MICROWAVE TECHNIQUES

PHILIPS TECHNICAL LIBRARY

MICROWAVE TECHNIQUES

H. Mooijweer

Macmillan Education

© N.V. Philips' Gloeilampenfabrieken, Eindhoven, 1971

Softcover reprint of the hardcover 1st edition 1971

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, without permission.

SBN 333 12030 2

ISBN 978-1-349-01067-7 ISBN 978-1-349-01065-3 (eBook)

DOI 10.1007/978-1-349-01065-3

First published 1971 by

THE MACMILLAN PRESS LTD

London and Basingstoke

Associated companies in New York Toronto Melbourne

Dublin Johannesburg and Madras

PHILIPS

Trademarks of N.V. Philips' Gloeilampenfabrieken

FOREWORD

After an introduction concerning the necessity of using Maxwell's equations when dealing with phenomena in the microwave frequency range, the theoretical and experimental basis of electromagnetism is briefly summarized in the first part of this book (field strength, dielectric displacement, electric flux, Biot and Savart's law, magnetic flux, Faraday's law of induction). Maxwell's well-known laws of electromagnetism are then derived from the foregoing, in the integral form in which he first proposed them. The concept of the propagation of electromagnetic energy in the form of waves is illustrated with reference to these laws in their integral form. They are then rewritten in differential form, and the general boundary conditions for the electromagnetic field at the surface of conductors and the interface between dielectrics are discussed.

Consideration of Maxwell's equations for an unbounded dielectric (for the sake of simplicity, the dielectric is assumed lossless, and the electric field is assumed to have only one non-zero component, which is a function of time and of one position coordinate only) leads to the wave equation, with travelling plane waves as solutions; the propagation velocity, dispersion and polarization of these waves are discussed, together with the Poynting vector as a measure of the energy content of the waves.

The propagation of electromagnetic waves in a conducting medium is then discussed, and it is found that the basic wave type here is the linearly polarized plane wave. The complex notation for electromagnetic waves is introduced at this point; the theory of complex numbers is briefly reviewed in an appendix.

The solution of the wave equation in this case leads to damped travelling waves (with attenuation constant and phase constant). We then consider the transmission and reflection of plane polarized electromagnetic waves, normally incident on the interface between air and a perfect conductor, air and an ideal dielectric, and air and a lossy conductor. The concepts of standing waves (nodes and anti-nodes), the standing-wave ratio and the reflection coefficient are introduced at this stage.

The above-mentioned basic theory takes up about one third of the book: the rest is concerned with waveguides, being divided more or less equally between parallel-wire transmission lines and rectangular waveguides.

After a brief introduction to the concept of waveguides in general, we start by considering parallel-wire transmission lines (coaxial line, Lecher line, etc.). The propagation of the waves along these lines (by the TEM mode) is discussed with reference to the 'telegraphers' equations', and we are introduced here to voltage and current waves, the characteristic impedance, the propagation constant, phase velocity, group velocity, travelling and standing waves, reflection coefficient in waveguides, line segments of finite length (not terminated by a matched load), and input impedance. Various applications of lengths of parallel-wire transmission line (open or short-circuited) are then discussed: as self-inductances or capacitances in the UHF range, as wave-meter, as impedance transformer, etc. This section of the book is closed by a discussion of a number of components used in these lines (directional couplers, short-circuit plungers, attenuators, matched loads, power dividers, etc.).

The Smith chart, a useful graphical aid to the calculation of both parallel-wire transmission lines and rectangular waveguides, is discussed in an appendix.

The third part of the book deals with rectangular waveguides. We start with a theoretical treatment of the propagation of electromagnetic waves in a rectangular waveguide (solution of Maxwell's equations with the appropriate boundary conditions; solution of the wave equations by separation of the variables; the TE and TM modes; propagation constant; cut-off frequency; principal mode; phase and group velocity in waveguides; waveguide wavelength). The concept of impedance in waveguides is developed by analogy with that for parallel-wire transmission lines; we find that no absolute value of the impedance can be defined, and normalized impedances are introduced to deal with this.

Wave propagation in round waveguides and the higher modes in coaxial lines are mentioned in passing. As with parallel-wire transmission lines, we then deal with the various waveguide components, after an introduction to the information in waveguide handbooks about the more general types of discontinuities such as inductive and capacitive diaphragms. The other components dealt with include impedance transformers (sliding screw, E-H tuners, quarter-wave transformers, tapers, etc.), short-circuiting plungers, bends, transitions from waveguides to coaxial lines, attenuators, directional couplers, matched loads, T-junctions and filters.

