Modern Small Antennas

If you're involved in designing and developing small antennas, this complete, cutting-edge guide covers everything you need to know. From fundamentals and basic theory to design optimization, evaluation, measurements, and simulation techniques, all the essential information is included. You'll also get many practical examples from a range of wireless systems, whilst a glossary is provided to bring you up to speed on the latest terminology. A wide variety of small antennas is covered, and design and practice steps are described for each type: electrically small, functionally small, physically constrained small, and physically small. Whether you are a professional in industry, a researcher, or a graduate student, this is your essential guide to small antennas.

Kyohei Fujimoto is a Professor Emeritus at the University of Tsukuba, Japan, and is also a Senior Scientist at the Foundation for Advancement of International Science. He has published extensively on the subject of antennas and has written several books including the classic *Small Antennas* (1987). He is a Life Fellow of the IEEE, a Fellow of the IEICE, and a member of Sigma Xi.

Hisashi Morishita is a Professor in the Department of Electrical and Electronic Engineering at the National Defense Academy, Japan, where he has worked since 1992. His research has long been concerned with small antennas and mobile communications, on which he has so far published many papers in major technical journals. He is a member of the IEICE and a senior member of the IEEE.

"*Modern Small Antennas* is a clearly written, comprehensive, yet practical treatment for the design and development of the physically small and compact antennas required by many of today's wireless systems. It is an indispensable day-to-day desk reference for the small antenna designer."

Gary A. Thiele, University of Dayton

"This book on small antennas is masterfully written. The wealth of design information on the state-of-the-art on small antenna configurations is unparallel to any existing book on this subject. Both the antenna practicing engineers and researchers should find the book very valuable."

Yahya Rahmat-Samii, University of California, Los Angeles

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Preface

Small antenna, big impact!

More than 20 years have elapsed since the first book on small antennas was published in 1987. Small antennas have been used for a long time, from the earliest communications to present-day applications in various small wireless systems; typically mobile phones and other hand-held equipment that emerged into common use several decades ago. Publication of the first small-antenna book dates back to 1987, starting with its planning in 1981, when we, the late Professor J. R. James and I (Fujimoto), saw the necessity of a book on small antennas. At that time design techniques vital for development and successful fabrication of small antennas had not been systematically treated and were seldom even recorded in the literature. Hoping to improve that situation, we agreed to produce a book entitled "Small Antennas." Six years later, in 1987, Research Studies Press, UK, published the book as the first text devoted to small antennas. We intended the book to provide data and information that should assist with the analysis, design, and development of practical small antennas. We were pleased that the book was used worldwide and was recognized as useful by many people who had taken advantage of data and practical examples provided in the book.

Now, more than 20 years later, I recognized that the original book no longer matches current trends in the discipline, and it calls for extensive updating to reflect current trends in advanced antenna technology and acute requirements of these times.

Coincidentally, at the ISAP 2006, Singapore, in 2006, quite a few attendees there asked me about renewal of the book "Small Antennas." There was a common recognition of the expanding boundaries of the wireless world that had grown with newly evolved systems, for which advanced antennas were required. Then, the present authors (Fujimoto and Morishita) started planning a renewed book and gathering materials necessary for it. I was happy at that time for having received inquiries of publishing a book on small antennas by some publishing companies, among which was Cambridge University Press (CUP), in the United Kingdom. Then, I contacted Dr. Julie Lancashire, Engineering Editor of the CUP, and got agreement for publishing a renewed version of "Small Antennas." Dr. Lancashire was formerly a commissioning editor of Artech House, UK, who supported us (the late Professor J. R. James and me) in editing "Handbook of Antenna Systems for Mobile Communications."

Today, small antenna technology has advanced along with progress in various wireless systems, for which small antennas are required. The most typical wireless systems requiring small antennas were mobile phones, having progressed to date through at least

four system generations. Mobile phones have evolved well beyond traditional voice-communication instruments to widely versatile systems, often referred to as "smart phones" and hand-held "tablets" that function as information terminals, being capable of handling high-rate data and video transmissions (both still and moving pictures) in addition to standard telephone capabilities. Besides mobile phones, numerous other types of wireless systems have been deployed. Representative systems are NFC (Near Field Communication), including RFID (Radio Frequency Identification), broadband wireless such as WLAN (Wireless Local Area Network) and WiMAX (Worldwide Interoperability for Microwave Access), wireless power transmission, radio control, body-centric communications, medical systems, and so forth. Most of these systems need small and compact antennas, as the equipment is generally very small and normally requires internal antennas to avoid damage in normal handling and to lend convenience for operators as well as better appearance.

