



POLITECNICO DI TORINO
Repository ISTITUZIONALE

The Wiener–Hopf Fredholm factorization technique to solve scattering problems in coupled planar and angular regions

Original

The Wiener–Hopf Fredholm factorization technique to solve scattering problems in coupled planar and angular regions / Daniele, Vito G.; Lombardi, Guido. - STAMPA. - 1(2020), pp. 279-302.

Availability:

This version is available at: 11583/2895912 since: 2021-04-20T12:23:26Z

Publisher:

SciTech Publishing, an imprint of The Institution of Engineering and Technology

Published

DOI:10.1049/SBEW528E_ch12

Terms of use:

openAccess

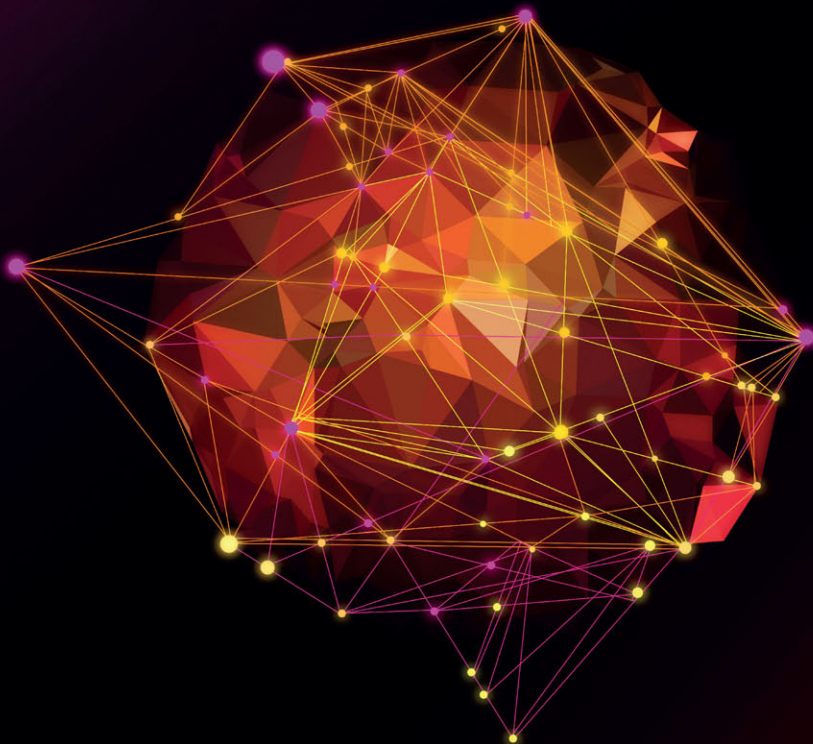
This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

(Article begins on next page)

Advances in Mathematical Methods for Electromagnetics

Edited by
Kazuya Kobayashi and Paul Denis Smith



Copyright © 2021, IET, or applicable copyright holder. All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, without the prior written permission of the copyright holder.

Advances in Mathematical Methods for Electromagnetics

The ACES Series on Computational and Numerical Modelling in Electrical Engineering

Andrew F. Peterson, PhD – Series Editor

The volumes in this series will encompass the development and application of numerical techniques to electrical and electronic systems, including the modelling of electromagnetic phenomena over all frequency ranges and closely related techniques for acoustic and optical analysis. The scope includes the use of computation for engineering design and optimization, as well as the application of commercial modelling tools to practical problems. The series will include titles for senior undergraduate and postgraduate education, research monographs for reference, and practitioner guides and handbooks.

Titles in the Series

K. Warnick, **“Numerical Methods for Engineering,”** 2010

W. Yu, X. Yang and W. Li, **“VALU, AVX and GPU Acceleration Techniques for Parallel FDTD Methods,”** 2014.

A.Z. Elsherbeni, P. Nayeri and C.J. Reddy, **“Antenna Analysis and Design Using FEKO Electromagnetic Simulation Software,”** 2014.

A.Z. Elsherbeni and V. Demir, **“The Finite-Difference Time-Domain Method in Electromagnetics with MATLAB Simulations 2nd Edition,”** 2015.

M. Bakr, A.Z. Elsherbeni and V. Demir, **“Adjoint Sensitivity Analysis of High Frequency Structures with MATLAB,”** 2017.

O. Ergul, **“New Trends in Computational Electromagnetics,”** 2019.

D. Werner, **“Nanoantennas and Plasmonics: Modelling, design and fabrication,”** 2020.

Advances in Mathematical Methods for Electromagnetics

Edited by
Kazuya Kobayashi and Paul Denis Smith

The Institution of Engineering and Technology

Published by SciTech Publishing, an imprint of The Institution of Engineering and Technology, London, United Kingdom

The Institution of Engineering and Technology is registered as a Charity in England & Wales (no. 211014) and Scotland (no. SC038698).

