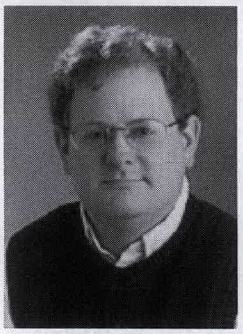

Daniel S. Weile
Dept. Of Electrical and Computer Engineering
University of Delaware
311 Dupont Hall
Newark, DE 19716 USA
Tel: +1 (302) 831-8784
Email: weile@ee.udel.edu

Electromagnetic Metamaterials: Physics and Engineering Explorations, Nader Engheta and Richard W. Ziolkowski (eds.), Piscataway, NJ, Wiley-IEEE Press, 2006, 414 pages, \$125, ISBN 978-0-471-76102-0.

With 27 authors contributing, the general treatment used throughout this book is excellent. It maximizes written descriptions based on standard basic electronic-engineering principles and uses mathematics in a concise format in order to impress the core basis upon which each major concept presented is predicated. As with most multi-authored texts on a single topic, the book contains some material that is repeated across several chapters. However, the repetition is minimal, and at times aids the reader by giving different perspectives on the same topic. This book is produced to a very high standard, with numerous color illustrations that allow the reader to rapidly assimilate the information that they are designed to convey.

Part 1 details with theoretical and physical assessment of double-negative (DNG) media. Chapter 1 is authored by the book's editors, Rick Ziolkowski and Nader Engheta. Both are themselves leading experts in this rapidly developing field of research, and they use their expert knowledge of the area in order to navigate readers less versed in the literature through the topic. Chapter 1 tells us how the topic of artificial materials is over 100 years old, with J. C. Bose conducting experiments on artificial-permeability media in 1898. A useful yet simple four-quadrant classification for materials having positive and/or negative permutations of permittivity and permeability is given in Chapter 1. It remains to be seen if the designations assigned stand the test of time. The short discussion that the authors of this chapter give regarding the two-time-derivative Lorentz metamaterial model provides a useful generic model, which expresses potential practical properties that are not readily derived from the classical Drude or Debye models. The study of metamaterials can be confusing to the novice, particularly the concept of negative refractive index in a material where both $\mu < 0$ and $\varepsilon < 0$. The phase-advance properties of DNG slabs is introduced using the classical reflection/transmission formula. A number of interesting physical properties – such as evanescent-wave amplification and hence sub-diffraction-limit image formation and phase compensation, which could be exploited for practical engineering benefit – are briefly discussed, using simple theoretical propositions. The preservation of causality in such media is also a difficult concept, which is treated in an empirical fashion based around FDTD studies.

Chapter 1 concludes with a very interesting overview of the use of materials in which ε and μ lie near zero, so that the refractive index is very much less than unity. For these cases, we are told about the possibility of enhancing antenna directivity and signal transmission through sub-wavelength holes. This chapter is well supported by over seventy well-chosen references.

Chapter 2 deals with waveguide and antenna applications of metamaterials that utilize at least one oppositely signed material. First, sub-wavelength cavities and parallel wave-guiding arrangements, offering the possibility of a single propagating mode in a large waveguide, are discussed, on the basis of the dispersion description of a TE-polarized signal. The treatment of the abstraction of different metamaterial types to one-dimensional transmission-line equivalents is given in largely qualitative terms. Extension to basic parallel-waveguide combinations of different metamaterial slabs illustrates anti-parallel power-flow characteristics. This work is extended to canonical cylindrical and spherical coaxial and shelled systems, where the interesting effects of interface-resonance phenomena are predicted for these structures. These considerations lead to the conclusion that it should be possible to build sub-wavelength open-cavity resonators, scattering-field enhancers, and "very interestingly" scattering-field absorbers. I expect that this section will be particularly tantalizing to any practicing engineers who would love to be able to order suitable metamaterials off the shelf in order to construct some of these artifacts. Simple artificial media assigned to offer single-negative media based around capacitive loops further wets the engineer's appetite in this respect, and the reader is encouraged by the possibility of being able to use commercial EM software to experiment with novel geometries. This is particularly true for the case of efficient electrically small dipoles, where reactive compensation is proposed using materials with $\mu > 0$ and $\varepsilon < 0$. This reader would have been interested to see how this work rests in relation to the Chu-Harrington limit.

In Chapter 3, the issue of using waveguide-based experiments in order to establish the basic electrical parameters of single- and double-negative metamaterials is discussed. An elaborated discussion of some of the issues related to non-normal incidence associated with waveguide-based measurements would have been welcomed. In addition, the chapter could have benefited from a more-detailed explanation of how permittivity and permeability could be routinely and robustly extracted from scattering parameters. The investigations presented yield an interesting result, that a rectangular waveguide loaded with axial material with $\varepsilon > 0$, $\mu < 0$ can lead to a means for waveguide miniaturization, since the waveguide width can be made arbitrarily smaller than half a wavelength in the filling material. The experiment illustrating concepts of a sub-wavelength resonator, comparing a composite of double-positive and double-negative materials is interesting. However, in this reviewer's view, it could have benefited from a presentation of the measured Q factor for the arrangements presented.

