

# CONTENTS

---

<b>PREFACE</b>	<b>xvii</b>
<b>GETTING FILES FROM THE WILEY ftp AND INTERNET SITES</b>	<b>xix</b>
<b>SYMBOLS LIST AND GLOSSARY</b>	<b>xxi</b>
<b>1 INTRODUCTION</b>	<b>1</b>
1.1 System Design Process / 1	
1.2 Organization of the Book / 2	
1.3 Appendixes / 3	
1.4 Spreadsheets / 3	
1.5 Test and Simulation / 3	
1.6 Practical Skepticism / 4	
1.7 References / 5	
<b>2 GAIN</b>	<b>7</b>
2.1 Simple Cases / 8	
2.2 General Case / 9	
2.2.1 <i>S</i> Parameters / 9	
2.2.2 Normalized Waves / 11	
2.2.3 <i>T</i> Parameters / 12	

- 2.2.4 Relationships Between  $S$  and  $T$  Parameters / 13
- 2.2.5 Restrictions on  $T$  Parameters / 14
- 2.2.6 Cascade Response / 14
- 2.3 Simplification: Unilateral Modules / 15
  - 2.3.1 Module Gain / 15
  - 2.3.2 Transmission Line Interconnections / 16
  - 2.3.3 Overall Response, Standard Cascade / 25
  - 2.3.4 Combined with Bilateral Modules / 28
  - 2.3.5 Lossy Interconnections / 32
  - 2.3.6 Additional Considerations / 38
- 2.4 Nonstandard Impedances / 40
- 2.5 Use of Sensitivities to Find Variations / 40
- 2.6 Summary / 43
  - Endnotes / 45

### 3 NOISE FIGURE

47

- 3.1 Noise Factor and Noise Figure / 47
- 3.2 Modules in Cascade / 49
- 3.3 Applicable Gains and Noise Factors / 54
- 3.4 Noise Figure of an Attenuator / 55
- 3.5 Noise Figure of an Interconnect / 56
- 3.6 Cascade Noise Figure / 56
- 3.7 Expected Value and Variance of Noise Figure / 58
- 3.8 Impedance-Dependent Noise Factors / 59
  - 3.8.1 Representation / 60
  - 3.8.2 Constant-Noise Circles / 61
  - 3.8.3 Relation to Standard Noise Factor / 62
  - 3.8.4 Using the Theoretical Noise Factor / 64
  - 3.8.5 Summary / 65
- 3.9 Image Noise, Mixers / 65
  - 3.9.1 Effective Noise Figure of the Mixer / 66
  - 3.9.2 Verification for Simple Cases / 69
  - 3.9.3 Examples of Image Noise / 69
- 3.10 Extreme Mismatch, Voltage Amplifiers / 74
  - 3.10.1 Module Noise Factor / 76
  - 3.10.2 Cascade Noise Factor / 78
  - 3.10.3 Combined with Unilateral Modules / 79
  - 3.10.4 Equivalent Noise Factor / 79

- 3.11 Using Noise Figure Sensitivities / 79
- 3.12 Mixed Cascade Example / 80
  - 3.12.1 Effects of Some Resistor Changes / 81
  - 3.12.2 Accounting for Other Reflections / 82
  - 3.12.3 Using Sensitivities / 82
- 3.13 Gain Controls / 84
  - 3.13.1 Automatic Gain Control / 84
  - 3.13.2 Level Control / 86
- 3.14 Summary / 88
  - Endnotes / 90

