

Multiband Integrated Antennas for 4G Terminals

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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!

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July 2008

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

<i>Band Designation</i>	<i>Alternate Description(s)</i>	<i>Transmit Frequency (Uplink) (MHz)</i>	<i>Receive Frequency (Downlink) (MHz)</i>
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

Q defined in (1.12) and (1.14) will hold over a wide range of frequencies. Additionally, the equivalent Q determined from the inverse of the antenna's bandwidth, Q_B , will be greater than the lower bound defined in (1.15).

For the antenna exhibiting the return loss behavior depicted in Figure 1.12, where the impedance match extends over multiple operating bands or frequencies of minimum return loss, there will be multiple impedance resonances (and/or antiresonances) within the specified VSWR bandwidth and the relationships between impedance, bandwidth, and Q , defined in (1.12) and (1.14) may not hold over narrow or wide ranges of frequency. Additionally, the equivalent Q determined from the antenna's impedance properties, Q_Z , and the inverse of the antenna's bandwidth, Q_B , may be less than the lower bound defined in (1.15). However, the antenna's exact Q determined from (1.11) will always be greater than this lower bound.

Finally, in any of the return loss graphs presented in Figures 1.10 through 1.12, it is possible for closely spaced multiple impedance resonances to exist within the frequencies of minimum return loss.

1.6 Fundamental Approaches to Small Integrated Antenna Design

The primary focus of this text is the discussion of the design and performance properties of multiband integrated antennas. While this chapter covers introductory or fundamental topics, the remainder of the book focuses on general and specific design approaches for achieving multiband operation with an integrated antenna. These approaches include discussions and examples of planar (wire and patch) antennas, multiband fractal antennas, the planar inverted-F antenna (PIFA), and so forth.

Prior to the specific details of these advanced design approaches, this section discusses the basic performance properties of the wire monopole antenna, its transition into an inverted-L antenna (ILA), an inverted-F antenna (IFA), and finally into the PIFA. The emphasis here is to discuss the basic trade-offs associated with reducing the size of the antenna and the simple technique for impedance matching used in the IFA and PIFA antennas. There is no attempt here to optimize any of the antenna designs for a specific size, frequency of operation, bandwidth, or multiple band operation, which will be dealt with in other chapters.

1.6.1 The Monopole Antenna

Consider a straight-wire monopole antenna that is assumed to be mounted over an infinite, highly conducting ground plane. The monopole antenna exhibits its first series resonance at a frequency where its height, h , is approximately equal to $\lambda/4$. At this resonant frequency its radiation resistance is approximately 36Ω , its conductor loss resistance is relatively low (for reasonable conductor diameters), its radiation efficiency is in excess of 90%, and its 3:1 fractional VSWR bandwidth is typically on the order of 25% (relative to 50Ω , the monopole is not matched at resonance). The actual bandwidth will vary as a function of conductor diameter.

In virtually all modern wireless communication applications in the 824-MHz–2.5-GHz frequency range, the $\lambda/4$ monopole (and associated ground

plane) is too large for device integration. With decreasing frequency (and fixed height) or decreasing height (and fixed frequency), the monopole's reactance becomes increasingly capacitive and the radiation resistance is eventually ($ka \leq 0.5$) given by [1],

$$R_r \approx 40\pi^2 \left(\frac{h}{\lambda}\right)^2 \quad (1.19)$$

The increase in capacitive reactance and reduction in radiation resistance result in an increase in VSWR, mismatch loss, and a reduction in radiation efficiency. There is also an associated decrease in the fractional VSWR bandwidth with decreasing height. Both the decrease in radiation resistance and bandwidth have been shown to be directly a function of the reduction in antenna height, or more precisely, the value of $(h/\lambda)^2$ [9]. Typically, in the design of small antennas, the first significant challenge is mitigating the high VSWR and mismatch loss by first tuning the antenna to resonance and then impedance matching the antenna to the desired characteristic impedance Z_{CH} , or designing the antenna such that its radiation resistance is equal to Z_{CH} .

For reasonable values of ka , ($0.1 \leq ka \leq 0.5$), the radiation efficiency may be less of an issue with appropriate choice of conductor diameter and antenna design. In addition to being a function of ka , practical issues associated with the choice of design frequency also become significant. As noted earlier, it is easier to design a small antenna at HF frequencies than it is at the frequencies associated with typical wireless communications systems, which primarily operate between 800 MHz and 2.5 GHz or higher.

