Asymmetric Passive Components in Microwave Integrated Circuits

HEE-RAN AHN
# Contents

**Preface** xi

1 **Introduction** 1

1.1 Asymmetric Passive Components 1

1.2 Circuit Parameters 2

1.3 Asymmetric Four-Port Hybrids 3

1.3.1 Asymmetric Ring Hybrids 3

1.3.2 Asymmetric Branch-Line Hybrids 4

1.4 Asymmetric Three-Port Power Dividers 5

1.5 Asymmetric Two-Port Components 6

References 6

2 **Circuit Parameters** 10

2.1 Scattering Matrix 10

2.1.1 Transmission-Line Theory 11

2.1.2 Basis-Dependent Scattering Parameters of a One-Port Network 12

2.1.3 Voltage- and Current-Basis Scattering Matrices of \( n \)-Port Networks 14

2.1.4 Complex Normalized Scattering Matrix 17

2.2 Scattering Parameters of Reduced Multiports 18

2.2.1 Examples of Reduced Multiports 21

2.3 Two-Port Network Analysis Using Scattering Parameters 23
2.4 Other Circuit Parameters
  2.4.1 ABCD Parameters 29
  2.4.2 Open-Circuit Impedance and Short-Circuit Admittance Parameters 29
  2.4.3 Conversion Matrices of Two-Port Networks Terminated in Arbitrary Impedances 36

2.5 Analyses of Symmetric Networks 43
  2.5.1 Analyses with Even- and Odd-Mode Excitations 43
  2.5.2 Useful Symmetric Two-Port Networks 45
  2.5.3 Properties of Symmetric Two-Port Networks 47

2.6 Analyses with Image Parameters 47
  2.6.1 Image Impedances 47
  2.6.2 Image Propagation Constants 49
  2.6.3 Symmetrical and Common Structures 50

Exercises 52

References 54

3 Conventional Ring Hybrids 56
  3.1 Introduction 56
  3.2 Original Concept of the 3-dB Ring Hybrid 57
  3.3 Conventional Ring Hybrids 62
    3.3.1 Coupled Transmission Lines 62
    3.3.2 Ring Hybrids with Coupled Transmission Lines 68
    3.3.3 Wideband Ring Hybrids 71
    3.3.4 Symmetric Ring Hybrids with Arbitrary Power Divisions 74
    3.3.5 Conventional Lumped-Element Ring Hybrids 77
    3.3.6 Mixed Small Ring Hybrids 80
  3.4 Conventional 3-dB Uniplanar Ring Hybrids 84
    3.4.1 Uniplanar T-Junctions 85
    3.4.2 Transitions 86
    3.4.3 Wideband Uniplanar Baluns 86
    3.4.4 Uniplanar Ring Hybrids 88

Exercises 90

References 91
4 Asymmetric Ring Hybrids 93
  4.1 Introduction 93
  4.2 Derivation of Design Equations of Asymmetric Ring Hybrids 93
  4.3 Small Asymmetric Ring Hybrids 99
  4.4 Wideband or Small Asymmetric Ring Hybrids 100
    4.4.1 Microstrip Asymmetric Ring Hybrids 100
    4.4.2 Uniplanar Asymmetric Ring Hybrids 102
  4.5 Miniaturized Ring Hybrids Terminated in Arbitrary Impedances 106
    4.5.1 Asymmetric Lumped-Element Ring Hybrids 106
  Exercises 122
  References 122

5 Asymmetric Branch-Line Hybrids 125
  5.1 Introduction 125
  5.2 Origin of Branch-Line Hybrids 125
  5.3 Multisection Branch-Line Couplers 127
  5.4 Branch-Line Hybrids for Impedance Transforming 132
  5.5 Asymmetric Four-Port Hybrids 139
    5.5.1 Analyses of Asymmetric Four-Port Hybrids 139
    5.5.2 Conventional-Direction Asymmetric Branch-Line Hybrids 140
    5.5.3 Anti-Conventional-Direction Asymmetric Branch-Line Hybrids 147
  Exercises 150
  References 151