This book is designed to provide readers with the latest data and information that would be useful for engineers and researchers to design and develop small antennas, placing particular emphasis on practical usefulness. With that emphasis on practicality, this book purposely does not aim to concern itself too deeply with underlying theory. Extensive bibliographic references accompany each chapter to guide readers needing to pursue details to a greater degree.

It is worth mentioning that this book is unique in treating four types of small antennas, differing from conventional small-antenna books so far published, in which only ESA (Electrically Small Antennas) are dealt with. The categories of small antennas here are based on functions, physically constrained size, and physically small dimensions, in addition to electrically small size in comparison with the wavelength. Hence, the book endeavors to cover these four types of small antennas which are practically employed in various wireless systems that require not only electrically small size, but also enhanced performances or improved characteristics, even with reduced size. This book provides design concepts of small antennas, and many examples based on them are given. Novel design methods such as applications of integration techniques, inclusion of environmental materials in the antenna design, applications of electromagnetic (EM) composite structure and the latest topical EM materials like metamaterials, are described along with many examples. Antennas today are no longer a single device, but constructed within a composite structure to perform sophisticated functions even with physically small dimensions. We the authors sincerely hope that our book is useful for readers who need to design, develop, and create novel and sophisticated small antennas.

In this book, some important small antennas applicable to human body communications and those employed in medical uses such as endoscopes and cancer treatment are omitted, although they are unquestionably interesting subjects and important antennas.

Small antennas have vital importance in small wireless equipment, as in some cases they will determine the limits of system performances; in turn they can promote further deployment and advancement of novel sophisticated wireless systems and modern information systems that are beneficial and ameliorative for human life and society. Thus, even though their size is small, quite big is the impact of small antennas on the human

condition as well as on their technically related fields such as antennas, communications, and information concerns, to which they contribute greatly and significantly.

We say again "Small Antennas, Big Impact!"

The contents of this book, consisting of eleven chapters, and the persons in charge of each chapter are described briefly as follows.

Chapter 1 Introduction (K. Fujimoto)

This chapter presents introductory remarks on small antennas, starting with a brief history of small antennas, followed by comments on the current status of practical small antennas and some related subjects such as fundamental limitations and so forth. Then, explanation of the concepts underlying small antennas is given, which is unique in categorizing in a wider sense into four types that include functionally small, physically constrained small, and simply physically small, in addition to electrically small that differs from conventional books. Then, variations of small antenna types are covered briefly, ranging from simple examples like dipoles to a variety of geometries constructed with basic shapes and structures, modified structures, composite designs, and designs integrated with materials, including metamaterials.

Chapter 2 Small antennas (K. Fujimoto)

This chapter begins with a definition of small antennas categorized into four types from the viewpoint of function, physical dimensions, and partly constrained physical dimensions, in addition to dimensions small in comparison with the wavelength. The four types are: (1) FSA (Functionally Small Antenna), (2) PCSA (Physically Constrained Small Antenna), (3) PSA (Physically Small Antenna), and (4) ESA (Electrically Small Antenna). The significance of small antennas can be recognized as the essential and indispensable feature in a great many types of small wireless equipment and the fact that they may often determine the performance level of wireless systems; in turn, newly emerged wireless systems have been aided by small antennas in cases where they couldn't even operate properly without them.

Chapter 3 Properties of small antennas (K. Fujimoto and Y. Kim)

This chapter starts with a discussion on specific characteristics of small antennas; typically impedance, antenna Q, bandwidth, and radiation efficiency. Impedance matching of small antennas, particularly when the size is only a small fraction of a wavelength, exhibits difficulty, because of the antenna's small radiation resistance and large reactance compared with the connected circuit impedance. Some useful methods for matching are introduced. Other issues specifically noted regarding small antennas are proximity effect that cannot be avoided in almost all cases due to the installation inside small equipment.

The proximity effects usually deteriorate antenna performances; however, in a way it can be turned into enhancement of the antenna performance, when materials near an antenna can be utilized as a part of the radiator.

Chapter 4 Fundamental limitation of small antennas (K. Fujimoto)

Typical work on the fundamental limitation of small antennas is reviewed, beginning with that done by Wheeler, up to recent work by Thal. H. A. Wheeler was a pioneer who treated small antennas first in 1947, discussed performances of small antennas, and introduced the concept of the fundamental limitation of small antennas. Chu followed Wheeler's work in 1948 and derived the minimum possible Q of an antenna for either TE or TM wave mode radiation that is known as Chu's limitation. After Chu, many researchers such as Hansen, Harrington, Collin, Rothchild, Fante, McLean, Folts, Thiel, Geyi, Best, and Yaghjian discussed and calculated antenna Q by using each individual method. Best and Yaghjian uniquely gave relationships between Q, impedance, and bandwidth. Thal had shown the most verifiable Q by calculating reactive energy inside Chu's sphere, a topic that had been ignored by Chu. Hansen later showed a new method for calculating Q, which gave a more rigorous value.

