Passive Microwave Remote Sensing of the Earth

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Preface

The inclusion of the methods and means of microwave diagnostics into space observations in the 1970s was, undoubtedly, a significant landmark in the development of remote sensing of the Earth as a whole. When compared with the use of just the optical and infrared spectral ranges, the study and understanding of the microwave patterns in the Earth's surface–atmosphere system brings the essentially different physical information capacity of microwave sensing to the study of terrestrial objects. It is this circumstance that has drastically changed both the configuration of potential satellite systems, designed for sensing the Earth, and the character and information saturation of remote sensing as a whole. At present, none of the planned large satellite missions for investigating the Earth (or, which is interesting, those for detailed investigation of the planets) manages without applying either passive or active radiophysical devices in some configuration. In addition, the other advantages of microwave diagnostics – such as the possibility of obtaining information at any time of the day, the wide weather range, the independence of solar illumination – have attracted the attention of a great swathe of researchers. And, in many cases, it has been these circumstances that have played a key part in the early stages of introducing radiophysical methods into remote-sensing tasks. However, the subsequent development of these methods has shown that the basic importance of introducing them into remote sensing is on a quite different plane, that is in the diffraction nature of the interaction of microwave electromagnetic waves with rough objects of the Earth's surface and with meteostructures in the Earth's atmosphere, and, on the other hand – with the features of quantum radiation of physical objects in the microwave range.

An obviously high physical information capacity of microwave methods has impelled a lot of experts in various disciplines – meteorologists, geophysicists, oceanologists, geologists, soil scientists – to actively participate in mastering remotely sensed microwave information. However, not possessing special knowledge in radiophysics, interested researchers sometimes interpret wrongly the radiopatterns of the physical objects they are studying because they are using geometrical optics methodology for the optical range, which is natural for a human being. The author has had many opportunities to discover this fact through his personal experience in collaborating with experts in various disciplines during his 25-year period of work in the area of microwave remote sensing of the Earth.

In the field of the application of microwave observation data, a book was needed which would give a systematic and unified presentation of the fundamental statements and basic principles of the theory of natural radiation of physical objects, as well as of the various instrumental and methodological issues of microwave measurements. In addition, it seemed useful to present a unified and systematic description of recent achievements in microwave sensing, which would be easily accessible to advanced undergraduate and postgraduate students, to researchers and to instrument engineers. For this reason, unlike the well-known microwave sensing monographs, the present book was conceived, on the one hand, as a manual for a course of lectures on radiophysical methods in the remote sensing of the Earth and, on the other hand, as a text giving a systematized idea of the possibilities and modern achievements of the microwave diagnostics method, intended for a wide range of specialists and other interested readers.

The present book was prepared on the basis of lecture courses delivered by the author for many years (1975–2002) to senior students at the Moscow Physical and Technical Institute (Dolgoprudny town) and at the Moscow State University of Geodesy and Cartography (Moscow). This approach has substantially conditioned both the structure of the book and the character of the educational material. The presentation is configured in such a manner that the reader can acquire the necessary fundamental knowledge of the quantum mechanism of thermal radiation, and the most complete ideas on the modern level of development of microwave diagnostics. The content of this book is much broader than the requirements usually claimed for a manual for students. Many parts of the book contain detailed information and can be used as a work of reference on some special issues of microwave remote diagnostics.

Chapter 1 deals with the science and application aspects of remote sensing of the Earth, the role and place of radiophysical methods, the basic statements of electromagnetic theory, the physical features of thermal radiation, and the possibilities of passive and active microwave diagnostics methods. Chapter 2, devoted to basic statements of the representation and transformation of random signals and fields, has a reference character to some extent. Nevertheless, the information given in this chapter will be very necessary for further mastering of the material. The basic methods and schemes of noise signal measurement are considered in Chapter 3.

The fundamental law of nature, which relates the quantum fluctuation radiation of an object of any physical nature with its dissipation macro-properties and is named the fluctuation–dissipation theorem (FDT), is the subject considered in Chapter 4. In addition, this chapter analyses the quasi-stationary FDT approximation, known as the Nyquist formula, and the geometric-optical approximation – the Kirchhoff law – which are very important for applications. Chapter 5 chiefly pays attention to the basic characteristics of radiation fields and to the physical aspects of forming the radiation fields of microwave antennas. This chapter also considers the basic methods of measuring the parameters of ground and onboard antenna systems, introduces the equation for antenna smoothing and analyses the procedures of reconstruction (restoration) of radio-emissive microwave images.

