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Balamati Choudhury and Rakesh Mohan Jha
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**Soft Computing in Electromagnetics**

Better communication systems demand high performance electromagnetic structures along with accurate, reliable and fast techniques to solve electromagnetic (EM) problems. A novel computing technique, called soft computing, is gaining popularity in a multitude of EM applications in order to tackle computationally intensive problems. It differs from conventional computing techniques by not relying on strict mathematical formulations. Soft computing techniques often seek to emulate biological systems like neural networks, swarm behaviour, etc. Fast-converging algorithms that mimic animal and human behaviour are currently emerging as the choice for replacing computationally intensive, time consuming, three-dimensional EM simulations; this development has simplified the process of EM design immensely.

Characterized by their ability to provide quick, robust and economically viable solutions despite imprecision, uncertainties and approximations in the formulation, soft computing methods such as genetic algorithm (GA), artificial neural network (ANN) and fuzzy logic have been widely used for microwave design. Similarly, they also play an important role in design and optimization applications in electromagnetics, such as EM design and performance enhancement of antennas, frequency selective surfaces (FSS), radar absorbing material (RAM) and metamaterials. This book emphasizes the suitability of soft computing techniques such as particle swarm optimization (PSO), bacterial foraging optimization (BFO) along with GA and ANN, for various EM design and optimization applications.

The application of soft computing concepts in the field of metamaterial antennas, radar absorbers, transmission line characterization and optimized radar absorbing material (RAM) is discussed in detail along with their usage for optimizing fault detection, EM propagation and path loss prediction. This book also introduces systematic implementation of soft computing tools in a relatively new area of metamaterials. Soft computing is presented here as an effective tool to minimize computations in a CAD package for quick and accurate solutions. The development of two such CAD packages for design of metamaterial split ring resonators (SRR) and path-loss prediction is presented. Numerical examples and MATLAB codes are provided to facilitate understanding of the principles of soft computing techniques by a wider readership.

**Balamati Choudhury** works as a Scientist at the Centre for Electromagnetics, CSIR-National Aerospace Laboratories, Bangalore. Her areas of interest include soft computing techniques, computational electromagnetics, and novel applications of metamaterials. She was recipient of the CSIR-NAL Young Scientist Award for the year 2013–2014 for her contribution in the area of Computational Electromagnetics for Aerospace Applications.

**Rakesh Mohan Jha** heads the Centre for Electromagnetics, CSIR-National Aerospace Laboratories, Bangalore. He worked as an SERC (UK) Post-Doctoral Research Fellow at Dept. of Engg. Sci., University of Oxford, England (in 1991–1992), and as Alexander von Humboldt Fellow at the Institute for High Frequency Techniques and Electronics of the University of Karlsruhe, Germany (in 1992–1993 and 2007). He was a warded Sir C.V. Raman Award for Aerospace Engineering for the Year 1999. Dr Jha was elected Fellow of INAE (FNAE) in 2010, for his contributions to the EM Applications to Aerospace Engineering.

 

# Soft Computing in Electromagnetics

Methods and Applications

**Balamati Choudhury**

**and**

**Rakesh Mohan Jha**

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*To*

*Professor Satya N. Atluri*

 

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# Preface

*At this point, we are at the throes of two revolutions — one is the information revolution and the other less visible one.... is the intelligent systems revolution.*

**—Lofti Zadeh**

Ever since the days of Aristotle, classical scientific thinking has been based on strict logic, well-constructed definitions and mathematical expressions. This approach to science changed drastically when Dr Lofti Zadeh published his famous paper '*Fuzzy sets. Information and Control*' in 1965. By introducing imprecision in science, Dr Zadeh created in-roads into developing greater understanding in the field of artificial intelligence and even certain areas of philosophy and psychology! This imprecision, he claims, had led to a revolution in intelligent systems that has affected the way we live.

Today, the idea conceived by Dr Zadeh has grown into a whole new field of science—the field of soft-computing. Algorithms that attempt to mimic animal and human behaviour, evolution, etc., have been developed and implemented in problems ranging from scientific ones to even problems in economics and humanities! Certain researchers have also noted that soft computing techniques offer an alternate methodology to solve mathematically intensive problems.

The extension of this wondrous computation technique into one of sciences most mathematically challenging field, that of electromagnetics, is not surprising. This book address the implementation of soft computing in numerous, common electromagnetic problems. In doing so, computationally intensive, time consuming, three-dimensional electromagnetic simulations may be replaced by these fast-converging algorithms, thereby simplifying the process of electromagnetic design. This realization has led to a concerted effort by the Center for Electromagnetics, CEM (to which the authors are affiliated) towards improving existing research in soft computing. This book is a culmination of these efforts.

Accurate, reliable and fast optimization techniques are *a priori* requirements to cater to the demand for high performance, real time electromagnetic design objectives. Soft computing techniques are emerging as important tools in design and optimization of various complex electromagnetic problems. In view of this, an attempt has been made in this book to cover soft-computing based solutions to such EM problems. A brief overview of the topics covered in the book is given below.