In Chapter 4, metamaterials are considered from a macroscopic perspective, so that the materials discussed can be characterized by their bulk constitutive parameters. The experimental characterization technique using a parallel-plate waveguide is discussed, together with the practical requirements for ensuring high-quality contacts to the "rodded" materials used in forming the various metamaterial structures tested. The effects that dielectric and conductor losses have on the insertion loss of the materials measured is alluded to in the chapter, but a more-through discussion would have been of considerable interest. The use of the terminology "left-handed" to describe a double-negative media, while consistent with the literature, remains at odds with the ONG (double negative) notation used in earlier book chapters.

Part 2 of the book deals with planar two-dimensional negative-index structures. In Chapter 5, antenna applications as well as sub-wavelength focusing using negative-refractive-index transmission-line structures are investigated. In this work, high-pass and low-pass one-dimensional and two-dimensional transmission lines are used in concert, and their propagation characteristics are shown to comply with Poynting's theorem for dispersive media. These line configurations lead to delay lines that are compact and exhibit linearity in their phase response, at least about the zero-degree phase region. The other examples for the deployment of these lines include reduced-frequency induced beam squint in series-fed antenna and array broadband baluns. The section on small-ring and backward-leaky-wave antennas would have benefited from a description of the effect of backward line losses on the radiating efficiency of antennas. The section on the two-dimensional transmission line details implementation of the Versalago lens. Subtitles related to the bandgap properties associated with mushroom two-dimensional transmission lines are particularly revealing.

Resonance-core antennas, based on two-dimensional anisotropic surfaces, are described in Chapter 6. The work in this chapter is an appetizer, inviting enterprising engineers to configure their own arrangements around the themes introduced in this chapter.

The treatment of couplers and resonator structures in Chapter 7 by the deployment of composites of high- and low-pass transmission-line structures leads to some interesting observations. Of particular interest is that for these composite structures, the band gap at an arbitrary transition frequency can be made to be zero, i.e., infinite-wavelength nonzero group velocity can be achieved. Microstrip hybrid implementation of these types of lines is described, together with their application in forming 0 dB backward couplers. The concept of a zero-order resonator is then introduced. It is applied to the design of a single-band antenna in which the uniform current distributors associated with this mode may lead to designs that exhibit increased antenna efficiency, due to reduced loss resistance with respect to radiation resistance. A dual-band antenna, operating at the second-order mode, is also described.

The second portion of the book considers electromagnetic bandgap (EBG) metamaterials. It begins with descriptions of various three-dimensional EBG media, starting with a review of the history and fundamental modeling of this class of media. First, the plane-wave method, together with a brief indication of convergence difficulties with the method, is given. The advantages of the transfer-matrix approach over the plane-wave method are then discussed. This is followed by a description of a classical rectangular FDTD solution methodology that permits all of the attendant advantages of this numerical scheme, when used with conventional media, to be brought to bear, here. Realization as well as characterization and application of EBG structures are next discussed. The manufacturing section of Chapter 9 is particularly interesting for those wishing to create such structures. Here, techniques are suggested based around mechanical means (e.g., drilling) and micromachining methods. These methods yield a variety of structures that can be used from 10 GHz through 2.4 THz. Importantly, a section on the effect that manufacturing tolerances have on EBG performance is also included. Surface wave effects that are useful when enhanced antenna-to-antenna isolation is required, complex reflection, coefficient assessment (useful for characterizing artificial magnetic conductor performance), and quasi-optical reflection and transmission measurements (based on time-domain spectroscopy for sub-millimeter-wave and terahertz structures) are all discussed. They are reasonably well supported by references to relevant publications. A short applications section, which includes illustrations of EBG variants of commercially relevant antennas, including a GPS antenna, a PIFA antenna, and a shaped dual-grid reflector antenna, completes the chapter.

The last chapter in this section deals with super-prism effects and more EBG-antenna applications. The chapter starts with some rigorous EM theory, designed to arm the theoretically minded with mathematical tools that can be used to obtain the dispersion characteristics of generic topologies. This then permits the highly dispersive nature of types of photonic crystals to be analyzed in detail. This observation leads to devices that ultimately could be deployed in wavelength multiplexers/demultiplexers. By evoking the conservation of the tangential wave vector, it is shown how a photonic crystal has the ability to provide directive radiation into free space, when a source is placed internal to it. This is an important observation that is exploited in demonstrations of highly directive three-dimensional EBG antennas.

The remainder of the book deals with two-dimensional planar EBG structures, starting with high-impedance ground planes. Here, textured printed-circuit-board patterns with vias to ground provide high-impedance (zero-degree reflection phase) near to the resonant frequency of the structure. In addition, they also provide bandgap properties. The geometry of the device supports the inclusion of tunable elements such as varactor diodes. The overall arrangement is shown to give opportunities for low-complexity electronically agile reflectors for beam steering, as well as low-profile steerable leaky-wave antennas, and reduced-ripple monopole-antenna solutions. A recipe for the synthesis of these high-impedance surfaces is provided.

