# PROPAGATION OF SHORT RADIO WAVES

*MASSACHUSETTS INSTITUTE OF TECHNOLOGY*

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# PROPAGATION OF SHORT RADIO WAVES

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# PROPAGATION OF SHORT RADIO WAVES

*PROPAGATION OF SHORT RADIO WAVES*

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# *Foreword*

THE tremendous research and development effort that went into the development of radar and related techniques during World War II resulted not only in hundreds of radar sets for military (and some for possible peacetime) use but also in a great body of information and new techniques in the electronics and high-frequency fields. Because this basic material may be of great value to science and engineering, it seemed most important to publish it as soon as security permitted.

The Radiation Laboratory of MIT, which operated under the supervision of the National Defense Research Committee, undertook the great task of preparing these volumes. The work described herein, however, is the collective result of work done at many laboratories, Army, Navy, university, and industrial, both in this country and in England, Canada, and other Dominions.

The Radiation Laboratory, once its proposals were approved and finances provided by the Office of Scientific Research and Development, chose Louis N. Ridenour as Editor-in-Chief to lead and direct the entire project. An editorial staff was then selected of those best qualified for this type of task. Finally the authors for the various volumes or chapters or sections were chosen from among those experts who were intimately familiar with the various fields and who were able and willing to write the summaries of them. This entire staff agreed to remain at work at MIT for six months or more after the work of the Radiation Laboratory was complete. These volumes stand as a monument to this group.

These volumes serve as a memorial to the unnamed hundreds and thousands of scientists, engineers, and others who actually carried on the research, development, and engineering work the results of which are herein described. There were so many involved in this work and they worked so closely together, even though often in widely separated laboratories, that it is impossible to name or even to know those who contributed to a particular idea or development. Only certain ones who wrote reports or articles have even been mentioned. But to all those who contributed in any way to this great cooperative development enterprise, both in this country and in England, these volumes are dedicated.

L. A. DUBRIDGE

# *Preface*

Most of the volumes of the Radiation Laboratory Series are devoted to specific radar subjects such as components, systems and their applications, or measurement techniques. This volume, however, treats the phenomena associated with the propagation of short radio waves between terminal points, whether they be the radar antenna serving a dual purpose or the antennas of a communications system. The intention is to present a summary of the state of knowledge in the microwave-propagation field at the close of the war. There has been no attempt to produce either a handbook or textbook, but only an interim report on a rapidly changing subject. An attempt has been made to survey all relevant information that was available, from whatever source, and to summarize as much of it as was feasible.

The preparation of the book was undertaken primarily by the Propagation Group (Group 42), and all of its thirty-odd members contributed either directly or indirectly to the material given here. In addition, substantial contributions have been made by authors who were not members of this group but who worked closely with the group during the war. The division of authorship was to a certain extent arbitrary. The principal criterion was, of course, familiarity with the subject matter, and where possible the people who had made original contributions were favored. There were limiting factors, however, such as the degree of availability of possible authors and the fact that it was impractical to have a large number of writers. Unfortunately, it is impossible to give adequate recognition to all those who have contributed directly or indirectly or even to represent the correct proportion of the contributions of those whose names appear here.

A vast amount of material was available for consideration—much more than could have been presented in one volume. Consequently, some topics have been omitted completely, as, for example, diffraction by trees, hills, and obstacles other than the earth or objects used as radar targets. In this case, as in some others, no significant original work on the subject was done at the Radiation Laboratory, and reviewing work done entirely by others did not appear desirable. Other subjects that have been omitted are the numerous attempts at application of radiometeorology to forecasting of radio and radar propagation performance and the climatological studies needed to make such knowledge useful on

a world-wide scale. In this case, authors were not available to undertake the work. In choosing the meteorological material that was to be presented, it was decided that in the limited time available it was feasible to present only the material considered to have the soundest fundamental background and to eliminate material that involved an appreciable amount of speculation or that would require reworking or further research to put it into the desired form. In general, throughout the book when similar decisions were necessary, they were nearly always made in favor of an exposition of selected material rather than a sketchy, uncritical report of a large amount. We are aware that despite our attempts to include data from many sources our own work tends to predominate; knowing it most thoroughly, we have treated it in greatest detail.