#### **4 NONLINEARITY IN THE SIGNAL PATH**

91

- 4.1 Representing Nonlinear Responses / 91
- 4.2 Second-Order Terms / 92
  - 4.2.1 Intercept Points / 93
  - 4.2.2 Mathematical Representations / 95
  - 4.2.3 Other Even-Order Terms / 97
- 4.3 Third-Order Terms / 97
  - 4.3.1 Intercept Points / 99
  - 4.3.2 Mathematical Representations / 100
  - 4.3.3 Other Odd-Order Terms / 101
- 4.4 Frequency Dependence and Relationship Between Products / 102
- 4.5 Nonlinear Products in the Cascades / 103
  - 4.5.1 Two-Module Cascade / 104
  - 4.5.2 General Cascade / 105
  - 4.5.3 IMs Adding Coherently / 106
  - 4.5.4 IMs Adding Randomly / 108
  - 4.5.5 IMs That Do Not Add / 109
  - 4.5.6 Effect of Mismatch on IPs / 110
- 4.6 Examples: Spreadsheets for IMs in a Cascade / 111
- 4.7 Anomalous IMs / 115
- 4.8 Measuring IMs / 116
- 4.9 Compression in the Cascade / 119
- 4.10 Other Nonideal Effects / 121
- 4.11 Summary / 121
  - Endnote / 122

**5 NOISE AND NONLINEARITY**

**123**

- 5.1 Intermodulation of Noise / 123
  - 5.1.1 Preview / 124
  - 5.1.2 Flat Bandpass Noise / 125
  - 5.1.3 Second-Order Products / 125
  - 5.1.4 Third-Order Products / 130
- 5.2 Composite Distortion / 133
  - 5.2.1 Second-Order IMs (CSO) / 134
  - 5.2.2 Third-Order IMs (CTB) / 136
  - 5.2.3 CSO and CTB Example / 136
- 5.3 Dynamic Range / 137
  - 5.3.1 Spurious-Free Dynamic Range / 137
  - 5.3.2 Other Range Limitations / 139
- 5.4 Optimizing Cascades / 139
  - 5.4.1 Combining Parameters on One Spreadsheet / 139
  - 5.4.2 Optimization Example / 143
- 5.5 Spreadsheet Enhancements / 146
  - 5.5.1 Lookup Tables / 146
  - 5.5.2 Using Controls / 147
- 5.6 Summary / 147
  - Endnotes / 147

**6 ARCHITECTURES THAT IMPROVE LINEARITY**

**149**

- 6.1 Parallel Combining / 149
  - 6.1.1 90° Hybrid / 150
  - 6.1.2 180° Hybrid / 152
  - 6.1.3 Simple Push–Pull / 154
  - 6.1.4 Gain / 155
  - 6.1.5 Noise Figure / 156
  - 6.1.6 Combiner Trees / 156
  - 6.1.7 Cascade Analysis of a Combiner Tree / 157
- 6.2 Feedback / 158
- 6.3 Feedforward / 159
  - 6.3.1 Intermods and Harmonics / 160
  - 6.3.2 Bandwidth / 161
  - 6.3.3 Noise Figure / 161
- 6.4 Nonideal Performance / 162
- 6.5 Summary / 163
  - Endnotes / 163

**7 FREQUENCY CONVERSION****165**

- 7.1 Basics / 165
  - 7.1.1 The Mixer / 165
  - 7.1.2 Conversion in Receivers / 167
  - 7.1.3 Spurs / 168
  - 7.1.4 Conversion in Synthesizers and Exciters / 170
  - 7.1.5 Calculators / 170
  - 7.1.6 Design Methods / 170
  - 7.1.7 Example / 171
- 7.2 Spurious Levels / 171
  - 7.2.1 Dependence on Signal Strength / 171
  - 7.2.2 Estimating Levels / 173
  - 7.2.3 Strategy for Using Levels / 175
- 7.3 Two-Signal IMs / 176
- 7.4 Power Range for Predictable Levels / 177
- 7.5 Spur Plot, LO Reference / 180
  - 7.5.1 Spreadsheet Plot Description / 180
  - 7.5.2 Example of a Band Conversion / 182
  - 7.5.3 Other Information on the Plot / 184
- 7.6 Spur Plot, IF Reference / 186
- 7.7 Shape Factors / 196
  - 7.7.1 Definitions / 197
  - 7.7.2 RF Filter Requirements / 197
  - 7.7.3 IF Filter Requirements / 200
- 7.8 Double Conversion / 202
- 7.9 Operating Regions / 203
  - 7.9.1 Advantageous Regions / 203
  - 7.9.2 Limitation on Downconversion, Two-by-Twos / 206
  - 7.9.3 Higher Values of  $m$  / 209
- 7.10 Examples / 211
- 7.11 Note on Spur Plots Used in This Chapter / 216
- 7.12 Summary / 216
  - Endnotes / 217

