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Antenna Theory and Microstrip Antennas

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ANTENNA THEORY and MICROSTRIP ANTENNAS

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内 容 简 介

本书天线基础理论部分从线、面基本辐射单元特性出发，介绍由此组成的离散和连续阵的分析综合. 对天线的几个主要参数，系统给出了多种表示法及其相互联系; 极化的表示和传输线理论相对应; 收发互易由计算接收天线的方向图引入. 同时也介绍了数字波束形成和智能天线等近代进展. 优化设计部分着重介绍商用软件的有效使用，其中包括空域映射、内插和外推、自适应采样等技术. 微带天线部分力求与天线基本理论紧密结合并形成系统，其中包括规则和非规则贴片的设计、方向图计算、阵列设计和有限阵阵中互耦分析、阵列近场诊断. 结合介绍高频方法介绍了微带反射阵、Fresnel 区板天线和有限尺寸对方向图的影响. 分析方法涉及腔模和全波. 在全波分析部分深入浅出介绍了谱域方法的精髓.

本书为普通高等教育“十五”国家级规划教材，可作为相关专业本科生和研究生教材，也可作为工程技术人员的参考书.

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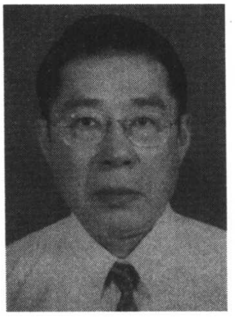
About the Author

Professor Da-Gang Fang was born in Shanghai, China, in 1937. He graduated from the graduate school of Beijing Institute of Posts and Telecommunications, Beijing, China, in 1966.

From 1980 to 1982, he was a visiting scholar at Laval University (Quebec, Canada), and the University of Waterloo (Ontario, Canada). Since 1986, he has been a Professor at the Nanjing University of Science and Technology (NUST), Nanjing, China. Since 1987, he had been a Visiting Professor with six universities in Canada and in Hong Kong. He has authored and co-authored two books, two book chapters and more than 360 papers. He is also the owner of three patents. His research interests include computational electromagnetics, microwave integrated circuits and antennas and EM scattering.

Prof. Fang is a Fellow of IEEE and CIE (Chinese Institute of Electronics), an associate editor of two Chinese journals and is on the Editorial or Reviewer Board of several international and Chinese journals. He was TPC chair of ICMC 1992, vice general chair of PIERS 2004, the member of International Advisory Committee of six international conferences and TPC co-chair of APMC 2005. He was also the recipient of National Outstanding Teacher Award and People's Teacher Medal, and the Provincial Outstanding Teacher Award. His name was listed in Marquis Who is Who in the World (1995) and in International Biographical Association Directory (1995).



PREFACE

(1) There are many excellent text books and handbooks on antenna theory and design. Recently, due to the increasing importance of microstrip antennas, several excellent text books and handbooks on them have been published and this topic has become a separate course. The purpose of this book is to serve either as a text book to cover both the antenna fundamentals and the microstrip antennas or a self-study book for those attempting to plunge into this area. This book tries to make a good balance and combination between the antenna fundamentals and microstrip antennas.

(2) For the full wave analysis and optimized design of antennas, there are many excellent books on computational electromagnetics and especially several powerful commercial softwares available. This book is devoted to the introduction of techniques useful for the effective application of these softwares. Spectral domain approach is an important tool in analyzing the microstrip structures including the microstrip antennas, in near-field measurement and in high-frequency method. This book gives a systematic introduction to this approach. The main purpose of introducing this approach is not for the numerical computation but for the understanding of some significant concepts.

(3) The literature on antennas is vast and there are a variety of mathematical formalisms and numerical schemes, which often intimidate those who attempt to enter this field. In universities, it is a great challenge for professors to cover sufficient fundamentals with reasonably in-depth practical knowledge in a one-term course. In industry, one may find it hard to get a general understanding of the field before engaging in any specialized techniques. I believe that a concise and readable book with a good treatment between scope and depth, theoretical background and application materials, foundations and recent progress will be a welcome addition to the arsenal of books on this subject.

