinforced in this chapter.

With the information provided in all chapters it becomes obvious that the antenna design has to be integrated into handset design at the very early stages, and that an increasingly important role of antenna design will require hands-on knowledge of both theoretical and practical aspects. While tremendous efforts are placed on gaining 1 or 2 dB in the MMIC, 10-dB differences in mean effective gain (MEG) are commonplace, and the use of smartly designed and truly integrated antennas could help the communications performance much more that it does today.

I sincerely hope that you find this book useful for your research or technological projects, and apologize in advance for the unavoidably complex scientific jargon and structure of the material we have prepared, as well as for those inevitable mistakes we could have made in the writing and editing processes.

I also have to express my sincere thanks to all authors for accepting my invitation, for their patience on my sticking-to-schedule demands, and particularly to Eric Willner, Jessica Thomas, Allan Rose, Rebecca Allendorf, and Barbara Lovenvirth, commissioning and developmental editors for the publisher at different stages, for their encouragement and support all throughout the making of this work.

Good reading.

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July 2008

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CHAPTER 1

Electrically Small Multiband Antennas

Steven R. Best

1.1 Introduction

In today's environment of almost constant connectivity, wireless devices are ubiquitous. As the RF electronics technology for these wireless devices continues to decrease in size, there is a corresponding demand for a similar decrease in size for the antenna element. Unfortunately, the performance requirements for the antenna are rarely relaxed with the demand for smaller size. In fact, the performance requirements generally become more complex and more difficult to achieve as the wireless communications infrastructure evolves.

In the early deployment of cellular, Digital Cellular System (DCS), Personal Communications Service/System (PCS), and Global System for Mobile Communications (GSM) networks, the wireless device typically had to operate within a single band, defined by the specific carrier's license(s). In today's environment, the wireless device is often required to operate in more than one band that may include several GSM frequencies, 802.11 (Wi-Fi), 802.16 (Wi-Max) and Global Positioning System (GPS) as defined in Table 1.1. Frequencies below GSM 800 are not presented.

From the antenna engineer's perspective, an antenna that operates continuously without tuning from 824 MHz through 2,500 MHz is considered a single band but also wideband antenna. In today's wireless device terminology, an antenna that covers more than one of the wireless communications bands is considered a multiband antenna. For example, an antenna that simultaneously covers two separate bands encompassing frequencies of 824–960 MHz and 1,710–1,990 MHz is considered a four-band or quad-band antenna since it provides coverage of the GSM 800, GSM 900, GSM 1800, and GSM 1900 frequencies.

In addition to dealing with the challenges of designing a small antenna, antenna engineers must also deal with the challenge of designing the small antenna to operate over multiple frequency bands. The chapters that follow in this book discuss many of the advanced techniques used in the design of small multiband antennas. This chapter serves as an introduction to the remaining chapters in that it introduces the definition of a small antenna, it provides definitions of the fundamental performance properties of antennas, and it details fundamental limitations associated with the design of small antennas. In addition, this chapter provides a discussion on the most fundamental approaches and antenna types used in the design of small wideband antennas. Finally, it concludes with a discussion on the effects of the finite ground plane on antenna performance, a significant issue in the design of integrated antennas, where the ground plane may be a significant or dominant portion of the radiating structure.

Table 1.1 Wireless Communications Bands and Their Frequency Designations

Band Designation	*Alternate Description(s)*	*Transmit Frequency (Uplink) (MHz)*	*Receive Frequency (Downlink) (MHz)*
GSM 800 or GSM 850	AMPS DAMPS	824–849	869–894
P-GSM 900	Primary GSM 900	890–915	935–960
E-GSM 900	Extended GSM 900	880–915	925–960
GSM-R 900	Railways GSM 900	876–915	921–960
T-GSM 900	TETRA GSM 900	870.4–915	915.4–921
GPS		N/A	1,565.42–1,585.42
GSM 1800	DCS 1800	1,710–1785	1,805–1880
GSM 1900	PCS 1900	1,850–1910	1,930–1990
UMTS		1,885–2,025 1,710–1,755 (US)	2,110–2,200 2,110–2,155 (US)
802.11 b/g/n	Wi-Fi; ISM	2.4 – 2.4835 GHz ISM	
802.11 a/h/j	Wi-Fi; UNII	5.15–5.35 GHz (UNII) 5.47–5.725 GHz 5.725–5.825 GHz (ISM/UNII) 4.9–5 GHz (Japan) 5.03–5.091 GHz (Japan)	
802.15.4	Zigbee	898 MHz 915 MHz 2.4-GHz ISM	
802.15.1 1a	Bluetooth	2.4–2.4835-GHz ISM	
802.15.3	UWB	Typically > 500 MHz bands within the 3.1 – 10.6-GHz spectrum	
802.16	Wi-Max	Various bands within the 2–11-GHz spectrum. Mobile Networks: 2–6 GHz Fixed Network: < 11 GHz	

1.2 The Definition of Electrically Small

Prior to defining the performance properties and fundamental limitations of the electrically small antenna, it is necessary to define the parameter that establishes whether or not the antenna is in fact, electrically small. Consider a typical device integrated antenna mounted at the center of a large, conducting ground plane, as shown in Figure 1.1. Mounted at the center of a large ground plane, the