Resolving problems such as fault detection and compensation in active antenna arrays are important for the aerospace community; finding out real time, cost effective solutions to these problems will help in handling critical situations. In addition, (i) need for miniaturized antennas, (ii) reduction of mutual coupling, and (iii) overall improvement in EM performance, are issues that concern antenna engineers worldwide. This book yields solutions to these issues through the soft-computing route, and gives a new perspective to solving such nonlinear problems.

This book also introduces the implementation of soft computing techniques in a relatively new area in science and technology—that of metamaterial and its applications. A user friendly CAD package for metamaterial *split ring resonator* (SRR) design using soft computing is also included in this book. Some of the important applications in electromagnetics such as antenna design and performance enhancement through *particle swarm optimization* (PSO) and bacterial foraging (BFO) have been included.

This book also covers the design and optimization of radar absorbing material (RAM) using PSO. The PSO algorithm is used to determine the optimum thickness of each layer of a Jaumann absorber followed by a more complicated problem statement, which necessitates the need for selection of materials from a database and optimizes the thickness of each layer of material for improved RAM performance. Later, the same algorithm is used to design metamaterial based RAM in both microwave and terahertz regimes.

Other topics covered in this book include the characterization of planar transmission line using artificial neural network (ANN) and a CAD package for ray-tracing in rural and urban environments.

To summarize, this book covers approaches to solving various complex electromagnetic problems through the novel route of soft computing. The theory behind these techniques is presented along with algorithms and the corresponding software codes. None of the books available so far covers such widespread topics and novel approaches towards real time and cost effective solutions.

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It is our pleasure to acknowledge Ms Arya Menon who completed her off-campus undergraduate dissertation at CSIR-National Aerospace Laboratories. Indeed the work carried out by her was appreciated all around and we found it only fitting to invite her to adapt her dissertation as Chapter 8 of this book. We thank her for transferring the necessary copyrights for facilitating the production and circulation of the book in hand.

Beyond the technical aspects, correction of grammatical error is also a very pertinent area. We would like to extend our thanks to Mrs Balamani Vinayakumar for her help in going through the entire book for syntax error editing.

Without the concerted support of the publisher it is simply not feasible to write a book within a short span of time. Mr Manish Choudhary, Commissioning Editor, Cambridge University Press, has always been very responsive in this regard and we would like to thank him for all his inputs. We very much appreciate the meticulous effort made by Mr Hardip Grewal, Desk Editor (STM), Cambridge University Press, to improve the diction of the text and for ensuring that this book broadly conforms to the Cambridge University Press style and format.

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Needless to mention the gratitude, Balamati owes to her parents Mrs Binodini Choudhury and Mr Gajendra Kumar Choudhury and her uncle Mr Bipin Padhy for their blessings and constant encouragement. Further, she owes a lot to her brothers Balakrishna and Basudev, and their spouses Babita and Sujata, for their immense support coupled with a tinge of proud feeling of completion of this book.

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# Abbreviations

| | |
|---|---|
| AMC | Artificial magnetic conductors |
| ANN | Artificial neural network |
| BFO | Bacterial foraging |
| BGA | Binary genetic algorithm |
| BPSO | Binary particle swarm optimisation |
| BST | Barium strontium titanate |
| CD | Circular dichroism |
| CG | Conjugate gradient |
| CLPSO | Comprehensive learning particle swarm optimisation |
| CPGA | Continuous parameter genetic algorithm |
| CSRR | Circular split ring resonator |
| DLSR | Dual log-spiral resonator |
| DM | Dielectric materials |
| EBG | Electronic band gap |
| ECA | Equivalent circuit analysis |
| EM | Electromagnetic |
| ESS | Electromagnetic smart screen |
| FDTD | Finite difference time domain |
| FEL | Free electron laser |
| FEM | Finite element method |
| FSS | Frequency selective surface |
| GA | Genetic Algorithm |
| GNP | Gold nano-particles |
| HMM | Hyperbolic metamaterial |
| HZ-FSS | High impedance frequency selective surface |
| IPS | In-plane switching mode |
| IR | Infrared |
| LC | Liquid crystal |
| LDM | Lossy dielectric materials |
| LHM | Left-handed material |
| LIM | Low refractive index metamaterial |

 

| | |
|---|---|
| LMM | Lossy magnetic materials |
| MFDM | Multilayer finite-difference method |
| MIC | Microwave integrated circuits |
| MIMO | Multiple input, multiple output |
| MLP | Multi-layer perceptron |
| MLS | Method of least square |
| MOPSO | Multi-objective particle swarm optimisation |
| MOPSO | Multi-objective particle swarm optimisation |
| MTL-PSO | Multi-conductor transmission line particle swarm optimisation |
| NEP | Noise equivalent power |
| NN | Neural networks |
| NSGA | Non-dominated sorting genetic algorithm |
| PCS | Personal communication systems |
| PEC | Perfect electric conductor |
| PIFA | Planar inverted F antenna |
| PMM | Periodic method of moments |
| PRS | Partially reflecting surface |
| PSO | Particle swarm optimisation |
| RAM | Radar absorbing material |
| RCS | Radar cross section |
| RLM | Relaxation-type magnetic materials |
| RPSO | Real valued particle swarm optimisation |
| SLL | Sidelobe level |
| SRR | Split ring resonator |
| SSRR | Square split ring resonator |
| THz-TDS | Terahertz time domain spectroscopy |
| UWB | Ultra wideband |
| ZIM | Zero index metamaterial |

