## Microwave and Optical Waveguides

## **Nigel J Cronin**

School of Physics University of Bath, UK

Institute of Physics Publishing Bristol and Philadelphia

## Contents

.

Preface			
1	Introduction		
	1.1	What is a waveguide?	1
	1.2	Why do we need waveguides?	1
	1.3	Why are there many types of waveguide?	3
2	Transmission Lines		
	2,1	The parallel-wire transmission line	5
	2.2	The line equations	8
	2.3	Characteristic impedance	10
	2.4	Characteristic impedance in terms of fields	11
	2.5	The terminated transmission line	11
		Examples	12
	2.6	The input impedance of a terminated line	13
		Examples	14
	2.7	The parallel-plate transmission line	15
	2.8	Characteristic impedance of parallel-plate line	16
	2.9	Microstrip	17
		Example	17
	2.10	Coaxial cable	20
		Example	22
	2.11	Dispersion and velocities of propagation	22
	2.12	Dispersion in transmission lines	24
		Problems	24
3	Rectangular Waveguides		27
	3.1	Plane-wave analysis of rectangular waveguide	27
	3.2	The magnetic field	32
	3.3	Waveguide modes as solutions of the wave equation	33
	3.4	Transverse electric modes	34
	3.5	Waveguide mode designation	38
	3.6	Waveguide cut-off conditions	38

\_\_\_\_\_

vii

## viii MICROWAVE AND OPTICAL WAVEGUIDES

	3.7	Single-moded waveguide	40		
	3.8	The rest of the waveguide modes	40		
	3.9	Transverse magnetic modes	41		
	3.10	Current flow in the waveguide walls	41		
	3.11	Power flow along the guide	42		
	3.12	Waveguide losses	44		
	3.13	Dispersion in rectangular waveguide	49		
		Problems	51		
4	The Planar Dielectric Waveguide				
	4.1	Total internal reflection	53		
	4.2	Transverse phase resonance, the eigenvalue equation	58		
	4.3	Graphical solutions of the eigenvalue equation	59		
		Example	60		
	4.4	Field patterns	61		
	4.5	Energy distribution	63		
		Example	65		
	4.6	The asymmetric planar dielectric waveguide	65		
	4.7	Graphical solution of the asymetric eigenvalue equation	66		
		Example	67		
	4.8	Field patterns in the asymmetric guide	68		
	4.9	Solutions of the wave equation	70		
	4.10	Radiation modes	72		
	4.11	Excitation of the waveguide	12		
	4.12	Problems	73 77		
5	Circular Metal Pipe Waveguide				
	5.1	Relationships between field components	79		
	5.2	Circular metal pipe waveguide	82		
	5.3	Transverse magnetic modes	82		
	5.4	The eigenvalue equation, cut-off conditions	84		
	5.5	Transverse electric modes	86		
		Example	87		
	5.6	Dispersion	87		
	5.7	Waveguides of arbitrary shape	88		
		Problems	90		
6	Circular Dielectric Waveguides, the Optical Fibre				
	6.1	Waveguide modes in the optical fibre	92		
	6.2	Exact solution of the eigenvalue equations: outline (Hondros and Debye 1910)	94		
	6.3	Weakly guiding fibres—linearly polarized (LP) modes	95		

6.4	Cut-off conditions in linearly polarized modes	98	
	Example	99	
6.5	Cut-off conditions in the fundamental LP <sub>01</sub> mode	99	
6.6	field patterns in linearly polarized modes	100	
	Example	100	
6.7	Field patterns in the $LP_{01}$ mode	103	
6.8	LP modes as a sum of exact solutions	104	
6.9	Normalized waveguide parameters	105	
	Example	106	
6.10	Energy distribution in the weakly guiding fibre	107	
	Example	108	
6.11	Dispersion and group velocity	108	
	Problems	111	
Appendix 1: Bessel Functions			
Appendix 2: Reading List			
Index			

Ĺ

.

0