Much of the wartime work was necessarily done in haste without adequate preliminary planning, care in execution, or sufficient analysis of results. If we appear to be overly critical or pedantic here, the reader is asked to understand that this arises, at least in part, from the reaction of the authors to the nature of much of the source material from which the following chapters are formed. We have not hesitated to point out the need for critical examination of the data reviewed here, for such an examination must certainly be one of the first steps in further research in the field. We have also made numerous suggestions for future investigations.

The methods employed in recent propagation research are, we believe, rather important, and we have described them in some detail when it appeared that the description would aid others in future plans. Apparatus details involving radio-frequency techniques are omitted, as most of them are covered in other volumes of this series, but methods of planning experiments and of analyzing results are emphasized. The meteorological instrumentation and new measurement techniques are also emphasized, as they are of utmost importance in investigations of the effects of atmospheric refraction on microwave transmission.

Nomenclature and symbols were matters about which positive decisions were necessary if the book was to be readable. The present choice is the result of considerable deliberation and compromise among several well-established but highly conflicting systems. It embodies as much as possible of the best or of the most firmly established features of each system. A serious attempt has been made to avoid undue overlapping use of symbols but at the same time to adhere to uniform usage throughout the book; some inconsistencies appear inevitable, however.

We have attempted to acknowledge the sources of all our information, even though, unfortunately, these sources are frequently in the form of reports that possibly will never be generally available. Some of the reports cited here are beginning to appear in the literature as this material goes to press, however, and the appropriate footnote references have been inserted wherever possible. When the source of experimental material is not specifically stated, it may be assumed to be the Radiation Laboratory,

but because of the high mobility of ideas, it is not always possible to be certain of their origin. Except for the measurements on oxygen and water-vapor absorption, ship and aircraft cross sections, and a few miscellaneous items, almost all of the Radiation Laboratory material is the work of the Propagation Group or of its close associates.

The information summarized here represents a large investment of effort by many persons and agencies, and it is impossible to acknowledge fully our indebtedness to all of them. Our principal indebtedness is to the remainder of the Propagation Group, whose work contributed so much to this volume. Second, we must acknowledge particular indebtedness to the several authors who at considerable inconvenience to themselves contributed their services long after the termination of the activities of the Radiation Laboratory Office of Publications.

We should like to acknowledge specifically the very great assistance rendered by the several branches of the armed services, who contributed generously in both man power and in equipment such as boats, aircraft, housing facilities, and the many other items necessary to carry on field operations on a large scale. We should like to thank the members of the U.S. Weather Bureau and its several branch offices, whose personnel not only contributed information but in some cases participated in our research program. We are also greatly indebted to Dr. Charles Brooks of the Blue Hill Observatory of Harvard University for his meteorological advice. Most of the aircraft soundings in Chapter 3 were obtained by Robert H. Burgoyne and Earl G. Boardman, who contributed his aircraft and his services as skillful pilot. This work deserves special mention because of its hazardous and highly exacting nature.

In an attempt to ensure accuracy in reporting the work of other groups, we have submitted portions of the manuscript for review to several individuals and organizations. Particular thanks are due to the following people: Sir Edward Appleton, Dr. R. L. Smith-Rose, and the other members of the Tropospheric Wave Propagation Committee in England; Dr. John B. Smyth of the U.S. Navy Electronics Laboratory; A. B. Crawford of the Bell Telephone Laboratories; Professor Paul A. Anderson of Washington State College; Dr. H. H. Beverage of RCA Laboratories; K. A. Norton and Dr. T. J. Carroll of the Central Radio Propagation Laboratory, Bureau of Standards; and Professor C. R. Burrows of Cornell University. The corrections and suggestions offered by these men have been of great value in integrating the descriptions of the work with which they are most familiar. Thanks are also due Norma W. Donelan for her aid in final preparation of the manuscript.

CAMBRIDGE, MASS.
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DONALD E. KERR

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