# Symbols

## Lower case

| | |
|---|---|
| $a$ | Length of SRR |
| $a_n$ | Amplitude distribution |
| $c$ | Speed of light |
| $c_1$ | Cognitive constant |
| $c_2$ | Social constant |
| $d$ | Spacing between array elements |
| $d_z$ | Thickness of the metamaterial in the direction of wave propagation. |
| $f$ | Transfer function |
| $f_o$ | Centre frequency |
| $f_{err}$ | Cost function for resonant frequency |
| $f_m$ | Damping frequency |
| $f_{mo}$ | Magnetic resonant frequency |
| $f_r$ | Resonant frequency |
| $g$ | gap between SRR ring |
| $h$ | height of substrate |
| $\hat{i}_\theta$ | Unit vector in the elevation direction |
| $\hat{i}_\phi$ | Unit vector in the azimuth direction |
| $i$ | number of input layer neurons |
| $j$ | number of hidden layer neurons |
| $k$ | number of output layer neurons |
| $n$ | Refractive index |
| $o$ | Output of the neural network |
| $p$ | Solution search space |
| $r_{ext}$ | External radius of SRR |
| $s$ | Number of bacteria in search space |
| $t$ | thickness |
| $w$ | Width of SRR |
| $w_{ik}$ | Weights of hidden layer |
| $w_{eff}$ | Effective width of the strip |
| $z$ | Impedance |

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## Upper case

| | |
|---|---|
| $A$ | Amplitude |
| $A_d$ | Amplitude of desired signal |
| $AF_o$ | Instantaneous array factor |
| $AFd$ | Measured array factor |
| $A_{tar}$ | Total absorption |
| $A_{iTM}$ | Absorption coefficient for TM polarization |
| $A_{iTE}$ | Absorption coefficient for TE polarization |
| $C$ | Gap capacitance |
| $Cpul$ | per unit length capacitance |
| $C_S$ | Effective capacitance |
| $C(i)$ | Tumble step size in the random direction |
| $E$ | Averaged squared error energy |
| $E$ | Electric field |
| $E_t$ | Tangential component of electric field |
| $E_i$ | Incident field |
| $E_T$ | Transmitted field |
| $G$ | Antenna gain |
| $H$ | Magnetic field |
| $H_t$ | Tangential component of magnetic field |
| $J_{cc}(\theta, P(j, k, l))$ | Cost function in BFO |
| $K(k)$ | Complete elliptical integral |
| $L$ | Total Inductance |
| $M$ | Number of neurons |
| $N$ | Number of antenna elements |
| $N_p$ | Number of particles |
| $N_d$ | Number of dimensions |
| $N_t$ | Number of time steps |
| $N_c$ | Number of chemotaxis steps |
| $N_s$ | Number of swimming steps |
| $N_{re}$ | Number of reproduction steps |
| $N_{ed}$ | Number of elimination and dispersal steps |
| $P_{ed}$ | Elimination-dispersal with probability |
| $R$ | Reflectance |
| $S_{11}$ | Scattering parameter from Port 1 |
| $S_{21}$ | Scattering parameter from Port 2 |
| $T$ | Transmittance |
| $W$ | Weight matrix connecting the hidden to the output neurons |
| $V$ | Weight matrix connecting the inputs to the hidden neurons |
| $V_{\min}$ | Minimum particle velocity |
| $V_{\max}$ | Maximum particle velocity |
| $X_{\min}$ | Minimum particle position |
| $X_{\max}$ | Maximum particle position |
| $Y$ | Output from hidden layer neurons |
| $Z_o$ | Impedance of free space |

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## Greek

| | |
|---|---|
| $\alpha$ | Attenuation constant |
| $\beta$ | Progressive phase shift |
| | Intermediate error functions |
| | Permittivity of the medium |
| o | Free space permittivity |
| eff | Effective dielectric constant |
| r | Relative permittivity |
| ′ r | Real part of complex relative permittivity |
| ″ r | Imaginary part of complex relative permittivity |
| | Learning rate |
| *o* | Impedance of free space |
| | Elevation angle |
| | Wavelength |
| o | Free space permeability |
| r | Relative permeability |
| | Permeability of the medium |
| *i* | Permeability of $i^{th}$ layer |
| ′ eff | Real part of magnetic permeability |
| ″ eff | Imaginary part of magnetic permeability |
| | Filling factor of inductance |
| | Azimuth angle |
| *d* | Azimuth angle of desired signal |
| | Angular frequency |
| 0 | Reflection coefficient |