© The Institution of Engineering and Technology 2021

First published 2020

This publication is copyright under the Berne Convention and the Universal Copyright Convention. All rights reserved. Apart from any fair dealing for the purposes of research or private study, or criticism or review, as permitted under the Copyright, Designs and Patents Act 1988, this publication may be reproduced, stored or transmitted, in any form or by any means, only with the prior permission in writing of the publishers, or in the case of reprographic reproduction in accordance with the terms of licences issued by the Copyright Licensing Agency. Enquiries concerning reproduction outside those terms should be sent to the publisher at the undermentioned address:

The Institution of Engineering and Technology
Michael Faraday House Six
Hills Way, Stevenage Herts,
SG1 2AY, United Kingdom

www.theiet.org

While the authors and publisher believe that the information and guidance given in this work are correct, all parties must rely upon their own skill and judgement when making use of them. Neither the authors nor publisher assumes any liability to anyone for any loss or damage caused by any error or omission in the work, whether such an error or omission is the result of negligence or any other cause. Any and all such liability is disclaimed.

The moral rights of the authors to be identified as authors of this work have been asserted by them in accordance with the Copyright, Designs and Patents Act 1988.

British Library Cataloguing in Publication Data

A catalogue record for this product is available from the British Library

ISBN 978-1-78561-384-5 (hardback)

ISBN 978-1-78561-385-2 (PDF)

Typeset in India by MPS Limited

Printed in the UK by CPI Group (UK) Ltd, Croydon

Contents

| | |
|--|------------|
| About the editors | xxi |
| Introduction | 1 |
| <i>Kazuya Kobayashi and Paul D. Smith</i> | |
| References | 16 |
| 1 New insights in integral representation theory for the solution of complex canonical diffraction problems | 17 |
| <i>J.M.L. Bernard</i> | |
| 1.1 Representations of spectral function in frequency and time domain, for the scattering by a polygonal region | 18 |
| 1.1.1 Basic elements in Sommerfeld–Maliuzhinets representation and properties | 18 |
| 1.1.2 Spectral functions f_{\pm} attached to the radiation of a single face and simple relation to f | 20 |
| 1.1.3 Spectral function f from far field radiation of one face with arbitrary shape | 22 |
| 1.1.4 Exact causal time domain representation of a field above a dispersive wedge-shaped region | 23 |
| 1.2 Several orders asymptotic representation for scattering by a curved impedance wedge | 25 |
| 1.2.1 Asymptotic representation in a region without creeping waves | 25 |
| 1.2.2 Several orders asymptotic expressions in a region with creeping waves terms | 27 |
| 1.2.3 Some validations concerning the expression of $f = \sum_{n \geq 0} f_n/k^n$ for arbitrary wedge angle | 30 |
| 1.3 A novel expression of the field for arbitrary bounded sources above a passive or active impedance plane | 32 |
| 1.3.1 Formulation of the problem | 32 |
| 1.3.2 An expression of potentials $(\mathcal{E}_{inc}, \mathcal{H}_{inc})$ for bounded sources J and M | 34 |
| 1.3.3 Expression of the potentials $(\mathcal{E}_s, \mathcal{H}_s)$ for an impedance plane | 34 |

| | | |
|----------|--|-----------|
| 1.4 | Spectral representation of the field for 3D conical scatterers | 36 |
| 1.4.1 | Formulation | 36 |
| 1.4.2 | Expression of the potentials with Kontorovich–Lebedev integrals | 38 |
| 1.4.3 | Potentials and properties for an incident plane wave | 41 |
| | References | 44 |
| 2 | Scattering of electromagnetic surface waves on imperfectly conducting canonical bodies | 47 |
| | <i>Mikhail A. Lyalinov and Ning Yan Zhu</i> | |
| 2.1 | Introduction and survey of some known results | 47 |
| 2.1.1 | Electromagnetic surface waves on impedance surfaces | 49 |
| 2.1.2 | Electromagnetic surface waves on a right circular conical surface | 54 |
| 2.2 | Excitation of an electromagnetic surface wave by a dipole located near a plane impedance surface | 56 |
| 2.3 | Scattering of a skew incident surface wave by the edge on an impedance wedge | 59 |
| 2.3.1 | Integral equations for the spectra | 61 |
| 2.3.2 | Far-field expansion | 62 |
| 2.3.3 | Reflection and refraction of an incident surface wave at the edge of an impedance wedge | 63 |
| 2.3.4 | Beyond the critical angle of edge diffraction | 65 |
| 2.4 | Conclusion | 67 |
| | Appendix A | 68 |
| A.1 | Brewster angles | 69 |
| | Acknowledgement | 69 |
| | References | 69 |
| 3 | Dielectric-wedge Fourier series | 73 |
| | <i>Svend Berntsen</i> | |
| 3.1 | Introduction | 73 |
| 3.2 | The diffraction problem | 75 |
| 3.2.1 | The Hilbert-space problem | 75 |
| 3.2.2 | The singular-field problem | 76 |
| 3.3 | Integral equations | 77 |
| 3.4 | The solution of the integral equation | 79 |
| 3.5 | The Bessel–Hankel Fourier series | 81 |
| 3.6 | Incident plane waves | 87 |
| 3.7 | Numerical results | 88 |
| 3.8 | Summary | 92 |
| | Appendix A | 92 |
| | Acknowledgment | 93 |
| | References | 94 |

