Contents

Preface xi

1 Electromagnetic waves 1
1.1 Introduction 1
1.2 Maxwell's equations 2
1.3 Electromagnetic waves in non-conducting media 5
1.4 Energy flow in an electromagnetic wave 8
1.5 Electromagnetic waves in conducting materials 9
1.6 Propagation of waves in plasmas 12
1.7 Polarization of waves 14
1.8 Propagation in gyromagnetic media 15
1.9 Boundary conditions 18
1.10 Conclusion 23
Exercises 23

2 Waves guided by perfectly conducting boundaries 25
2.1 TEM transmission lines 25
2.2 Reflection of waves by a conducting plane 27
2.3 Transverse electric waves 29
2.4 Transverse magnetic waves 34
2.5 Propagation in a rectangular waveguide 36
2.6 Power flow in a rectangular waveguide 40
2.7 Higher-order modes in a rectangular waveguide 43
2.8 Other waveguides 48
2.9 Conclusion 49
Exercises 50

3 Waves with dielectric boundaries 51
3.1 Reflection of waves by a dielectric boundary 51
3.2 Total internal reflection 52
3.3 The Brewster angle 53
3.4 Dielectric waveguides 54

3.5 Mono-mode and multi-mode optical fibres
3.6 Radomes, windows and optical blooming
3.7 Quasi TEM waveguides
3.8 Non-TEM waveguides
3.9 Conclusion
Exercises

4 Waves with imperfectly conducting boundaries
4.1 Waves incident normally on a conducting surface
4.2 Transmission through a thin conducting sheet
4.3 Electromagnetic screening
4.4 Waves incident obliquely on a conducting surface
4.5 Losses in transmission lines and waveguides
4.6 Microwave attenuators
4.7 Microwave loads
4.8 Conclusion
Exercises

5 Antennas
5.1 Introduction
5.2 Magnetic vector potential
5.3 Retarded potentials
5.4 Small electric dipole
5.5 The reciprocity theorem
5.6 Small magnetic dipole
5.7 Half-wave dipole
5.8 Dipole arrays
5.9 Radiation from apertures
5.10 Slot antennas
5.11 Phased array antennas
5.12 Conclusion
Exercises

6 Coupling between wave-guiding systems
6.1 Introduction
6.2 Discontinuities
6.3 Broadband matching techniques
6.4 Coupling without change of mode
6.5 Coupling with change of mode
6.6 Coupling by apertures
6.7 Effect of holes in screens on screening effectiveness
6.8 Waveguide directional couplers
6.9 Distributed coupling
6.10 Conclusion
Exercises

7 Electromagnetic resonators and filters 158
7.1 Introduction 158
7.2 Transmission-line resonators 162
7.3 Cavity resonators 168
7.4 Effect of resonance on screened enclosures 171
7.5 Dielectric resonators 173
7.6 Fabry–Pérot resonators 176
7.7 Filter theory 177
7.8 Transmission-line filters 180
7.9 Waveguide filters 183
7.10 Optical filters 187
7.11 Conclusion 188
Exercises 188

8 Ferrite devices 190
8.1 Introduction 190
8.2 Microwave properties of ferrites 190
8.3 Resonance isolators 194
8.4 Phase shifters and circulators 196
8.5 Junction circulators 198
8.6 Faraday rotation devices 200
8.7 Edge mode devices 202
8.8 YIG filters 204
8.9 Conclusion 205
Exercises 205

9 Solid state microwave devices 206
9.1 Introduction 206
9.2 Semiconductor materials 206
9.3 Diodes 209
9.4 Transistors 215
9.5 Detectors and mixers 218
9.6 Switches 221
9.7 Oscillators 223
9.8 Amplifiers 225
9.9 Monolithic microwave integrated circuits 227
9.10 LEDs and laser diodes 227
9.11 Conclusion 229

10 Vacuum devices 230
10.1 Introduction 230
10.2 Space-charge waves 230
10.3 Klystron amplifiers 234
10.4 Slow-wave structures 242
10.5 Travelling wave tubes 248

10.6 Crossed-field tubes
10.7 Fast-wave devices
10.8 Electron accelerators
10.9 Conclusion
Exercises

11 Microwave measurements
11.1 Introduction
11.2 Measurement of frequency
11.3 Measurement of power
11.4 Measurement of gain and loss
11.5 Measurement of return loss
11.6 Measurement of impedance
11.7 Time-domain reflectometry
11.8 Spectrum analyser measurements
11.9 Electromagnetic compatibility measurements
11.10 Measurement of resonators
11.11 Measurement of dielectric properties
11.12 Conclusion
Exercises

12 Systems using electromagnetic waves
12.1 Introduction
12.2 Radio wave propagation
12.3 Radio communications
12.4 Television broadcasting
12.5 Microwave communications
12.6 Radar
12.7 Electronic countermeasures
12.8 Industrial and domestic applications
12.9 Medical applications
12.10 Computer-aided design of microwave systems
12.11 Conclusion
Exercises

References

Appendix A Transmission lines

Appendix B Vector formulae

Appendix C Constants and properties of materials

Appendix D Answers to selected problems

Index