Preface

Radio waves in the ionosphere was first published in 1961. Since then there have been many major advances that affect the study of radio propagation, and three in particular. The first is the use of space vehicles and rockets, which have enabled the top side of the ionosphere to be studied and have revealed the earth's magnetosphere and magnetotail. The second is the advance of the subject 'plasma physics' which has transformed our knowledge of the physical processes in ion plasmas. The third is the use of computers, large and small, which, by removing the need for laborious calculations, have changed our attitude to theoretical results, even though they are sometimes wrongly used as a substitute for clear physical thinking. Moreover some important textbooks have appeared in the intervening 20 years. They are too numerous all to be mentioned, but four have a special bearing on the subjects of this book. These are: T.H. Stix (1962), *Theory of plasma waves*; K. Rawer and K. Suchy (1967), *Radio observations of the ionosphere*; K. Davies (1969), *Ionospheric radio waves*; and V.L. Ginzburg (1970), *Propagation of electromagnetic waves in plasma.*

Some of the topics mentioned in *Radio waves in the ionosphere*, here abbreviated to RWI, are of importance in other branches of physics. Two in particular have formed the subject of numerous mathematical papers. These are (a) 'W.K.B. solutions', and (b) the study of ordinary linear homogeneous differential equations of the second order.

W.K.B. solutions have a special physical significance connected with ray theory. They are approximations that can be extended in many different ways to give higher accuracy. This is of the greatest mathematical interest, though sometimes complicated. The practical radio propagation engineer can use computed full wave solutions and rarely or never needs extensions of the W.K.B. solutions.

The differential equations governing radio propagation in a stratified ionosphere can often be reduced, over a small range of height, to equations of the second order, and a few such equations must be studied to reveal some important physical ideas.

But attempts are often made to use the same second order equation for the whole ionosphere. Many authors have tried to find all possible electron height distribution functions that can be used in this way to give solutions expressible in terms of known mathematical functions. This has led to some new results of mathematical interest, but they are only rarely of use to the propagation engineer.

For these reasons, unfortunately, the word 'mathematical' has come to mean something that the practical engineer can often disregard. The present book is concerned with ideas of theoretical physics that are useful in practical problems. The word 'mathematical' is avoided as far as possible.

This book covers roughly the same topics as RWI, but most of them have had to be treated rather differently, and some account has been added of phenomena at low frequencies where the effect of heavy ions is important. This is therefore a new book with a new title. It is not just a new edition of RWI. It is hoped that it will serve both as a textbook, for those comparatively new to the subject, and as a reference book for more experienced readers. The stress throughout is on understanding the basic physical principles, since the radio engineer who really understands the physics is well equipped to tackle practical problems.

The reader is assumed to be familiar with calculus, the theory of complex variables, vectors including the differential vector operators, matrices, and electromagnetic theory as far as Maxwell's equations and Poynting's theorem.

It is inevitable that many important topics are omitted. In most of the book it is assumed that the ionosphere is horizontally stratified, but this is only approximately true, since horizontal variations and irregularities play an important part in radio propagation. The extensive work on waves in media with irregularities is not covered here. Nor is there any discussion of reflections or scattering of radio waves from cylindrical structures such as meteor trails. The statistical mechanics of an ion plasma, and phenomena such as wave interaction, which depend on electron temperature, are only briefly referred to. In the theory of the propagation of radio waves between widely separated points near the earth's surface, the space between the earth and the ionosphere is often treated as a wave guide. This is a very large topic, beyond the scope of this book. A most powerful recent radio method of studying the ionosphere from the ground is the technique of incoherent scatter or Thomson scatter. Any account of this needs some detailed treatment of the physics of warm plasmas, and it is too large a subject to include here.

At the end of this book is a long list of references both to text books and to published papers. But no attempt has been made to provide a complete list of all important papers on the subject, since they are far too numerous. References have two main purposes. First they show the reader where to obtain more information on some topic. Second they are used to indicate who was the originator of some particular concept. This second purpose is sometimes difficult to achieve, especially when a new idea is worked out by several authors at about the same time. It must often happen that a reference cites an author who gives the clearest treatment even though he may not have been the first to publish the idea. An outstanding example of this is the dispersion relation for a cold electron magnetoplasma, often called the 'Appleton–Hartree' formula. Readers interested in the general history of ionospheric physics might find it useful to study the papers by Professor C.S. Gillmor (1976, 1978, 1981, 1982).

In the preface to the English edition of his book on electromagnetic waves in plasmas, already mentioned, Professor V.L. Ginzburg wrote: '[In the book]··· by Dr. K.G. Budden, *Radio Waves in the Ionosphere,* ··· out of 243 references to the literature, there is only one to Soviet work, and the date is 1948'. My reply to this just criticism is that, regrettably, I do not read the Russian language and this applies also to most readers outside the USSR. In 1961 when RWI was published, translations of Russian works were not readily available. The first purpose of the references was therefore best achieved by papers in western European languages. The position now is very different and there are many excellent English translations of textbooks and papers by Soviet authors. The second historical purpose of the references entails a rather tedious search of the journals, which is the task of the historian rather than the physicist. This book contains more references to Soviet work than RWI but I cannot claim that all the important ones are included. The interested reader is referred to Professor Ginzburg's own book.

I am most grateful to those readers of RWI who took the time and trouble to send in lists of errors. Particular thanks are accorded to Dr J.R. Wilts of the US Naval Electronics Laboratory Center, San Diego, California, who supplied the longest list.

I continue to be deeply indebted to all those colleagues who were mentioned in the preface of RWI. Since then others, including my research students, have contributed many useful ideas. Particular mention should be made of the group at Leicester University under Professor T.B. Jones, of workers at the Appleton laboratories (formerly at Slough, now part of the Rutherford–Appleton Laboratory at Chilton), and of workers at the British Antarctic Survey, Cambridge, especially Dr D. Jones. Special thanks are accorded to Professor J. Heading, University College of Wales, Aberystwyth, who, in correspondence over several years, has helped me to avoid rushing too far from the straight and narrow path into those complex regions where the angels fear to tread. Professor K. Suchy, Department of Theoretical Physics, Düsseldorf, West Germany, has, in his published work, contributed many important ideas and techniques to the subject. It was a pleasure to welcome him to Cambridge for the year 1980–1 as an Overseas Visiting Fellow at St John's College.

Since 1979 I have been in regular correspondence with Professor Ya.L. Al'pert, working in Moscow and we have collaborated in a research project (see Al'pert, Budden, Moiseyev and Stott, 1983). The work has contributed many valuable ideas

to this book. Professor Al'pert has been refused permission to leave Russia and has been working in comparative isolation. His own recent book (Al'pert, 1983) is a very full treatise and amplifies many of the topics discussed here.

But I am indebted most of all to the two colleagues who were mainly instrumental in getting me interested in radio waves. Professor Henry G. Booker's contributions to the theory are perhaps the most important and far-reaching of all. As an undergraduate I had the good fortune to attend his lectures in Cambridge. He has been kind enough to allow me to make free use of his extensive published work. Mr J.A. Ratcliffe was my *de facto* supervisor when I was a research student, and he was head of the Radio Section of the Cavendish Laboratory until 1960. Without his help and guidance since 1936, this book could not have been written. His own books *Magnetoionic theory* (1959) and *An introduction to the ionosphere and magnetosphere* (1972) are models of clear exposition and should be read by all readers of the present book.

Finally I must express my thanks to my wife who typed the whole book including the formulae, and to Mrs I. Tabecka for her skilful work on the diagrams.

Cavendish Laboratory,
Cambridge, 1984

K.G. Budden