| | | |
|----------|---|------------|
| 4 | Green's theorem, Green's functions and Huygens' principle in discrete electromagnetics | 97 |
| | <i>John M. Arnold</i> | |
| 4.1 | Introduction | 97 |
| 4.2 | Green's theorem for adjacency matrices | 99 |
| 4.2.1 | Adjacency matrix | 99 |
| 4.2.2 | Weighted adjacency matrix | 100 |
| 4.2.3 | Matrix of adjacency 1 | 100 |
| 4.2.4 | The vertex Laplacian matrix | 100 |
| 4.2.5 | Incidence matrices | 101 |
| 4.3 | Green's theorem on topological vector space | 101 |
| 4.4 | Difference forms and discrete exterior calculus | 104 |
| 4.4.1 | Simplicial decomposition | 104 |
| 4.4.2 | Dual forms | 105 |
| 4.4.3 | Hypercube decomposition | 106 |
| 4.4.4 | Contextual algebraic notation of forms | 106 |
| 4.4.5 | Manifolds, graphs and lattices | 107 |
| 4.4.6 | Essentials of cell decomposition | 108 |
| 4.5 | Higher order Green's theorem and Green's functions | 108 |
| 4.5.1 | Green's theorem for r-forms | 108 |
| 4.5.2 | Kirchhoff's theorem for r-forms | 109 |
| 4.5.3 | Green's function for r-forms | 109 |
| 4.6 | Dynamical systems on topological vector spaces: Maxwell's equations | 109 |
| 4.6.1 | Discrete Maxwell equations | 110 |
| 4.6.2 | Electromagnetic fields as differential forms | 111 |
| 4.7 | Time-domain Green's functions for dynamical systems | 112 |
| 4.8 | Discrete time | 114 |
| 4.9 | Discrete Green's theorem and Green's functions in computational field theory | 116 |
| 4.9.1 | Exterior–interior connection | 116 |
| 4.9.2 | Diakoptics | 117 |
| 4.10 | Conclusion | 117 |
| | References | 117 |
| 5 | The concept of generalized functions and universal properties of the Green's functions associated with the wave equation in bounded piece-wise homogeneous domains | 119 |
| | <i>M. Idemen</i> | |
| 5.1 | A short historical background | 119 |
| 5.1.1 | A remark | 123 |
| 5.2 | Some basic properties of the δ distribution | 124 |
| 5.2.1 | Distributions involving $\delta(R)$ and $\delta(R_1 - R_2)$ | 125 |

| | | |
|----------|---|------------|
| 5.3 | Green's functions associated with the wave equation in bounded partially homogeneous domains | 128 |
| 5.3.1 | The outgoing Green's function | 130 |
| 5.3.2 | The ingoing Green's function | 131 |
| 5.3.3 | Some universal properties of the outgoing and ingoing Green's functions | 132 |
| 5.4 | Proofs of the theorems | 133 |
| 5.4.1 | Proof of Theorem 1 | 133 |
| 5.4.2 | Proof of Theorem 2 | 133 |
| 5.4.3 | Proof of Theorem 3 | 134 |
| 5.4.4 | Proof of Theorem 4 | 134 |
| 5.4.5 | Proof of Theorem 5 | 135 |
| 5.4.6 | Proof of Theorem 6 | 136 |
| 5.5 | Application: An inverse initial-value problem connected with the photoacoustic tomography in bounded non-homogeneous domains | 138 |
| 5.5.1 | Extension of the inverse initial value problem to the range $(-\infty) < t < \infty$ | 139 |
| 5.5.2 | Solution of the extended problem | 140 |
| 5.5.3 | Proof of (5.64) | 142 |
| | References | 143 |
| 6 | Elliptic cylinder with a strongly elongated cross-section: high frequency techniques and function theoretic methods | 145 |
| | <i>Frédéric Molinet and Ivan Andronov</i> | |
| 6.1 | Introduction | 145 |
| 6.2 | Asymptotic currents on an elliptic cylinder with a truncated strongly elongated cross-section | 147 |
| 6.2.1 | Analysis of the interactions | 147 |
| 6.2.2 | Asymptotic field in the boundary layer due to a magnetic line current | 148 |
| 6.2.3 | Radiated field and total field | 152 |
| 6.2.4 | Spectral decomposition of the field in the boundary layer | 154 |
| 6.2.5 | Diffraction by the edge of a truncated elliptic cylinder | 156 |
| 6.2.6 | Asymptotic field in the boundary layer due to an incident plane wave | 157 |
| 6.2.7 | Asymptotic currents | 160 |
| 6.3 | Asymptotic currents on a cylinder with an ogival cross-section composed of two symmetric arcs of a strongly elongated ellipse | 161 |
| 6.3.1 | Presentation of the geometry and analysis of the problem | 161 |
| 6.3.2 | Asymptotic currents outside grazing incidence | 162 |
| 6.3.3 | Grazing incidence | 163 |
| 6.4 | Conclusion | 166 |
| | References | 168 |