Chapter 5 Subjects related with small antennas (K. Fujimoto)

This short chapter describes major subjects that concern small antennas; firstly investigation of fundamental characteristics of the small antenna, and secondly exploitation of methods or ideas of how to realize a practical small antenna. Discussed next are practical design problems that should be considered for small antennas; for instance, design issues for mobile terminals. Lastly, general topics are covered, such as problems in designing small antennas suitable for specific wireless systems, and the necessity of compromising between the theoretical designs and practical performances encountered when the antenna size is very small.

Chapter 6 Principles and techniques for making antennas small (H. Morishita and K. Fujimoto)

This chapter first covers principles of making antennas small, and follows with techniques to realize those principles for four types of small antennas. Each type is introduced with examples. One of the significant methods is to use materials, especially recently developed metamaterials (MM), by which novel small antennas may be created. Use of materials composed with SNG (Single Negative) and DNG (Double Negative) materials, including NRI (Negative Refractive Index) TL (Transmission Line) MMs, is described. A review to solve matching problems in very small antennas with application of SNG materials in the near field of a radiator is given.

Later in the chapter, optimization techniques in designing are introduced. Small antenna designers often encounter difficulty when an antenna is either too small to treat or is located in a complicated environment. Optimization techniques may be useful to ease such difficulty in designing. Four typical optimization techniques, GA (Genetic Algorithm), PSO (Particle Swarm Optimization), TO (Topology Optimization), and VMO (Volumetric Material Optimization) are described along with some application examples.

Chapter 7 Design and practice of small antennas I (K. Fujimoto)

This lengthy chapter along with the next (Chapter 8) intends to provide practical design methods and illustrative examples. The chapter consists of four sections corresponding to four types of small antenna: ESA, PCSA, FSA, and PSA. This chapter is the first part, where ESA is dealt with. Design methods based on the principles shown in Chapter 6 are discussed and then numerous design examples taken from some related journals are provided.

Chapter 8 Design and practice of small antennas II (K. Fujimoto)

Following the previous chapter's treatment of ESA, this again-lengthy chapter describes design methods and practical examples for the remaining three types of small antennas, PCSA, FSA, and PSA. In FSA, methods to enhance antenna performances, typically wideband, multiband, and UWB (Ultra Wideband) operations, are described. Integration of function into antenna structure is added as an important method to produce FSA, which includes reconfigurable antennas. Typical methods to produce PCSA are applications of EM materials/structures such as HIS (High Impedance Surface), EBG (Electromagnetic Band Gap), and DGS (Defected Ground Surface) as well as PEC (Perfect Electric Conductor) ground plane, by which antennas of low profile, wide bandwidth, higher gain, and arrays with closely spaced elements are realized. Today we see various small widely deployed RFID devices, which employ very small antennas that are considered as the most representative PSA.

Chapter 9 Evaluation of small antenna performance (H. Morishita)

At first, specific problems that must be considered for evaluation of small antenna performances are discussed. In small-antenna measurements, a prime important matter is balanced and unbalanced geometries in the antenna structure and feed line to achieve measurement errors as small as possible. Optical fiber systems can replace coaxial cable systems in the small-antenna measurements to avoid serious errors due to unfavorable current flow on the feed cable. Recommended practices in measuring important antenna parameters such as impedance, radiation patterns, and efficiency are described.

Chapter 10 Electromagnetic simulation (H. Morishita and Y. Kim)

Electromagnetic (EM) simulation plays an important role in designing an antenna and finding its characteristics, especially when the antenna is too small to deal with and/or it is employed in complicated environments so that conventional design or evaluation of antenna characteristics is almost impossible. This chapter explains concepts of EM simulation first and then describes typical EM simulators. The typical simulation methods considered here are the IE3D, FIDELITY, HFSS, and MW studio, which are based on the Method of Moments (MoM), FDTD (Finite-Difference Time-Domain), FEM (Finite Element Method), and FIT (Finite Integration Technique), respectively. Examples of simulation applied to practical antenna models for either design or evaluation of performances are described.

Chapter 11 Glossary (K. Fujimoto and N. T. Hung)

This chapter gives a catalog of typical small antennas to provide readers with data and information for assisting design and development. Most of the antennas treated are covered in more detail elsewhere in the book, alongside a few antennas covered in other literature. The glossary list gives a brief view of each antenna, its antenna type, its main features, and applications for every antenna, along with references and the chapter/section number where the antenna is described.

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