Finally, some attention is devoted to cavity resonators. The generation and amplification of microwaves (klystron, magnetron, travelling-wave tube, etc.) and their radiation (antennae) are not discussed in this book.

Modern components based on magnetic and semiconducting materials are mentioned in an appendix.

The main aim has been to give a general picture of microwave techniques, while avoiding the reference to vector analysis which makes most of the literature on this subject so difficult to some readers.

H. MOOIJWEER.

CONTENTS

Foreword	v
1. Introduction	1
Electromagnetic fields in unbounded media	
2. Basic experiments	7
3. Maxwell's equations	20
3.1 Maxwell's equations in integral form	20
3.2 Maxwell's equations in differential form	22
4. Boundary conditions for electromagnetic fields	27
4.1 Interfaces between dielectrics	27
4.2 Interface between dielectrics and ideal conductors	31
5. Electromagnetic waves in unbounded dielectrics	33
5.1 The wave equation for plane waves	33
5.2 Polarization of waves	40
5.3 The Poynting vector	41
6. Electromagnetic waves in conducting media	45
6.1 Complex notation	45
6.2 Propagation of electromagnetic waves in unbounded conducting media	48
7. Reflection and transmission of electromagnetic waves at interfaces	52
7.1 Electromagnetic waves from free space incident on ideal conductors	52
7.2 Electromagnetic waves from free space incident on perfect dielectrics	56
7.3 Electromagnetic waves from free space incident on media of finite conductivity	60
Wave bearing systems	
8. General considerations	63

Parallel-wire transmission lines

9. Derivation of the telegraphers' equations	73
9.1 The propagation constant	78
9.2 Phase velocity and group velocity	79
10. General properties of parallel-wire transmission lines	82
10.1 Infinitely long transmission lines; characteristic impedance	82
10.2 Calculation of line constants L and C	85
10.3 Transmission lines of finite length; standing waves and reflection	88
10.4 Input impedance	93
11. Applications of transmission lines	96
11.1 Transmission lines as UHF self-inductances or capacitances	96
11.2 Transmission lines as resonant circuits	99
11.3 Transmission lines as wavemeters	105
11.4 Impedance measurements with transmission lines	107
11.5 Transmission lines as impedance transformers	109
11.6 Discontinuities	115
12. Components in parallel-wire transmission lines	119
12.1 Supports	119
12.2 Short-circuit plungers	121
12.3 Matched loads	123
12.4 Attenuators	125
12.5 Detectors	126
12.6 Directional couplers	128
12.7 Filters	130
12.8 Power dividers	131
12.9 Measurement techniques	136

Waveguides

13. Wave propagation in rectangular waveguides	143
13.1 Introduction	143
13.2 TE or H waves	146
13.3 TM or E waves	151
14. Properties of rectangular waveguides	156
14.1 Propagation constant and cut-off frequency	156
14.2 Phase velocity and group velocity; guide wavelength	160
14.3 Standing waves and reflection	162
14.4 Impedance in waveguides	166
14.5 Attenuation in waveguides	173
15. Wave propagation in circular waveguides	175
16. Higher modes in coaxial lines	177

17. Waveguide components	179
17.1 Discontinuities	179
17.2 Impedance transformers	188
17.3 Short-circuit plungers	194
17.4 Bends	194
17.5 Transitions from waveguide to coaxial line	197
17.6 Detection	199
17.7 Standing-wave detectors	200
17.8 Phase shifters	204
17.9 Attenuators and matched loads	205
17.10 Directional couplers	206
17.11 T-junctions	209
17.12 Power dividers	213
17.13 Filters	215
17.14 Flanges	221
Cavity resonators	
18. Introduction to the cavity resonator	225
19. Simple cavity resonators	228
19.1 Introduction	228
19.2 Rectangular parallelepiped	231
19.3 Circular cylinders	236
19.4 Coaxial cavity resonators	243
20. Equivalent circuits and coupling coefficients of cavity resonators	244
Appendices	
Appendix 1 Complex numbers	253
Appendix 2 The Smith chart	266
Appendix 3 Solid-state microwave components	276
Appendix 4 Frequency ranges and waveguide dimensions	286
Bibliography for further reading	289
Index	291