| | | |
|----------|---|------------|
| 7 | High-frequency hybrid ray–mode techniques | 169 |
| | <i>Hiroshi Shirai</i> | |
| 7.1 | Introduction | 169 |
| 7.2 | Ray–mode conversion technique | 170 |
| 7.3 | Modal excitation at the aperture | 171 |
| | 7.3.1 Formulation | 171 |
| | 7.3.2 Numerical results | 174 |
| 7.4 | Diffraction by a slit on a thick conducting screen | 177 |
| | 7.4.1 Background | 177 |
| | 7.4.2 Formulation | 177 |
| | 7.4.3 Diffraction by a thin slit | 182 |
| | 7.4.4 Diffraction by a thick and loaded slit | 182 |
| | 7.4.5 Diffraction by a trough | 185 |
| 7.5 | Conclusions | 186 |
| | Acknowledgments | 186 |
| | References | 186 |
| | | |
| 8 | Scattering and diffraction of scalar and electromagnetic waves using spherical-multipole analysis and uniform complex-source beams | 189 |
| | <i>Ludger Klinkenbusch and Hendrik Brüns</i> | |
| 8.1 | Introduction | 189 |
| 8.2 | Solution of Maxwell’s equations in sphero-conal coordinates | 191 |
| | 8.2.1 Sphero-conal coordinates | 191 |
| | 8.2.2 Solution of the Helmholtz equation in sphero-conal coordinates | 192 |
| | 8.2.3 Vector spherical-multipole expansion of the electromagnetic field in the presence of a PEC semi-infinite elliptic cone | 196 |
| 8.3 | Complex-source beams | 198 |
| | 8.3.1 Converging and diverging CSB | 198 |
| | 8.3.2 Uniform CSB | 200 |
| 8.4 | Green’s function of the semi-infinite elliptic cone for an incident uniform complex-source beam | 202 |
| | 8.4.1 Scalar Green’s function | 202 |
| | 8.4.2 Dyadic Green’s function | 203 |
| 8.5 | Numerical evaluation | 204 |
| | 8.5.1 Convergence analysis | 204 |
| | 8.5.2 Numerical results for an acoustically soft or hard semi-infinite elliptic cone | 206 |
| | 8.5.3 Numerical results for a perfectly conducting semi-infinite elliptic cone | 208 |
| 8.6 | Conclusions | 212 |
| | References | 213 |

| | | |
|-----------|---|------------|
| 9 | Changes in the far-field pattern induced by rounding the corners of a scatterer: dependence upon curvature | 215 |
| | <i>Audrey J. Markowskei and Paul D. Smith</i> | |
| 9.1 | Problem formulation | 218 |
| 9.2 | Numerical results and discussion | 221 |
| 9.3 | Analytic bounds for the far-field difference | 222 |
| 9.3.1 | Integral equations for the difference in surface quantities | 222 |
| 9.3.2 | Approximate integral equation for the difference Δ | 223 |
| 9.3.3 | The far-field difference | 236 |
| 9.4 | Conclusion | 239 |
| | References | 239 |
| 10 | Radiation from a line source at the vertex of a right-angled dielectric wedge | 241 |
| | <i>Anthony D. Rawlins</i> | |
| 10.1 | Introduction | 241 |
| 10.2 | Formulation of the boundary value problem | 242 |
| 10.3 | Singular integral equation for the double Laplace transform of the electric field | 244 |
| 10.4 | Approximate solution of the singular integral equation | 246 |
| 10.5 | Calculation of $E^{(1)}(0,0)$ | 248 |
| 10.6 | Radiated far field | 249 |
| 10.7 | Conclusions | 250 |
| | References | 253 |
| 11 | Wiener-Hopf analysis of the diffraction by a thin material strip | 255 |
| | <i>Takashi Nagasaka and Kazuya Kobayashi</i> | |
| 11.1 | Introduction | 255 |
| 11.2 | The case of E polarization | 256 |
| 11.2.1 | Formulation of the problem | 256 |
| 11.2.2 | Factorization of the Kernel functions | 259 |
| 11.2.3 | Formal solution of the Wiener–Hopf equation | 261 |
| 11.2.4 | Asymptotic solution of a certain integral equation in the complex plane | 263 |
| 11.2.5 | High-frequency asymptotic solution | 266 |
| 11.2.6 | Scattered far field | 268 |
| 11.3 | The case of H polarization | 269 |
| 11.4 | Numerical results and discussion | 272 |
| 11.5 | Conclusions | 276 |
| | Acknowledgment | 276 |
| | References | 276 |