Finally, the maximum achievable bandwidth is generally limited by the lower and upper bounds defined in previous sections. Achieving bandwidths that approach these bounds can be challenging and often requires judicious approaches to the antenna design and full use of the physically available volume and/or full ka sphere [10, 11]. Optimum bandwidth is usually achieved when the radiating electric currents are such that they flow along the outside volume of the sphere defined by the value of ka .

Considering again the short monopole that has increasing capacitive reactance and decreasing radiation resistance, the first objective is to make it resonant (tuning) and the second objective is to then match it to the desired characteristic impedance, typically 50Ω . Tuning of the resonant frequency is easily accomplished by making the short monopole an inverted-L as described in the next section.

1.6.2 The Inverted-L Antenna

A short, straight-wire monopole as described in the previous section has a high capacitive reactance and a low radiation resistance as defined by (1.19). Tuning of the capacitive reactance such that the total feed point reactance X_A is equal to 0 is easily accomplished by increasing the conductor length while at the same time maintaining the same height, h , where $h \ll \lambda$. One of the simplest techniques for tuning a short wire is the inverted-L configuration, as illustrated in Figure 1.13. An alternate view of this configuration is that the straight-wire monopole of height $h = \lambda/4$ is bent over to reduce its height. This maintains nearly the same res-

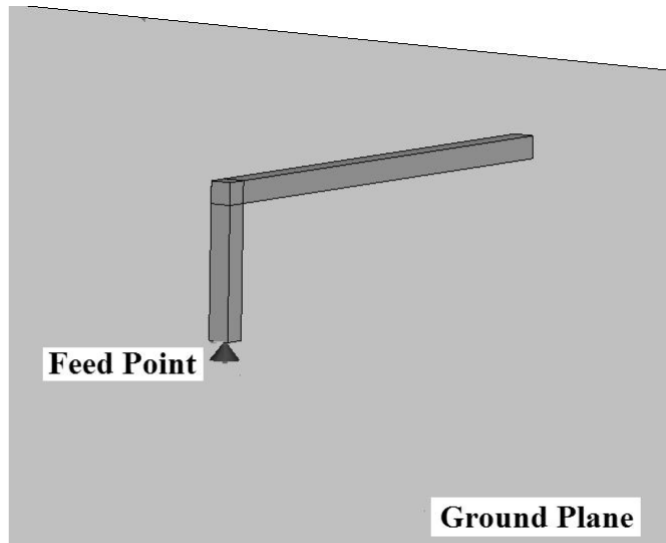


Figure 1.13 Depiction of the inverted-L antenna designed to operate at 2.45 GHz.

onant frequency but the radiation resistance and bandwidth are reduced as a function of the decreasing value of $(h/\lambda)^2$.

If the overall cylindrical diameter of the inverted-L antenna is too large, the horizontal section of wire can simply be meandered in nearly any geometric configuration to reduce the antenna's overall diameter. Meandering does not necessarily have a significant effect on the resonant frequency, which, as necessary, can easily be adjusted by increasing or decreasing the wire length for a decrease or increase in resonant frequency, respectively. The radiation resistance of the meandered inverted-L antenna does not change appreciably, particularly with respect to a 50Ω characteristic impedance, since the value of $(h/\lambda)^2$ does not change appreciably.

A typical curve of impedance versus frequency for an Inverted-L antenna is shown in Figure 1.14, where the low radiation resistance at resonance is evident on the Smith chart. This inverted-L antenna, similar to that depicted in Figure 1.13, has a height of 8 mm and a total conductor length of 29.8 mm. The conductor diameter (width) is 1 mm. It is resonant at approximately 2.45 GHz with a resonant resistance of $7.9\ \Omega$. The inverted-L is mounted over an infinite ground plane. The next design step is to impedance match the inverted-L by making it an inverted-F antenna, as described in the next section.

1.6.3 The Inverted-F and Planar Inverted-F Antennas

Inverted-L antennas as described in the previous section typically have low resonant resistances. A typical curve of impedance versus frequency was presented in Figure 1.14. Any antenna that exhibits this behavior ($R_A(\omega_0) \ll Z_{CH}$) can be impedance matched to Z_{CH} using a parallel inductance connected directly at the feed point. When a relatively large value of parallel inductance is connected at the feed point, there is only a marginal change in the antenna's total feed-point impedance. When a relatively small value of parallel inductance is connected at the feed point, there is a substantial transformation of the antenna's total feed-