

# Contents

<b>Acknowledgements</b>	<b>V</b>
<b>1 Introduction</b>	<b>1</b>
<b>2 Metamaterials: Fundamental Revolution and Potential Future</b>	<b>3</b>
2.1 Metamaterials - The Story so Far . . . . .	3
2.1.1 How the Subject Started? . . . . .	3
2.1.2 Wave Propagation in Left-Handed Media . . . . .	5
2.1.3 Negative Permittivity . . . . .	7
2.1.4 Negative Permeability . . . . .	8
2.1.5 First Experimental Work Towards LHM . . . . .	10
2.2 Definition of Metamaterials . . . . .	11
2.3 Hot Applications of Metamaterials . . . . .	12
2.4 Microwave Metamaterials . . . . .	14
2.4.1 Transmission Line Approach . . . . .	14
2.4.2 CPW-SRRs Approach . . . . .	15
2.5 Basics of Microwave Filters, Dispersion Engineering, and Metasurfaces . . . . .	17
2.5.1 Microwave Filters . . . . .	17
2.5.2 Dispersion Engineering . . . . .	18
2.5.3 Metasurfaces . . . . .	20
<b>3 Simulation Techniques and Measurements Procedures</b>	<b>22</b>
3.1 Computational Electromagnetics Overview . . . . .	22
3.1.1 CST MWS - Finite Integration Technique . . . . .	23
3.1.2 Ansoft HFSS - Finite Element Method . . . . .	26
3.1.3 CST MWS versus Ansoft HFSS . . . . .	27
3.2 Structures Preparation Steps . . . . .	28
3.3 Measurements . . . . .	29
3.3.1 Designing the TRL Calibration Kits . . . . .	29
3.3.2 CPW Structures Measurements . . . . .	30
3.3.3 Metasurfaces Structures Measurements . . . . .	31
<b>4 CPW Filters Based on Novel Metamaterial Resonators</b>	<b>33</b>
4.1 Introduction . . . . .	33
4.2 CPW Compact Bandstop Filters-Recent Advances . . . . .	34
4.2.1 Single Layer CPW Filter Synthesis . . . . .	34
4.2.2 CPW-SRRs and CPW-CSRRs Comparison . . . . .	38

4.2.3	Spurious Elimination Using Miniaturized CUSRs . . . . .	41
4.2.4	Bandwidth Modifying Slots . . . . .	43
4.2.5	Miniaturization of CPW Bandstop Filter with Spiral Resonators . . . . .	46
4.3	CPW Compact Bandpass Filters . . . . .	48
4.3.1	Narrow BPF Incorporating Bandwidth Modifying Slots . . . . .	48
4.3.2	Miniaturized BPF Based on Metamaterial Resonators-A Conceptual Study . . . . .	52
4.3.3	Very Compact BPF Based on Spiral Metamaterial Resonators . . . . .	56
4.4	Summary . . . . .	57
<b>5</b>	<b>Dispersion Analysis of CPW LHM</b>	<b>60</b>
5.1	Coplanar Waveguide Left-Handed Media . . . . .	60
5.2	Physical Meaning of Phase Delay and Group Delay . . . . .	61
5.3	LHM Structures . . . . .	62
5.4	Dispersion Analysis . . . . .	63
5.5	Transmission Results . . . . .	64
5.6	Summary . . . . .	69
<b>6</b>	<b>Novel Asymmetric Microwave and Terahertz Metasurfaces</b>	<b>70</b>
6.1	Introduction . . . . .	70
6.2	Planar Asymmetric Metamaterial Resonators . . . . .	71
6.2.1	Microwave Thin-Film Sensing with Asymmetric Resonators . . . . .	74
6.2.2	Terahertz Thin-Film Sensing with Asymmetric Resonators . . . . .	76
6.3	Applying the Babinet Principle to Asymmetric Resonators . . . . .	78
6.4	High Q-factor Metasurfaces Based on Miniaturized aSRRs . . . . .	81
6.4.1	The Basic Principle . . . . .	82
6.4.2	Parametric Study of aSRRs and caSRRs . . . . .	84
6.5	Summary . . . . .	86
<b>7</b>	<b>Conclusions</b>	<b>88</b>
	<b>Bibliography</b>	<b>90</b>
	<b>List of Publications</b>	<b>101</b>