(4) In this book, the principle of presentation is to explain profound and abstract concepts in simple terms and being concise. I tried to organize the contents logically and uniformly to lead the readers to draw inferences about other cases from one instance. Problems and answers provide necessary supplement to the text and are used as an instrument to help the readers to

gain insights and to facilitate understanding the subtle points, usefulness of the principles, and the techniques discussed in the text. This book includes my teaching and research experiences in this area over many years. Moreover, this book contains some recent developments including our own research results published in international journals. The contents of this book have been used as teaching materials in Laval University (Canada) in 1987 and in Chinese University of Hong Kong (Hong Kong) in 2002 and in Nanjing University of Science and Technology for more than a decade. For senior undergraduate-level course (two credits), the materials in Chapter 1 through Chapter 3 should be covered. The materials in Chapter 4 through Chapter 6 are suitable for graduate-level course with two credits and those in Chapter 4 through Chapter 8 are suitable for the graduate course with three credits.

(5) I have benefited from many experts through their excellent books and papers. I would like to express my sincere thanks to them, especially to Professors C. A. Balanis, W. L. Stutzman and G. A. Thiele, R. S. Elliot, R. E. Collin and F. J. Zucker, and S. M. Lin for their antenna books; J. A. Kong, N. H. Fang for their electromagnetic theory books; K. F. Lee and W. Chen, S. S. Zhong for their microstrip antenna books; R. H. Clarke, J. Brown and E. V. Jull for their diffraction theory book; Y. R. Samii and E. Michielssen for their genetic algorithm book; Q. J. Zhang and K. C. Gupta for their neural network book, J. Litva and T. K. Y. Lo for their digital beamforming book; Y. L. Chow, my former mentor when I was a visiting scholar in the University of Waterloo in 1981, for his deep insight to the complicated electromagnetic phenomena and his fuzzy electromagnetics which have been giving me a lot of enlightenment; R. Mittra, K. A. Michalski and J. R. Mosig, J. W. Bandler, E. K. Miller, C. H. Chan, K. M. Luk, E. K. N. Yung, J. Huang, K. L. Wu, D. M. Fu, R. S. Chen for their papers. Professor N. H. Fang, as the reviewer of this book, gave many invaluable comments on both the scientific content and the writing and I gratefully acknowledge his contribution. The guidance and support from my former supervisor, Academician of Chinese Academy of Science Professor P. D. Ye and Academician of Chinese Academy of Science Professor S. G. Liu are also very much appreciated.

(6) I also wish to thank my graduate students who attended my course. Their active feedback, suggestions and corrections to the manuscripts especially careful proof-reading by Y. Lu are very helpful. Some of them made important contributions to the research work involved in this book. I especially would name J. J. Yang, W. X. Sheng, Y. P. Xi, L. P. Shen, Y. X. Sun, Y. Ding, L. L. Wang, R. Zhang, C. Z. Luan, B. Chen, H. Wang, X. G. Chen, N. Shahid, N. N. Feng, H. Q. Tao, G. B. Han, F. Ling, Y. M. Tao, K. Sha,

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The support from the Ministry of Education through its listing of this book in the national scheduled text books, from the Bureau of Education in Jiangsu Province through its awarding of the antenna course as Provincial Distinguished Graduate Course, and the financial support from the graduate school and the education division of our University, the support from Professor Z. Liu, the Dean of School of Electronic Engineering and Optoelectronic Technology, and from the Defense Key Antenna and Microwave Laboratory through the grants: 00JS07.1.IBQ0201 and 51437080104BQ0206 are also very much acknowledged.

My wife, a physician, took care of my health and almost all family chores, in addition to her own busy practice to support my writing. I wish the publication of this book would partly pay back my debt of gratitude to her.

Finally, the comments and the criticisms from the readers will be very much appreciated. (E-mail: fangdg@mail.njust.edu.cn)

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CONTENTS

Chapter 1

BASIC CONCEPTS OF ANTENNAS

1.1 Introduction

For wireless systems, the antenna is one of the critical components. A good design of the antenna can relax system requirements and improve overall system performance. The wireless systems include a large variety of different kinds, such as radar, navigation, landing systems, direct broadcast TV, satellite communications, mobile communications and so on. An antenna could be as large as 100m by 100m for radio telescope or as small as the order of inches in built-in handsets. All of them play an important role in science and daily life. Today we enjoy much benefit from wireless, and the significant contributions from antenna should not be underestimated.

Antenna is an electromagnetic transducer, which is used to convert, in the transmitting mode, guided waves within transmission lines to radiated free-space waves or to convert, in the receiving mode, free-space waves to guided waves.

