REMOTE SENSING

A Series of Advanced Level Textbooks and Reference Works

MICROWAVE REMOTE SENSING

ACTIVE AND PASSIVE

VOLUME III

From Theory to Applications

FAWWAZ T. ULABY
RICHARD K. MOORE
ADRIAN K. FUNG

ARTECH HOUSE, INC.

MICROWAVE REMOTE SENSING

ACTIVE AND PASSIVE

Volume III

From Theory to Applications

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Volume III

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A Series of Advanced Level Textbooks and Reference Works

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To our Families,
whose support and encouragement made this work possible

Editor's Foreword

This volume is one of a series on remote sensing designed to cover remote sensing subjects with the breadth and depth required for use by students in graduate level courses and at the same time to serve as general reference texts for remote sensing engineering and applications scientists. The areas to be covered include theory and techniques, modeling, instruments, and applications.

The first volume, by Dr. Philip N. Slater of the Committee on Remote Sensing and Optical Sciences Center at the University of Arizona, dealt with remote sensing optics and optical systems, an area in which Dr. Slater has published extensively and has established international recognition.

The present volume will be one of three on active and passive microwave remote sensing, by Professors Fawwaz T. Ulaby, Richard K. Moore, and Adrian K. Fung of the University of Kansas. These authors have made important contributions to microwave theory, instrumentation, and practical applications from the earliest days of remote sensing in the United States, as these three volumes amply demonstrate.

It is an especial pleasure to acknowledge that each of these authors has been a patient mentor to me, and that I have learned much from them. A large number of the radar remote sensing engineers and applications scientists in the United States and throughout the world have been trained by them. A list of their engineering Ph.D. students now reads like an international Who's Who — from Korea to Thailand, Canada to Chile, Western Europe to Australia, as well as the United States. The scientists who have visited their Remote Sensing Laboratory over the last two decades have quite literally come from all over the world, and the range of their questions and interests has served to stimulate the already catholic research concerns of the group at Kansas. The extent of their teaching interests and experience, and their international experience, is reflected in this volume in the clear exposition of these experienced teachers and scientists. I commend the volumes in this series to you, and look forward to using them with my own students.

DAVID S. SIMONETT

Apologia

The original plan for this book called for 21 chapters: the first six to appear in Vol. I, the next six in Vol. II, and the last nine in Vol. III. The plan also called for publication of the three volumes in consecutive years. Volumes I and II appeared in print in 1981 and 1982, respectively, and contained the material originally proposed. Volume III, however, will not be available until 1985 and will not contain either Chapter 15, Altimeters, or Chapter 16, Synthetic-Aperture Radar Processing. For these shortcomings, we offer our sincere apologies.

FAWWAZ T. ULABY
RICHARD K. MOORE
ADRIAN K. FUNG

August 1984

Preface

Over the past two decades, *microwave remote sensing* has evolved into an important tool for monitoring the atmospheres and surfaces of planetary objects, with special emphasis on observations of the planet earth. The term "microwave remote sensing" encompasses the physics of radiowave propagation in and interaction with material media, including surface and volume scattering and emission; the techniques used for designing microwave sensors and processing the data they acquire; and the translation of the measured data into information about the temporal or spatial variation of atmospheric or surface and medium parameters or properties. Sensors usually are divided into two groups according to their modes of operation: *active* sensors are those that provide their own source of illumination and therefore contain a transmitter and a receiver, while *passive* sensors are simply receivers that measure the radiation emanating from the scene under observation. Active microwave sensors include *radar imagers*, *scatterometers*, and *altimeters*, and passive microwave sensors are often referred to as *microwave radiometers*.

Aside from their traditional meterological and military applications, radars have been used extensively for mapping geological structures and features, particularly in those parts of the world where cloud cover presents a serious problem to optical sensors. Other application areas, some demonstrated and others still in the research phase, include vegetation mapping, discrimination of sea-ice types, measuring ocean wind speed and direction, mapping soil moisture content and snow water content, and land-use evaluations. Microwave radiometers have been used from satellite platforms to retrieve the atmospheric temperature and water vapor density over the oceans, to estimate the liquid-water content of clouds and to discriminate between different types of sea ice as an aid to navigation in arctic waters. Other potential applications which are still in the research phase include the monitoring of the spatial distribution of soil moisture content and snow water content, which are important factors in agriculture, hydrology, and meteorology.