| | |
|---|------------|
| 12 The Wiener-Hopf Fredholm factorization technique to solve scattering problems in coupled planar and angular regions | 279 |
| <i>Vito G. Daniele and Guido Lombardi</i> | |
| 12.1 Introduction | 279 |
| 12.2 The WH equations of the problem | 281 |
| 12.3 Reduction of the WH equations to FIEs | 283 |
| 12.3.1 The Fredholm equation of the region (c) | 284 |
| 12.3.2 The Fredholm equations of the region (b) | 286 |
| 12.3.3 The Fredholm equation of the angular region (a) | 288 |
| 12.4 Solution of the FIE | 292 |
| 12.5 Analytical continuation of the numerical solution | 294 |
| 12.6 A novel test case | 298 |
| 12.7 Conclusion | 301 |
| Appendix A | 301 |
| References | 301 |
| | |
| 13 On the analytical regularization method in scattering and diffraction | 303 |
| <i>Yury A. Tuchkin</i> | |
| 13.1 Introduction | 303 |
| 13.2 Instability in the numerical solution of infinite algebraic systems | 304 |
| 13.3 The ARM: when is it necessary? | 308 |
| 13.4 Potentials and their pseudodifferential representations | 309 |
| 13.5 Solution of the key diffraction problems | 313 |
| 13.5.1 Dirichlet BVP | 313 |
| 13.5.2 Neumann BVP | 315 |
| 13.6 Diffraction by a semi-transparent obstacle | 316 |
| 13.6.1 The BVP description | 316 |
| 13.6.2 Integral representation for $u^{s(+)}$ and $\partial_n u^{s(+)}$ | 317 |
| 13.6.3 Reduction of the BVP to a system of integral equations | 318 |
| 13.6.4 Reduction of the system of integral equations to an infinite system of linear algebraic equations | 319 |
| 13.7 Diffraction of waves with complex frequencies and spectral theory of open cavities | 320 |
| 13.7.1 Description of the BVP | 320 |
| 13.7.2 Dirichlet BVP for complex-valued wave numbers | 322 |
| 13.7.3 Qualitative features of the Dirichlet BVP | 322 |
| 13.7.4 Numerical calculation of complex-valued eigen-wavenumbers and eigenmodes | 322 |
| 13.8 ARM: considerations for implementation | 323 |
| 13.9 ARM: various applications and conclusion | 324 |
| References | 325 |

| | |
|---|------------|
| 14 Resonance scattering of E-polarized plane waves by two-dimensional arbitrary open cavities: spectrum of complex eigenvalues | 329 |
| <i>Elena D. Vinogradova</i> | |
| 14.1 Introduction | 329 |
| 14.1.1 Preliminary remarks | 329 |
| 14.1.2 Development of a systematic approach | 330 |
| 14.2 Mathematical background | 331 |
| 14.2.1 Schematic description of the MAR | 331 |
| 14.2.2 Scheme for finding the complex eigenvalues | 333 |
| 14.3 Computation of the complex eigenvalues for various open cavities | 336 |
| 14.3.1 Circular cylinder with longitudinal slit | 336 |
| 14.3.2 Elliptic cavity with moveable longitudinal slit | 337 |
| 14.3.3 Open rectangular cavity with finite flanges | 343 |
| 14.4 Resonance response of slotted cavities | 347 |
| 14.4.1 Surface current calculations | 348 |
| 14.4.2 Far-field calculations | 350 |
| 14.5 Conclusion | 355 |
| References | 357 |
| | |
| 15 Numerical solutions of integral equations for electromagnetics | 359 |
| <i>Roberto D. Graglia and Andrew F. Peterson</i> | |
| 15.1 The EFIE and MFIE for perfectly conducting bodies | 359 |
| 15.2 Some alternative formulations to remediate fictitious internal resonances | 361 |
| 15.3 Integral equations for homogeneous dielectric bodies | 361 |
| 15.4 Formulations that remediate fictitious internal resonances for dielectric targets | 363 |
| 15.5 Single-source integral equations for dielectric bodies | 364 |
| 15.6 Low-frequency breakdown of integral equations | 365 |
| 15.7 Numerical solution of integral equations | 365 |
| 15.8 Vector basis functions | 366 |
| 15.9 Interpolatory and hierarchical vector basis functions | 367 |
| 15.10 Singular vector basis functions | 369 |
| 15.11 Summary | 371 |
| References | 372 |
| | |
| 16 Electromagnetic modelling at arbitrarily low frequency via the quasi-Helmholtz projectors | 381 |
| <i>Adrien Merlini, Alexandre Dély, Kristof Cools and Francesco P. Andriulli</i> | |
| 16.1 Introduction | 381 |
| 16.2 Notation and background | 383 |

| | | |
|--------|---|-----|
| 16.2.1 | Frequency domain | 383 |
| 16.2.2 | Time domain | 388 |
| 16.3 | The low-frequency breakdown in the FD | 391 |
| 16.3.1 | Illustration of the problem | 391 |
| 16.3.2 | Analysis of the low-frequency breakdown | 392 |
| 16.3.3 | Traditional LS decomposition | 396 |
| 16.4 | The large time step breakdown in the TD | 398 |
| 16.5 | DC instabilities | 398 |
| 16.6 | The qH projectors | 401 |
| 16.7 | An effective solution to the low-frequency breakdown for the EFIE | 402 |
| 16.7.1 | Leveraging the qH projectors | 402 |
| 16.7.2 | Implementation details | 404 |
| 16.8 | Solution to the large time step breakdown and the DC instability for the TD-EFIE | 405 |
| 16.8.1 | Preconditioning | 406 |
| 16.8.2 | Time discretization | 407 |
| 16.8.3 | Numerical results | 409 |
| 16.9 | Conclusions | 411 |
| | References | 411 |

