

Electromagnetic Waves in Chiral and Bi-Isotropic Media

I. V. Lindell, A. H. Sihvola,
S. A. Tretyakov, A. J. Viitanen

Artech House
Boston • London

Contents

1	Introduction	1
1.1	Early Studies on Chiral and Biaxotropic Media	1
1.1.1	Optical Activity	2
1.1.2	Electromagnetic Activity	4
1.1.3	Magnetoelectric Activity	7
1.1.4	The Fedorov School	8
1.1.5	Biaxotropic Media	12
1.2	Characterization of Bi-Isotropic (BI) Media	13
1.2.1	Constitutive Relations	13
1.2.2	Material Structure and Characteristic Figures	14
	References	18
2	Fields in Homogeneous BI Media	23
2.1	Wavefield Decomposition	23
2.1.1	Wavefield Postulates	24
2.1.2	Wavefield Vectors	28
2.1.3	Sources of the Wavefields	29
2.1.4	Wavefields as Self-Dual Fields	31
2.2	Plane Waves in Homogeneous BI Media	32
2.2.1	Plane-Wave Relations	33
2.2.2	Polarization Rotation	35
2.2.3	Angle Between Field Vectors	36
2.2.4	Wavelengths of the Plane Wave	38
2.3	Green Functions	39
2.3.1	Dyadic Sources and Fields	39
2.3.2	Solving for the Green Dyadics	40
2.3.3	The Far Field from a Dipole	42
2.4	Reciprocity and Nonreciprocity	43
2.4.1	The Reciprocity Theorem	43
2.4.2	Demonstration of Nonreciprocity	46

2.5 Huygens' Principle	47
2.6 Power and Energy in BI Media	49
2.6.1 Conditions for Medium Parameters	49
2.6.2 Wavefield Decomposition of Power	51
2.7 Electromagnetostatics in BI Media	53
2.7.1 Basic Equations	53
2.7.2 Fields Due to Charges	53
2.7.3 Bi-Isotropic Transmission Line	55
References	57
3 Plane Waves in Layered Media	59
3.1 Normal Incidence, Single Interface	59
3.1.1 Circular Polarization	60
3.1.2 General Polarization	66
3.2 Nonsymmetric Transmission-Line Theory	71
3.2.1 Transmission-Line Equations	71
3.2.2 Input Impedance of a Terminated Line	73
3.2.3 Transmission Through a Line Section	76
3.3 Normal Incidence on BI Slab	77
3.3.1 Reflection and Transmission	77
3.3.2 BI Slab Between Simple Isotropic Half Spaces	79
3.3.3 Polarization Rotation	83
3.4 Vector Transmission-Line Theory	91
3.4.1 Systems of Plane Waves	92
3.4.2 Vector Voltages and Currents	93
3.4.3 Propagation Dyadics	95
3.4.4 Dyadic Characteristic Admittances	96
3.4.5 Reflection Dyadic	98
3.4.6 Transmission Dyadic	100
3.4.7 Input Admittance Dyadic	101
3.5 Oblique Incidence, Single Interface	103
3.5.1 The Characteristic Admittances	104
3.5.2 Reflection and Transmission	104
3.5.3 Eigenproblem of the Interface	106
3.5.4 Brewster Angles	109
3.6 Oblique Incidence on BI Slab	114
3.6.1 Dyadic Admittance and Reflection	114
3.6.2 Special Case	115
References	116