The antenna application theme of the previous chapter is further elaborated in Chapter 12. There it is shown how two-dimensional EBGs can be used to enhance antenna directivity, and to reduce mutual coupling between patch antennas where the patches are operated within the EBG bandgap region. In this chapter, an empirical working definition for the usable operating-frequency band of an EBG-based antenna, based on the reflection phase properties of the EBG, is discussed. In addition, a bent-dipole antenna arrangement for crude electronic two-dimensional beam-pattern reconfiguration by a simple means using four diode switches is illustrative of what an ingenious mind can do with these surfaces. FSS-based EBG structures are analyzed by various MoM methodologies, e.g., electric (patch FSS) and magnetic (slot FSS) current-formulation methods. The pole-zero matching method for dispersion analysis is developed, and used to yield the equivalent admittance matrix of the FSS-based metamaterial. This well-written chapter requires a fair degree of mathematical competence for understanding. However, a close reading of the formulations used for the particular geometric discussions will be rewarding for those wishing to further develop a comprehensive understanding of grounded dielectric-backed frequency-selective structures. In this chapter, a more-comprehensive description of convergence-related issues would have been welcome. In the final chapter, solutions for the provision of inclusions that are resonant, and hence can be used to form artificial magnetic conductors that occupy minimal real estate, are suggested through the use of space-filling curves. The relative bandwidth of the Peano and Hilbert surfaces are compared in considerable detail, and the effect of length-scale differences on resonance production are highlighted. The chapter rounds off by introducing the possibility of a connection between the Hilbert space-filling curve and double-negative material.

In summary, the topics selected, together with the order in which they are presented and the general style of presentation used throughout the book are logical. This leads to a highly readable text, which will be of benefit to those wishing to obtain a concise introduction to the field, or for those wishing to use the book as a route map to the more detailed investigations itemized in the comprehensive reference lists associated with each chapter.

Reviewed by:

Vincent Fusco
The Institute of Electronics, Communications and Information Technology (ECIT)
Queen's University Belfast
NI Science Park, Queen's Road, Queen's Island, Belfast BT3 9DT
E-mail: v.fusco@ecit.qub.ac.uk

EMP Note Series

The following EMP-related notes have recently been published and distributed:

SSN 518 "Extension of the Analytic Results for the Focal Waveform of a Two-Arm Prolate-Spheroidal Impulse-Radiating Antenna (IRA)," Serhat Altunc and Carl E. Baum, November 2006

SSN 519 "Comparison of Analytical and Numerical Results for a Prolate-Spheroidal Impulse-Radiating Antenna (IRA)," Serhat Altunc, Carl E. Baum, and Christos G. Christodoulou, November 2006

SSN 520 "The Folded Horn Antenna," Everett G. Farr, Leland H. Bowen, Carl E Baum, and William D. Prather, December 2006

SSN 521 "Transmission/Reflection at a Dielectric Slab," Carl E. Baum, December 2006

SSN 522 "Two Antennas For Differential Mesoband Operation," Carl E. Baum, December 2006

IN 603 "Scattering at One-Dimensional-Transmission-Line Junctions," Carl E. Baum, March 2007

MN 60 "Subnanosecond Sample Holder," Carl E. Baum, February 2007

PN 18 "Path Integrals in Electromagnetics," Carl E. Baum, February 2007

Reprinted (errors in previous version):

CESDN 53 "Scattered EM Field Responses of Canonical Scatterers Illuminated by an Impulse Radiating Antenna (IRA)," F.M. Tesche, D. V. Giri, and W. D. Prather, April 2006

Prof. Dr. Dr.-Ing. E.h. Carl E. Baum has retired from the Air Force Research Laboratory, and is now a Distinguished Research Professor at the University of New Mexico. He may be reached at The University of New Mexico, Department of Electrical and Computer Engineering, MSC01 1100, 1 University of New Mexico, Albuquerque, NM 87131-0001 USA; Tel: +1 (505) 277-0246; Fax: +1 (505) 277-1439; E-mail: carl.e.baum@ieee.org or cebaum@ece.unm.edu; or through his assistant, Charles Reuben, for note requests, address changes, etc., at Tel: +1 (505) 277-1082; e-mail: shawnee@unm.edu. The CDs of Collected Notes (*Sensor and Simulation Notes 1-422*, *Interaction Notes 1-568*, and *Miscellaneous Notes*) are still available from Charles Reuben.

Recent Books

The following is a list of recently published books that have been received by the Associate Editor since the last issue of the *Magazine* was published. Reviewers are sought for these books, so readers are encouraged to let the Associate Editor know if they are interested in reviewing a particular book.

Antenna Engineering Handbook (Fourth Edition), John L. Volakis (ed.), McGraw Hill, 2007

Antennas for Portable Devices, Zhi Ning Chen (ed.), John Wiley, 2007

Quantum Cryptography and Secret-Key Distillation, Gilles Van Assche, Cambridge, 2007