17 Resistive and thin dielectric disk antennas with axially symmetric excitation analyzed using the method of analytical regularization **417**

Nataliya Y. Bliznyuk and Alexander I. Nosich

| | | |
|--------|---|-----|
| 17.1 | Introduction | 417 |
| 17.2 | Formulation and GBC | 419 |
| 17.3 | Singular IEs and solution by MAR | 421 |
| 17.3.1 | Hyper-singular IE for a VED-excited resistive disk in free space | 421 |
| 17.3.2 | Eigenfunctions of the IE operator static limit for VED-excited PEC and resistive disks | 422 |
| 17.3.3 | Matrix equation and DIE for a VED-excited disk | 423 |
| 17.3.4 | Log-singular IE for a VMD-excited resistive disk in free space | 424 |
| 17.4 | Resistive disk MSA excited by VED | 426 |
| 17.4.1 | Dual IEs for a resistive disk MSA | 426 |
| 17.4.2 | Matrix equation for a resistive disk MSA | 426 |
| 17.5 | Thin disk DA excited by VED | 428 |
| 17.5.1 | Coupled set of DIES for a thin disk DA | 428 |
| 17.5.2 | Matrix equation for a thin disk DA | 428 |
| 17.6 | Numerical results | 429 |
| 17.6.1 | Radiation characteristics of resistive MSA | 430 |
| 17.6.2 | Radiation characteristics of thin disk DA | 432 |

| | | |
|-----------|--|------------|
| 17.7 | Conclusions | 435 |
| | References | 435 |
| 18 | Scattering and guiding problems of electromagnetic waves in inhomogeneous media by improved Fourier series expansion method | 439 |
| | <i>Tsuneki Yamasaki</i> | |
| 18.1 | Introduction | 440 |
| 18.1.1 | Formulation | 440 |
| 18.1.2 | Numerical results | 445 |
| 18.1.3 | Conclusions | 449 |
| 18.2 | Slanted layer and rhombic media with strips | 449 |
| 18.2.1 | Slanted layer | 449 |
| 18.2.2 | Rhombic media with strips | 450 |
| 18.2.3 | Conclusions | 453 |
| 18.3 | Elliptically layered, columnar, and rectangular media | 454 |
| 18.3.1 | Elliptically layered and columnar media | 454 |
| 18.3.2 | Rectangular media | 455 |
| 18.3.3 | Conclusions | 457 |
| 18.4 | Energy distribution of defect layers | 458 |
| 18.4.1 | Conclusions | 459 |
| 18.5 | Mixed positive and negative media | 460 |
| 18.5.1 | Conclusions | 465 |
| | References | 466 |
| 19 | Methods and fast algorithms for the solution of volume singular integral equations | 471 |
| | <i>Alexander B. Samokhin</i> | |
| 19.1 | Introduction | 471 |
| 19.2 | Formulation of the problems | 472 |
| 19.3 | Spectrum of integral operator | 475 |
| 19.3.1 | Spectrum for low-frequency case | 476 |
| 19.4 | Stationary iteration methods | 479 |
| 19.4.1 | Generalized simple iteration method | 479 |
| 19.4.2 | Generalized Chebyshev iteration method | 482 |
| 19.5 | Nonstationary iteration methods | 484 |
| 19.6 | Discretization of integral equations | 486 |
| 19.7 | Fast algorithms | 487 |
| 19.8 | Numerical results | 488 |
| 19.9 | Conclusion | 489 |
| | References | 490 |