4 Waveguides	119
4.1 Guided-Wave Solutions	120
4.1.1 Field Decomposition and Boundary Conditions	120
4.1.2 Vector Circuit Approach	124
4.2 Slab Waveguides	127
4.2.1 Closed Planar Bi-Isotropic Waveguides	127
4.2.2 Open Bi-Isotropic Plane Guides	133
4.3 Circular Waveguide	137
4.3.1 Isotropic Boundary Impedance	138
4.3.2 Anisotropic Boundary Impedance	143
4.3.3 Open Circular Bi-Isotropic Waveguide	145
4.4 Rectangular Waveguide	147
References	149
5 Propagation in Inhomogeneous Media	153
5.1 Geometrical Optics for BI Media	154
5.2 Polarization-Rotating Lens Antennas	155
5.2.1 Maxwell Fish-Eye Lens	158
5.2.2 Brown Lens	161
5.2.3 Luneburg Lens	163
5.2.4 Gutman Lens	167
5.3 WKB Approximation for Normal Incidence	171
5.3.1 The Coupling Equation	172
5.3.2 Reflection Dyadic	176
5.3.3 Special Cases	177
5.4 WKB Approximation for Oblique Incidence	180
5.4.1 WKB Approximation for Wave Propagation	182
5.4.2 Reflected Fields and Corrected Propagating Fields	184
5.4.3 Special Cases	187
References	191
6 Scattering and Mixing Theories	193
6.1 Polarizabilities of Small BI Scatterers	193
6.1.1 Bi-Isotropic Sphere	194
6.1.2 Bi-Isotropic Ellipsoid	197
6.1.3 Layered Chiral Sphere	198
6.1.4 Chiral Sphere in Chiral Background Material	200
6.2 Interpretation of Polarizability Expressions	201

6.2.1	Effect of Inclusion Parameters	202
6.2.2	Paramagnetic Parts Can Generate Diamagnetic Whole	203
6.2.3	Similarity of Bi-Isotropic and Anisotropic Polarizabilities	205
6.3	Modeling of Bi-Isotropic Mixtures	208
6.3.1	Effective Permittivity of a Mixture	208
6.3.2	Effective Parameters of BI Mixtures	209
6.3.3	Perturbation Expansions of Effective Parameters	215
6.3.4	Remarks on and Illustrations of Effective Material Parameters	218
6.3.5	Alternative Mixing Laws	223
6.3.6	Mixing Rules in Other Constitutive Relations	225
6.4	Dispersive Behavior of Chiral Materials	227
6.4.1	General Features	227
6.4.2	One-Resonance Condon Model	230
6.4.3	Effect of Mixing on Dispersion	233
6.5	Scattering by Large Objects	235
6.6	Scattering by Helices	239
	References	243
7	Measurement Techniques	251
7.1	Ellipsometric Measurements	252
7.1.1	Linear Polarization Measurements	253
7.1.2	Use of Eigenpolarizations in Reflection	256
7.1.3	Differential Circular Reflection	256
7.2	Reflection and Transmission from Slab	258
7.2.1	Pasteur Media	258
7.2.2	Small Tellegen Parameter	260
7.2.3	Large Tellegen Parameter	261
7.3	Waveguide and Resonator Techniques	262
7.3.1	Waveguide Perturbation	263
7.3.2	Resonator Perturbation	265
7.3.3	Chirality and Nonreciprocity Parameters	267
7.4	Practical Implementation Aspects	270
	References	272
8	Uniaxial Bianisotropic Media	275
8.1	Plane Waves in a Uniaxial Medium	275
8.1.1	Medium Parameters	275
8.1.2	Basic Equations	277

8.1.3 Axial Impedance and Admittance	278
8.1.4 Effective Anisotropic Media	281
8.1.5 Eigenpolarizations	284
8.2 Polarization Transformer	286
8.2.1 Transverse Eigenwaves	287
8.2.2 Polarizations of the Eigenwaves	288
8.2.3 Propagating Plane Wave	289
8.2.4 Quarter-Wave Transformer	290
8.3 Green Dyadic	298
8.3.1 The Operator Equation	298
8.3.2 Solving the Green Dyadic	300
8.3.3 The \bar{F} Dyadic	301
8.3.4 Field from a Dipole	303
References	304
Appendix A Notation	307
A.1 The Present Notation	307
A.2 Other Notations	308
A.3 Bianisotropic Media	311
References	312
Appendix B Complex Vectors	313
B.1 Ellipse of a Complex Vector	313
B.2 Polarization Vector	314
B.3 Two-Dimensional CP Vectors	315
B.4 Vector Bases	316
References	316
Appendix C Dyadics	317
C.1 Basic Properties of Dyadics	317
C.2 Two-Dimensional Dyadics	318
References	320
Appendix D Collection of Basic Formulas	321
D.1 Constitutive Equations	321
D.2 Wavefields in Homogeneous BI Media	322
D.3 Plane-Wave Relations	322

D.4 Green Dyadics	323
D.5 Guided Waves	323
D.6 Inhomogeneous BI Media	323
D.7 Polarizabilities for Small BI Sphere	324