6 Conventional Three-Port Power Dividers 154
  6.1 Introduction 154
  6.2 Three-Port 3-dB Power Dividers 155
  6.3 Three-Port Power Dividers with Arbitrary Power Divisions 156
  6.4 Symmetric Analyses of Asymmetric Three-Port Power Dividers 160
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.5</td>
<td>Three-Port 3-dB Power Dividers Terminated in Complex Frequency-Dependent Impedances</td>
<td>163</td>
</tr>
<tr>
<td>6.6</td>
<td>Three-Port 45° Power Divider/Combiner</td>
<td>167</td>
</tr>
<tr>
<td></td>
<td>Exercises</td>
<td>168</td>
</tr>
<tr>
<td></td>
<td>References</td>
<td>168</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Three-Port 3-dB Power Dividers Terminated in Different Impedances</td>
<td>170</td>
</tr>
<tr>
<td>7.1</td>
<td>Introduction</td>
<td>170</td>
</tr>
<tr>
<td>7.2</td>
<td>Perfect Isolation Condition</td>
<td>171</td>
</tr>
<tr>
<td>7.3</td>
<td>Analyses</td>
<td>173</td>
</tr>
<tr>
<td>7.4</td>
<td>Scattering Parameters of Three-Port Power Dividers</td>
<td>177</td>
</tr>
<tr>
<td>7.5</td>
<td>Lumped-Element Three-Port 3-dB Power Dividers</td>
<td>186</td>
</tr>
<tr>
<td>7.6</td>
<td>Coplanar Three-Port 3-dB Power Dividers</td>
<td>188</td>
</tr>
<tr>
<td></td>
<td>Exercises</td>
<td>189</td>
</tr>
<tr>
<td></td>
<td>References</td>
<td>190</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>General Design Equations for N-Way Arbitrary Power Dividers</td>
<td>192</td>
</tr>
<tr>
<td>8.1</td>
<td>Introduction</td>
<td>192</td>
</tr>
<tr>
<td>8.2</td>
<td>General Design Equations for Three-Port Power Dividers</td>
<td>193</td>
</tr>
<tr>
<td>8.2.1</td>
<td>Coplanar Three-Port Power Divider Terminated in 50 Ω, 60 Ω, and 70 Ω</td>
<td>196</td>
</tr>
<tr>
<td>8.2.2</td>
<td>Determining $Z_{Ad}$</td>
<td>197</td>
</tr>
<tr>
<td>8.3</td>
<td>General Design Equations for N-Way Power Dividers</td>
<td>199</td>
</tr>
<tr>
<td>8.3.1</td>
<td>Analyses of N-Way Power Dividers</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>Exercises</td>
<td>204</td>
</tr>
<tr>
<td></td>
<td>References</td>
<td>204</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Asymmetric Ring-Hybrid Phase Shifters and Attenuators</td>
<td>206</td>
</tr>
<tr>
<td>9.1</td>
<td>Introduction</td>
<td>206</td>
</tr>
<tr>
<td>9.2</td>
<td>Scattering Parameters of Asymmetric Ring Hybrids</td>
<td>207</td>
</tr>
<tr>
<td>9.3</td>
<td>Asymmetric Ring-Hybrid Phase Shifters</td>
<td>209</td>
</tr>
<tr>
<td>9.3.1</td>
<td>Uniplanar Asymmetric Ring-Hybrid $-135°$ Phase Shifter</td>
<td>216</td>
</tr>
</tbody>
</table>
9.4 Asymmetric Ring-Hybrid Attenuator with Phase Shifts 216
  9.4.1 Microstrip Asymmetric Ring-Hybrid 4-dB Attenuator with 45° Phase Shift 220

Exercises 222

References 223

10 Ring Filters and Their Use in a New Measurement Technique for Inherent Ring-Resonance Frequency 225
  10.1 Introduction 225
  10.2 Ring Filters 226
    10.2.1 Analyses of Ring Filters 226
    10.2.2 Measurements 230
  10.3 New Measurement Technique for Inherent Ring-Resonance Frequency 230
    10.3.1 Lossless Case 230
    10.3.2 Loss Case 234
  10.4 Conclusions 237

Exercises 238

References 238

11 Small Impedance Transformers, CVTs and CCTs, and Their Applications to Small Power Dividers and Ring Filters 240
  11.1 Small Transmission-Line Impedance Transformers 240
  11.2 Mathematical Approach for CVTs and CCTs 241
    11.2.1 CVTs and CCTs 242
    11.2.2 Microstrip CVTs and CCTs 247
    11.2.3 Bounded Length of CVTs and CCTs 248
    11.2.4 Phase Responses of CVTs and CCTs 251
  11.3 CVT3PDs and CCT3PDs 253
    11.3.1 Isolation Circuits of CVT3PDs and CVT3PDs 254
    11.3.2 Design of CVT3PDs and CCT3PDs 256
  11.4 Asymmetric Three-Port 45° Power Divider Terminated in Arbitrary Impedances 258
    11.4.1 Asymmetric 45° Power Divider Terminated in 30 Ω, 60 Ω, and 50 Ω 259
## CONTENTS

11.5 CVT and CCT Ring Filters 261
   11.5.1 Analyses of Ring Filters 262

Exercises 266
References 267

Appendix A: Symbols and Abbreviations 269
Appendix B: Conversion Matrices 272
Appendix C: Derivation of the Elements of a Small Asymmetric Ring Hybrid 276
Appendix D: Trigonometric Relations 279
Appendix E: Hyperbolic Relations 281
Index 283