

Contents

Contributors

ix

PART 1 Concepts, ideas, and methodologies in Metamaterial-by-Design

1. Metamaterials-by-Design: introduction and paradigm	3
Andrea Alù, Nader Engheta, Andrea Massa, and Giacomo Oliveri	
1.1. Introduction	3
1.2. Overview of the volume	5
1.3. Conclusions and acknowledgments	9
References	10
2. Task-oriented modeling and design of metasurfaces	13
Sergei Tretyakov and Ana Díaz-Rubio	
2.1. Design and modeling of local metasurfaces	14
2.2. Multi-physics methodology	27
References	35
3. Task-oriented design of metamaterials: principles and methodologies	37
Giacomo Oliveri, Marco Salucci, Arianna Benoni, and Andrea Massa	
3.1. Introduction and framework	37
3.2. Property-oriented versus task-oriented MTM design and the MbD loop	40
3.3. Inverse problem-based approaches for task-oriented MTM synthesis	47
3.4. Artificial intelligence for task-oriented MTM analysis and digital twin implementations	53
3.5. Task-oriented design approaches based on deterministic and evolutionary optimization strategies and applicative examples	59
3.6. Conclusions and outlook	66
References	66

PART 2 Applications of Metamaterials-by-Design paradigm in microwaves, terahertz, photonics, and optics for space, avionics, automotive, and medical scenarios

4. Aperiodic metasurface synthesis techniques and designs	75
Jordan Budhu and Anthony Grbic	
4.1. Introduction	75
4.2. Sheet impedance boundary condition	77
4.3. Design of aperiodic metasurfaces using analytical formulations derived from network models	79
4.4. Design of aperiodic metasurfaces using numerical techniques based on integral equations	92
4.5. Chapter conclusion	112
4.6. Acknowledgments and sponsors	113
References	113
5. Recent advancements in microwave MTM-powered application-oriented systems and devices	115
Mirko Barbuto, Filiberto Bilotti, Alessio Monti, Davide Ramaccia, Alessandro Toscano, and Stefano Vellucci	
5.1. Introduction	115
5.2. Topological synthesis of antenna radiation properties	116
5.3. Cloaking metasurfaces for compact radio platforms	122
5.4. Non-linear and waveform-dependent metasurfaces for smart antennas	127
5.5. Time-varying metamaterials and metasurfaces for complex wireless environments	136
5.6. Conclusions	141
References	143
6. Scattering-signature control via digital coding metasurfaces	147
Massimo Moccia, Giuseppe Castaldi, and Vincenzo Galdi	
6.1. Introduction and background	147
6.2. Basic theory	148
6.3. Experimental validation	157
6.4. Conclusions and perspectives	164
References	165
7. Task-oriented reconfigurable metasurfaces based on inverse design and temporal meta-systems	167
Lei Kang, Sawyer D. Campbell, Yuhao Wu, Jingwei Xu, Wending Mai, Eric B. Whiting, and Douglas H. Werner	
7.1. Introduction	167

7.2.	Active phase-change metasurfaces based on inverse design	173
7.3.	Time-varying metasurfaces and antennas	182
7.4.	Conclusions and outlook	195
	References	196
8.	Deep learning in metasurface design and optimization	203
	YiHan Ma and Yang Hao	
8.1.	Introduction to metasurface	203
8.2.	Machine learning in metasurface design	209
8.3.	Challenges and perspectives	227
	References	229
PART 3 Academic and industrial vision on task-oriented metamaterial technologies		
9.	Digital reconfigurable intelligent surfaces: on the impact of realistic reradiation models	235
	Marco Di Renzo, Abdelhamed Ahmed, Alessio Zappone, Vincenzo Galdi, Gabriele Gradoni, Massimo Moccia, and Giuseppe Castaldi	
9.1.	Introduction	235
9.2.	System model	241
9.3.	Optimization algorithm	244
9.4.	Numerical results	247
9.5.	Conclusions	253
	Acknowledgment	255
	References	303
10.	Task-oriented metamaterial technologies and applications: an industrial perspective	307
	Charlotte Tripont-Canseliet, Stefano Maci, and Jean Chazelas	
10.1.	Introduction	307
10.2.	The challenge of multifunctional metamaterials	309
10.3.	The challenge of multiscale modeling	315
10.4.	The challenge of ultimate miniaturization	320
10.5.	The challenge of SATCOM on the move applications	327
10.6.	The challenge of sense and avoid for UAVs	332
10.7.	The challenge of 6G communications	337
10.8.	Conclusions	340
	References	340

11. Metamaterial technologies and applications: a mobile communications industrial perspective	343
Renato Lombardi, Christian Mazzucco, Roberto Flamini, Claudio Massagrande, and Francesco Verní	
11.1. Introduction	343
11.2. Efficiency	346
11.3. Two sectors cell coverage for costs reduction	352
11.4. Coexistence with fixed satellite services (FSS)	356
11.5. Full-duplex	362
11.6. Dense urban coverage	366
11.7. Point-to-point communications	370
11.8. Conclusions	376
References	378
<i>Index</i>	383