The three components of microwave remote sensing — sensor-scene interaction, sensor design and measurement techniques, and the application of microwave remote sensing in geoscience — are the subject of this book. It should be emphasized, however, that the book is written from the standpoint of the physicist or engineer working in microwave remote sensing, rather than from the standpoint of the ultimate user, such as the geologist or hydrologist. We have attempted to establish the link, based on current knowledge, between the microwave sensor response and scene parameters such as soil moisture content, through intermediary parameters like the physical temperature and dielectric properties of the scene. The next step, which usually involves the incorporation of remotely sensed data into appropriate models, or the use of the data in conjunction with other sources of information, is outside the scope of this book. For example, we shall discuss how radar is used to map linear geological features, but the methodology involving the use of such information by the geologist, as one of several inputs, for delineating mineral and petroleum exploration sites, will not be covered.

The material covered in this book is divided into three volumes. Volume I, *Microwave Remote Sensing Fundamentals and Radiometry,* starts out with an introductory chapter on the history and applications of active and passive microwave remote sensing, followed by introductory treatments of electromagnetic wave propagation (Chapter 2), antennas (Chapter 3), and microwave interaction with atmospheric constituents (Chapter 5). These three chapters are intended to provide a review of those fundamental aspects of remote sensing that are common to all types of microwave sensors. The major topic of Volume I is microwave radiometry, which is treated in Chapters 4 and 6 and the latter part of Chapter 5. Chapter 4 begins by introducing radiometric concepts and quantities of interest, and then proceeds to treat the radiometric measurement problem for atmospheric and terrestrial sources of natural radiation. Emission by atmospheric gases, clouds, and rain is covered in Chapter 5 using the radiative-transfer formulations developed earlier in Chapter 4. Chapter 6 discusses the operation and performance characteristics of radiometer receivers, with special emphasis given to measurement precision, calibration techniques, and imaging considerations.

Volume II, *Radar Remote Sensing and Surface Scattering and Emission Theory,* consists of Chapters 7–12. The fundamental principles of radar backscattering measurements are covered in Chapter 7, which include measurement statistics, angle, Doppler and pulse discrimination techniques, and associated ambiguity functions. Chapters 8 and 9 describe the operation of real-aperture and synthetic-aperture sidelooking airborne radar systems, respectively, and Chapter 10 focuses on internal and external calibration techniques employed in scattering measurements.

Approaches used for modeling microwave interaction with material media are covered in Chapters 11–13. The primary purpose of Chapter 11 is to help the reader develop a "feel" for the physical mechanisms responsible for the scattering and emission behavior of homogeneous and inhomogeneous media. This is done through discussions of specific factors governing the scattering and emission (such as surface roughness, dielectric properties, penetration depth and dielectric inhomogeneity): and through the presentation of simple semi-empirical models. Theoretical models involving a higher degree of mathematical sophistication are developed in Chapters 12 and 13, with Chapter 12 being limited to treatments of extended surfaces (as for the ocean and bare soil), while Chapter 13 (of Volume III) considers scattering and emission models for the more general case of a layer of volume scatterers (as in a vegetation canopy) over a rough surface.

Volume III contains a chapter devoted to volume scattering and emission (Chapter 13), one chapter on scatterometers (Chapter 14), and five chapters on active and passive microwave remote-sensing applications. In addition, Volume III includes a special appendix containing a summary of the dielectric properties of several types of material media, including fresh and saline water, pure and sea ice, snow, soils, and vegetation.

The three-volume combination is intended as a graduate-level, three-semester course sequence in microwave remote sensing, although the organization of the book is such that, through the appropriate selection of relevant chapters, the book may be narrowed in scope to cover one-semester courses in specific subjects, such as active microwave systems, microwave radiometry, scattering and emission theories, or microwave remote-sensing applications. Additionally, this book is intended to serve remote-sensing engineers and scientists as a reference guide to those aspects of the remote-sensing process that pertain to the microwave part of the electromagnetic spectrum.

The authors wish to acknowledge the help and support of the many people who have contributed to the development of this book. Thanks are due to the agencies that have supported our research activities, especially the National Aeronautics and Space Administration, the National Science Foundation, and the Department of Defense. We are grateful, too, to Eni Njoku of the Jet Propulsion Laboratory (JPL), Jo Comiso of NASA Goddard, Joe Waters of JPL, and Ed Westwater of the National Oceanic and Atmospheric Administration for their helpful reviews of portions of this volume. We wish to give special thanks to our students, who have suffered through several semesters of having a text in the form of notes and who have provided many suggestions for improving and clarifying the presentation. Moreover, we are very grateful to Vera Sehon and her colleagues Megan Gannon and Chuck Andrew, of the Graphic Arts Service at the University of Kansas Center for Research, for their cheerful perseverance while completing the extensive artwork and photographic processing associated with this book.

Above all we wish to thank Kathy Brinkman and Julie Banhart for preparing the manuscript, and Lee Blackledge for her help in polishing its prose and syntax and coordinating its many parts.

FAWWAZ T. ULABY
RICHARD K. MOORE
ADRIAN K. FUNG

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