| | |
|--|------------|
| 20 Herglotz functions and applications in electromagnetics | 491 |
| <i>Mitja Nedic, Casimir Ehrenborg, Yevhen Ivanenko, Andrei Ludvig-Osipov, Sven Nordebo, Annemarie Luger, Lars Jonsson, Daniel Sjöberg, and Mats Gustafsson</i> | |
| 20.1 Introduction | 491 |
| 20.2 Basics about Herglotz functions | 492 |
| 20.3 Passive systems | 499 |
| 20.4 Sum rules and physical bounds | 503 |
| 20.5 Convex optimization and physical bounds | 507 |
| 20.6 Conclusions | 511 |
| Acknowledgments | 511 |
| References | 511 |
| | |
| 21 Scattering and guidance by layered cylindrically periodic arrays of circular cylinders | 515 |
| <i>Vakhtang Jandieri and Kiyotoshi Yasumoto</i> | |
| 21.1 Introduction | 515 |
| 21.2 Formulation of the problem | 517 |
| 21.2.1 Field expressions | 517 |
| 21.2.2 Calculation of the scattering amplitudes | 518 |
| 21.2.3 Reflection and transmission matrices | 520 |
| 21.2.4 Hertzian dipole source radiation in the layered cylindrical structure | 522 |
| 21.2.5 Plane wave scattering by the layered cylindrical structure | 523 |
| 21.2.6 Guidance in the layered cylindrical structure | 525 |
| 21.3 Numerical results and discussions | 526 |
| 21.3.1 Directivity of radiation of a dipole source coupled to the cylindrical EBG structure | 526 |
| 21.3.2 Light scattering by the metal-coated dielectric nanocylinders with angular periodicity | 534 |
| 21.3.3 Modal analysis of specific microstructured optical fibers | 539 |
| 21.4 Conclusion | 542 |
| Acknowledgment | 543 |
| References | 543 |
| | |
| 22 Analytical and numerical solution techniques for forward and inverse scattering problems in waveguides | 547 |
| <i>E.D. Derevyanchuk, Yu. V. Shestopalov and Yu. G. Smirnov</i> | |
| 22.1 Introduction | 547 |
| 22.2 Inverse problems | 549 |
| 22.2.1 General statement for inverse problems | 550 |
| 22.3 Inverse problems. Class I (Isotropic case) | 553 |

| | | |
|-----------|--|------------|
| 22.3.1 | Statement of the inverse problem for isotropic one-sectional diaphragm (Class I) | 553 |
| 22.3.2 | Explicit solution to the inverse problem | 553 |
| 22.4 | Inverse problems. Class AnI (Anisotropic case) | 557 |
| 22.4.1 | Statements of inverse problems for anisotropic one-sectional diaphragm (Class AnI) | 557 |
| 22.4.2 | Explicit formulas for the transmission coefficient | 557 |
| 22.4.3 | The existence and uniqueness of the solution to the inverse problem | 559 |
| 22.5 | Inverse problem for multi-sectional diaphragm. Class M | 560 |
| 22.6 | Numerical results | 562 |
| 22.6.1 | Example 1. Inverse problem for one-sectional anisotropic diaphragm | 563 |
| 22.6.2 | Example 2. Extraction of the complex permittivity of each section of three-sectional isotropic diaphragm | 563 |
| 22.6.3 | Example 3. Extraction of permittivity and permeability of one-sectional anisotropic diaphragm | 564 |
| 22.6.4 | Example 4. Extraction of permittivity tensor of two-sectional anisotropic diaphragm | 565 |
| 22.6.5 | Example 5. Inverse problem $P_{\varepsilon_1}^C$ | 566 |
| 22.7 | Conclusion | 566 |
| | Acknowledgments | 567 |
| | References | 567 |
| 23 | Beam-based local diffraction tomography | 571 |
| | <i>Ram Tuvi, Ehud Heyman and Timor Melamed</i> | |
| 23.1 | Introduction and overview | 571 |
| 23.2 | The UWB-PS-BS method | 572 |
| 23.2.1 | BS methods: an overview | 572 |
| 23.2.2 | The UWB-PS-BS method: a frequency domain formulation | 574 |
| 23.2.3 | The phase-space pulsed BS method: a TD formulation | 578 |
| 23.3 | UWB tomographic inverse scattering | 582 |
| 23.3.1 | Tomographic inverse scattering: frequency domain formulation | 582 |
| 23.3.2 | Time-domain diffraction tomography | 587 |
| 23.4 | Beam-based TD-DT | 589 |
| 23.4.1 | The beam-domain data | 589 |
| 23.4.2 | The beam-domain data-object relation within the Born approximation | 590 |
| 23.4.3 | Backpropagation and local reconstruction of $O(\mathbf{r})$ | 590 |
| 23.4.4 | Numerical examples | 592 |
| 23.5 | Conclusions | 594 |
| | Acknowledgments | 595 |
| | References | 595 |

| | |
|--|------------|
| 24 Modal expansions in dispersive material systems with application to quantum optics and topological photonics | 599 |
| <i>Mário G. Silveirinha</i> | |
| 24.1 Introduction | 599 |
| 24.2 Electrodynamics of dispersive media | 600 |
| 24.3 Hermitian formulation in the time domain | 602 |
| 24.4 Poynting theorem and stored energy | 603 |
| 24.5 Canonical momentum | 605 |
| 24.6 Modal expansions | 607 |
| 24.7 Green's function | 608 |
| 24.8 Positive and negative frequency components of the Green function | 610 |
| 24.9 Application to topological photonics | 611 |
| 24.10 Application to quantum optics | 613 |
| 24.11 Summary | 616 |
| Acknowledgments | 617 |
| References | 617 |
| | |
| 25 Multiple scattering by a collection of randomly located obstacles distributed in a dielectric slab | 621 |
| <i>Gerhard Kristensson and Niklas Wellander</i> | |
| 25.1 Introduction | 621 |
| 25.2 The geometry | 622 |
| 25.3 Integral representation | 623 |
| 25.4 Exploiting the integral representations | 625 |
| 25.5 Expansions of surface fields | 630 |
| 25.6 The transmitted and reflected fields | 634 |
| 25.7 Statistical problem—ensemble average | 635 |
| 25.8 Approximations | 641 |
| 25.9 Conclusions | 644 |
| Appendix A | 645 |
| Appendix B | 645 |
| Appendix C | 647 |
| Appendix D | 647 |
| Appendix E | 648 |
| References | 650 |
| | |
| 26 Electromagnetics of complex environments applied to geophysical and biological media | 653 |
| <i>Akira Ishimaru, Yasuo Kuga and Max Bright</i> | |
| 26.1 Introduction | 653 |
| 26.2 Stochastic wave theories | 653 |
| 26.3 Time-reversal imaging | 654 |

