

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.

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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.

xx PREFACE

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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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

xxiv ABBREVIATIONS

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
\vec{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}_θ	Unit vector in the elevation direction
\hat{i}_ϕ	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

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
C_{pul}	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_{1l}	Scattering parameter from Port 1
S_{2l}	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

Greek

α	Attenuation constant
β	Progressive phase shift
	Intermediate error functions
	Permittivity of the medium
ϵ_0	Free space permittivity
ϵ_{eff}	Effective dielectric constant
ϵ_r	Relative permittivity
ϵ_r'	Real part of complex relative permittivity
ϵ_r''	Imaginary part of complex relative permittivity
η	Learning rate
Z_0	Impedance of free space
	Elevation angle
	Wavelength
μ_0	Free space permeability
μ_r	Relative permeability
	Permeability of the medium
μ_i	Permeability of i^{th} layer
μ_r'	Real part of magnetic permeability
μ_r''	Imaginary part of magnetic permeability
μ_{eff}	Filling factor of inductance
	Azimuth angle
ϕ_d	Azimuth angle of desired signal
	Angular frequency
Γ	Reflection coefficient