In 1886, Hertz demonstrated the first wireless electromagnetic system. In 1901, Marconi succeeded in sending signals over large distance from England to Newfoundland. Since Marconi's invention, through the 1940s antenna technology was primarily focused on wire related radiation elements and their operation frequencies up to about UHF. It was not until World War II that modern antenna technology was born and new elements, such as waveguide aperture, horn, reflectors, lens, etc. were firstly introduced. The first use of phased array was reported in 1937. Most of the major advances in the theory of phased array antennas and their implementation occurred in 1960s. This kind of antenna can accomplish functions which the conventional one can not do. Because the antenna beam in phased arrays can be steered to a new direction in microseconds and it may be widened or narrowed in microseconds as well, thus providing much agility. Prior to 1950s, antennas with broadband pattern and impedance characteristics had bandwidths not much greater than about 2:1. In 1950s, a breakthrough in antenna development occurred which extended the maximum bandwidth to as great as 40:1 or more by using equiangle spiral or logarithmically periodic structures. Because the geometries of these antennas are specified by angle instead of linear dimensions, they have theoretically an infinite bandwidth. Therefore, they are referred to as frequency independent. The idea of microstrip antenna was introduced in 1950s by G.A.Deschamps, but it was not until 1970s that serious attention was paid to this element. To a large extent, the development of microstrip antennas has been driven by system requirements for antennas with low-profile, low-weight, low-cost, easy integrability into arrays or with microwave integrated circuits, or polarization diversity. Disadvantages of the original microstrip antenna configurations include narrow bandwidth, spurious feed radiation, poor polarization purity, limited power handling capacity, and tolerance problems. Much of the development work in microstrip antenna has thus gone into efforts to overcome these problems so as to satisfy increasingly stringent system requirements. This effort has resulted in the development of novel microstrip antenna configurations and the development of accurate and versatile analytical models for the understanding of the inherent limitation of microstrip antennas, as well as for their design and optimization[1–4].

The good marriage between signal processing and electromagnetics results in the signal processing antenna that makes use of the all information on the aperture completely and adaptively. This kind of antenna is capable of generating independently controllable multi-beam and may be conceived as smart antenna. The digital beamforming(DBF) is a good solution to this purpose and the microstrip antenna is a good candidate to serve as the antenna element[5, 6]. Although the smart antenna is recognized as the ultimate antenna in the sense of making full use of the information on the antenna aperture, it never closed the way of antennas development. The history from Hertz dipole in 1886 to the smart antenna in recent years shows that the application requirements have always been the motivation of the development of antennas. Both in the present time and in the future, there are many challenging problems facing the antenna scientists and engineers.

Advances made in computer architecture and technology during the 1960s-1980s have had a major impact on the advance of modern antenna technology, and they are expected to have an even greater influence on antenna engineering in the 21 century and beyond. Beginning primarily in the early 1960s, numerical methods were introduced that allowed previously intractable complex antenna system configurations to be analyzed and designed very accurately.

While in the past antenna design may have been considered a secondary issue in overall system design, today it plays a critical role. In fact, many system successes rely on the design and performance of the antenna. Also, while in the first half of 20-century antenna technology may have been considered almost a "cut and try" operation, today it is truly an engineering art. Analysis and design methods are such that antenna system performance can be predicted with remarkable accuracy. In fact, many antenna designs proceed directly from the initial design stage to the prototype without intermediate testing. The level of confidence has increased tremendously.

1.2 Radiation Mechanism

Now let us explain the mechanism by which the electric lines of force are detached from the antenna to form the free-space waves. Figure 1.1(a) shows the lines of force created between the arms of a small center-fed dipole in the first quarter of the period during which the charge has reached its maximum value (assuming a sinusoidal time variation) and the lines have traveled outwardly a radial distance $\lambda/4$. During the next quarter of the period, the original lines travel an additional $\lambda/4$ (a total of $\lambda/2$ from the initial point) and the charge density on the conductors begins to diminish. This can be thought of as being accomplished by introducing opposite charges, which at the end of the first half of the period have neutralized the charges on the conductors. The lines of force created by the opposite charges travel a distance $\lambda/4$ during the second quarter of the first half and they are shown as dashed lines in Figure 1.1(b). The end result is that there are lines of force pointed upward in the first $\lambda/4$ distance and the same number of lines directed downward in the second $\lambda/4$. Since there is no net charge on the dipole, then the lines of force must have been forced to detach themselves from the conductors and to unite together to form closed loops as shown in Figure 1.1(c). In the remaining second half of the period, the same process followed but in the opposite direction. After that, the process continues and forms the propagation of electromagnetic wave.

1.3 Two Kinds of Linear Elementary Sources and Huygens' Planar Element[8]

In antenna problems, one is interested in determining the fields at points remote from the source. One type of the elementary source is infinitesimal dipole, which may form the wire radiator. The wire radiator could be an