| | | |
|-----------|--|------------|
| 26.4 | Imaging through random multiple scattering clutter | 656 |
| 26.5 | Geophysical remote sensing and imaging, and super resolution | 656 |
| 26.6 | Wigner distribution function and specific intensity | 658 |
| 26.7 | Biomedical electromagnetism and optics | 660 |
| 26.8 | Heat diffusion in tissues | 660 |
| 26.9 | Ultrasound in tissues and blood | 661 |
| 26.10 | Low coherence interferometry and optical coherence tomography (OCT) | 663 |
| 26.11 | Waves in metamaterials and electromagnetic and acoustic Brewster's angle | 665 |
| 26.12 | Coherence in multiple scattering | 665 |
| 26.13 | Porous media | 667 |
| 26.14 | Seismic coda | 669 |
| 26.15 | Conclusion | 670 |
| | Acknowledgments | 670 |
| | References | 671 |
| 27 | Innovative tools for SI units in solving various problems of electrodynamics | 673 |
| | <i>Oleg A. Tretyakov, Oleksandr Butrym and Fatih Erden</i> | |
| 27.1 | Introduction | 673 |
| 27.2 | Novel format of Maxwell's equations in SI units: Energetic and mechanical field characteristics | 674 |
| 27.2.1 | Novel format of Maxwell's equations in SI units | 674 |
| 27.2.2 | Energetic characteristics of the electromagnetic field | 676 |
| 27.2.3 | Mechanical equivalents of the energetic field characteristics | 677 |
| 27.3 | Exact solutions for polarization of Lorentz media associated with a signal of finite duration | 678 |
| 27.3.1 | Rearrangement of the motion equation to its equivalent matrix format and solving a vector Cauchy problem | 678 |
| 27.3.2 | Exact explicit solutions for the amplitudes of the polarization vector | 681 |
| 27.4 | Upgrading the evolutionary approach to electrodynamics (<i>EAE</i>) | 684 |
| 27.4.1 | Comparison of two alternative approaches to the electromagnetic field theory | 684 |
| 27.4.2 | Separation of a self-adjoint operator from the vectorial Maxwell's equations | 686 |
| 27.4.3 | Normalization of the eigenvectors of operator \mathfrak{R} | 691 |
| 27.4.4 | Configurational orthonormal modal basis in the space of solutions \mathcal{L}_2 | 692 |
| 27.4.5 | Projecting the field vectors and Maxwell's equations onto the modal basis | 693 |

| | |
|---|------------|
| 27.5 Present state of art and recent advances | 697 |
| 27.6 Ongoing and future research | 701 |
| References | 701 |
| Index | 709 |

About the editors

Kazuya Kobayashi is a professor in the Department of Electrical, Electronic, and Communication Engineering at Chuo University, Japan. He has received a number of awards including The President's Award (2020) from URSI (International Union of Radio Science) and the M.A. Khizhnyak Award (2016) at the 16th International Conference on Mathematical Methods in Electromagnetic Theory. He is a Fellow of The Electromagnetics Academy and a Fellow of URSI. He has held various positions in the international radio science, electromagnetics, and optics communities including URSI Assistant Secretary-General for AP-RASC (since 2015); Chair of URSI Commission B (since 2017); Chair of the AP-RASC Standing Committee (since 2015); President of the Japan National Committee of URSI (2008-2018); Chair of the PIERS Young Scientists Award Committee, The Electromagnetics Academy (since 2018); Editor of *Radio Science* (since 2019); and Series Editor of *Springer Series in Optical Sciences* (since 2020). His research areas include developments of rigorous mathematical techniques as applied to electromagnetic wave problems; radar cross section; and scattering and diffraction.

Paul Denis Smith is a professor of mathematics at the Macquarie University, Australia. His awards include the best paper award at the 1987 International Symposium on Electromagnetic Compatibility. He served as associate editor of *J. IEEE Antennas and Propagation* from 2004 to 2011 and is currently an associate editor of *Radio Science* and a Board Member for *Proceedings of the Royal Society(A)*. He is president of the Australian URSI Committee and is a member of the Australian Academy of Science National Committee for Space and Radio Science. His research areas include analytical and semi-analytical techniques for wave scattering and diffraction.