The absolutely black-body model, which is paramount in thermal radiation theory and practice, and the fundamental laws of radiation of such a system are subjects of consideration in Chapter 6. Here the concepts of the emissivity of physical bodies of grey-body radiation character are introduced, and the experimental data on natural media emissivities are presented. The more detailed analysis of features of grey-body radiation and the elementary (but, nevertheless, widely used in observational practice) physical models for calculating the media of grey-body radiation character are considered in Chapter 7. Chapter 8 presents the rich set of experimental observational data on emissive characteristics and dielectric properties of substances distributed both on the Earth and on terrestrial planets.

Chapters 9 to 11 present the phenomenological basis and also give the analysis of basic equations and fundamental statements, which are necessary for studying radiation transfer in absorbing, radiating and dissipating media. The formal and approximate solutions of the equation of radiation transfer, presented in Chapter 9, are widely used in later chapters for consideration of the radiation transfer in disperse media (hydrometeors and aerosols in the atmosphere). Here an important component of the analysis is the consideration of diffraction scattering (Mie scattering) of electromagnetic waves on the individual particles (Chapter 10) which form the disperse mixtures. A principally new (namely, quantum-mechanical) methodology is offered in Chapter 11 to describe the radiation transfer in gaseous media with subsequent derivation of the transfer equation for the photon gas. The features of selective types of gas systems' radiation, principal among which are the physical mechanisms of line broadening and the modern shapes of lines, are outlined in detail here.

On the basis of the data obtained in previous sections, the spectral patterns of microwave radiation are formed in Chapter 12 for the ocean–atmosphere and land–atmosphere systems for observations from satellites and aircraft. The main focus is on the latest experimental results from studies of the thermal radiation of disturbed sea surface, cloudy atmosphere with various types of hydrometeors and moist soil surfaces with various types of vegetation. This chapter can be considered, to some extent, as a brief review of the modern state of microwave sensing.

In Chapter 13 the reader will find the detailed analysis of inversion problems in microwave sensing. This chapter includes consideration of empirical, semi-empirical, and physical algorithms for advanced inversion procedures.

Chapter 14 is devoted to the detailed historical analysis of time evolution of microwave airborne and spaceborne missions beginning with the first successful launches of Russian 'Kosmos-243' and 'Kosmos-384' satellites carrying microwave, multifrequency instruments. The original Russian microwave systems and then more modern ones are outlined in detail. The contemporary situation in the equipment part of planned microwave missions, the ways observation techniques and methods developed, the antenna systems, and the mastering of new frequency ranges are also considered in detail in this chapter.

The book's detailed Bibliography will certainly be useful, for both students and postgraduates in the relevant disciplines, and for researchers and engineers. These references cannot be considered exhaustive in certain more specialist areas.

Some of the experimental and natural results used in preparing this book were obtained by the author during his work in the Department of Microwave Remote Sensing of the Earth of the Institute for Space Research (Russian Academy of Sciences). The Department was headed at that time by the untimely deceased Professor V. S. Etkin (1931–1995). The natural experiments, carried out in the period of 1973–1982 with microwave equipment of heightened sensitivity, as well as the unique results obtained with these instruments, have determined in many respects the configuration of future aero-satellite microwave remote-sensing systems. The author is grateful to colleagues in the Department, whose support was indispensable for performing the unique full-scale (location) experiments, and, especially, to I. V. Pokrovskaya, M. D. Raev, M. G. Bulatov, V. M. Veselov, V. G. Mirovsky, I. V. Cherny, and V. Yu. Raizer. The author greatly regrets that we have already lost such active participants in the first stage of the experimental work as E. A. Bespalova and Yu. A. Militsky, who made so significant a contribution to its organization and implementation.

The author is grateful to Mr Yu. Preobrazhenskii for his constructive approach in translating the manuscript into English. The typing of the intricate draft by Mrs Nataly Komarova is appreciated. I also wish to express my thanks for the support and encouragement received from Clive Horwood, Chairman of Praxis Publishing.

The author has taken advantage of the advice and recommendations of his colleagues throughout the time the manuscript has been in preparation.

Acknowledging the complexity of the subject matter of this publication and desiring to perfect his presentation of it, the author will be glad to receive constructive comments and suggestions from interested readers (email: esharkov@iki.rssi.ru).

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3 False-colour polar projection map of 1.55-cm microwave radiometer data obtained on 16–18 December 1972 from the Nimbus 5 satellite in the vicinity of the South Pole. The white area enclosed in the upper right corner of Antarctica is open water in the Ross Sea between the Ross Ice Shelf and the sea ice pack.

4 Optical and radiothermal images of biological structures in the visual band (left) and at frequency 600 GHz (right): (a) the image of a birch leaf; (b) the image of an oak leaf. Radiothermal images are presented with false-colour maps. Images sizes are 40×40 mm.