Transmission lines

This rigorous treatment of transmission lines presents all the essential concepts in a clear and straightforward manner. Key principles are demonstrated by numerous practical worked examples and illustrations, and complex mathematics is avoided throughout.

Early chapters cover pulse propagation, sinusoidal waves and coupled lines, all set within the context of a simple loss-less equivalent circuit. Later chapters then develop this basic model by demonstrating the derivation of circuit parameters, and the use of Maxwell's equations to extend this theory to major transmission lines. Finally, a discussion of photonic concepts and properties provides valuable insights into the fundamental physics underpinning transmission lines.

Covering DC to optical frequencies, this accessible text is an invaluable resource for students, researchers, and professionals in electrical, RF, and microwave engineering.

Richard Collier is a former Director of the Electronic Engineering Laboratory of the University of Kent, and a former Senior Research Associate and Affiliated Lecturer at the Cavendish Laboratory, University of Cambridge. He is a Chartered Engineer, and a Fellow of the IET.

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Transmission Lines

Equivalent Circuits, Electromagnetic Theory, and Photons

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A man that looks on glass
On it may stay his eye;
Or if he pleaseth, through it pass,
And then the heaven espy.

George Herbert 1593–1633

"This book presents a new and refreshing look at the subject of electromagnetic transmission lines. The clarity of the explanations given in the book indicate Dr. Collier's many years of teaching this subject to both undergraduate and graduate level university students. It is an ideal reference book for this subject, and should be read by both scientists and electronic/electrical engineers needing to use and understand transmission lines."

Nick Ridler, IET Fellow

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Preface

The use of transmission lines has increased considerably since the author began his lectures on them at the University of Kent at Canterbury in October 1968. Now the mighty internet involves huge lengths of optical fibres, estimated at over 750 million miles, and similar lengths of copper cables. The ubiquitous mobile phones and personal computers contain circuits using microstrip, coplanar waveguide and stripline. However, despite all these widespread modern applications of transmission lines, the basic principles have remained the same. So much so, that the many classic textbooks on this subject have been essential reading for nearly a hundred years. It is not the purpose of this book to repeat the content of these standard works but to present the material in a form which students may find more digestible. Also this is an age where mathematical calculations are relatively simple to perform on modern personal computers and so there is less need for much of the advanced mathematics of earlier years. The aim of this book is to introduce the reader to a wide range of transmission line topics using a straightforward mathematical treatment which is linked to a large number of graphs illustrating the text. Although the professional worker in this field would use a computer program to solve most transmission line problems, the value of this book is that it provides exact solutions to many simple problems which can be used to verify the more sophisticated computer solutions. The treatment of the material will also encourage 'back-of-envelope' calculations which may save hours of computer usage. The author is aware of the hundreds of books published on every aspect of transmission lines and the myriads of scientific publications which appear in an ever increasing number of journals. To help the reader get started on exploring any topic in greater depth, this book contains comments on many of these specialist books at the end of each chapter. Following this will be the reader's daunting task to search through the scientific literature for even more information. It is the author's hope that this book will establish some of the basic principles of this extensive subject which make the use of some of these scientific papers more profitable.

Initially, transmission lines are described in this book in terms of an equivalent circuit containing two distributed elements. The first three chapters use this circuit to illustrate many of the features of transmission lines. Chapter 1 consists mainly of the author's lectures to first year undergraduate computer science students at the University of Kent. For this reason it is all about step waves and pulses on

transmission lines and avoids the use of Laplace transforms. This book introduces digital signals at several stages as they are by far the majority of the traffic on modern lines. The second chapter, on mainly sinusoidal waves, was given to electronic engineering students at the same university. This chapter covers the Smith chart and scattering matrices and their use in circuit analysis. Finally, the third chapter introduces the reader to coupling between transmission lines, including some unique circuits which use coupled waves.

Although these first three chapters are sufficient for many transmission line problems, there are some basic principles which this treatment omits. The most obvious ones are the values of both the velocity of propagation and the characteristic impedance which are just stated in the early chapters. Less obvious are the higher order modes of propagation which can exist on all transmission lines. So Chapter 4 covers the derivation of the capacitances and inductances needed to calculate the velocities of propagation and the characteristic impedances of many transmission lines. The method mainly uses just two line integrals from electromagnetism to derive the static fields required for the analysis. Chapter 5 uses Maxwell's equations to derive the electromagnetic wave picture of the lines. In particular it shows that the lines have multiple modes of propagation and it introduces metallic and dielectric waveguides which cannot be adequately described using a simple equivalent circuit. The treatment of Maxwell's equations is somewhat brief, as fuller descriptions are readily available elsewhere. However, the analysis of the various problems will illustrate how these important equations are used. The topic of attenuation was intentionally omitted up to this point, as it complicates the material in the earlier chapters. Chapter 6 is entirely devoted to this topic and includes both the skin effect and dispersion and the way they modify pulse shapes.

This is the point where most textbooks end, but with the rise of electrodynamics and quantum electrodynamics, the interest in the photon has greatly increased in recent years. This elusive fundamental particle or packet of energy is the basic component of all electromagnetic waves. So this book has included some thoughts on photons which bring out a few of the basic processes going on when a wave propagates. Chapter 7 concentrates on the two properties of photons: that they travel in straight lines and at the velocity of light. Many of the transmission lines are revisited to show that complex solutions of Maxwell's equations can be broken down into the propagation of plane waves. This is further developed by considering plane waves passing through dielectric and resistive films. This topic was studied by the author whilst he was working in the Microelectronics Research Laboratory in the Cavendish Laboratory at the University of Cambridge. Finally, the book ends in Chapter 8 with a close look at how photons interact with the guiding structures of transmission lines. Some of the comments in this part will prove interesting to anyone involved in photon propagation. There are various small sections at the end of this chapter on current hot-topics which could prove useful as a starting point for those interested in such areas.

The author wishes to thank the Cambridge University Press for publishing this book and in particular Julie Lancashire for commissioning the work and Elizabeth

Horne for sorting out the text. He would also like to thank the many colleagues and students at the University of Kent who made helpful comments about some of the content of the first six chapters. In particular, from the University of Cambridge, he would like to thank Professor Richard Philips and Dr David Hasko from the Cavendish Laboratory, as well as Chris Nickerby and Nilpesh Patel from Corpus Christi College for their help with the last two chapters. He would also like to acknowledge many helpful comments from Dr Nick Ridler of the National Physical Laboratory and Dr David Williams of Hitachi Cambridge.

Finally, I should like to acknowledge the loving support of my wife Ruth, who has helped to keep me going during the years needed to produce this book.