**8 CONTAMINATING SIGNALS IN SEVERE NONLINEARITIES****219**

- 8.1 Decomposition / 220
- 8.2 Hard Limiting / 223
- 8.3 Soft Limiting / 223

- 8.4 Mixers, Through the LO Port / 225
  - 8.4.1 AM Suppression / 225
  - 8.4.2 FM Transfer / 226
  - 8.4.3 Single-Sideband Transfer / 226
  - 8.4.4 Mixing Between LO Components / 228
  - 8.4.5 Troublesome Frequency Ranges in the LO / 228
  - 8.4.6 Summary of Ranges / 235
  - 8.4.7 Effect on Noise Figure / 236
- 8.5 Frequency Dividers / 240
  - 8.5.1 Sideband Reduction / 240
  - 8.5.2 Sampling / 241
  - 8.5.3 Internal Noise / 242
- 8.6 Frequency Multipliers / 242
- 8.7 Summary / 243
- Endnotes / 244

**9 PHASE NOISE**

**245**

- 9.1 Describing Phase Noise / 245
- 9.2 Adverse Effects of Phase Noise / 247
  - 9.2.1 Data Errors / 247
  - 9.2.2 Jitter / 248
  - 9.2.3 Receiver Desensitization / 249
- 9.3 Sources of Phase Noise / 250
  - 9.3.1 Oscillator Phase Noise Spectrums / 250
  - 9.3.2 Integration Limits / 252
  - 9.3.3 Relationship Between Oscillator  $S_{\phi}$  and  $L_{\phi}$  / 252
- 9.4 Processing Phase Noise in a Cascade / 252
  - 9.4.1 Filtering by Phase-Locked Loops / 253
  - 9.4.2 Filtering by Ordinary Filters / 254
  - 9.4.3 Implication of Noise Figure / 255
  - 9.4.4 Transfer from Local Oscillators / 255
  - 9.4.5 Transfer from Data Clocks / 256
  - 9.4.6 Integration of Phase Noise / 258
- 9.5 Determining the Effect on Data / 258
  - 9.5.1 Error Probability / 258
  - 9.5.2 Computing Phase Variance, Limits of Integration / 259
  - 9.5.3 Effect of the Carrier-Recovery Loop on Phase Noise / 260

9.5.4	Effect of the Loop on Additive Noise / 262	
9.5.5	Contribution of Phase Noise to Data Errors / 263	
9.5.6	Effects of the Low-Frequency Phase Noise / 268	
9.6	Other Measures of Phase Noise / 269	
9.6.1	Jitter / 269	
9.6.2	Allan Variance / 271	
9.7	Summary / 271	
	Endnote / 272	
<b>APPENDIX A</b>	<b>OP AMP NOISE FACTOR CALCULATIONS</b>	<b>273</b>
A.1	Invariance When Input Resistor Is Redistributed / 273	
A.2	Effect of Change in Source Resistances / 274	
A.3	Model / 276	
<b>APPENDIX B</b>	<b>REPRESENTATIONS OF FREQUENCY BANDS, IF NORMALIZATION</b>	<b>279</b>
B.1	Passbands / 279	
B.2	Acceptance Bands / 279	
B.3	Filter Asymmetry / 286	
<b>APPENDIX C</b>	<b>CONVERSION ARITHMETIC</b>	<b>289</b>
C.1	Receiver Calculator / 289	
C.2	Synthesis Calculator / 291	
<b>APPENDIX E</b>	<b>EXAMPLE OF FREQUENCY CONVERSION</b>	<b>293</b>
<b>APPENDIX F</b>	<b>SOME RELEVANT FORMULAS</b>	<b>303</b>
F.1	Decibels / 303	
F.2	Reflection Coefficient and SWR / 304	
F.3	Combining SWRs / 306	
F.3.1	Summary of Results / 306	
F.3.2	Development / 307	
F.3.3	Maximum SWR / 308	
F.3.4	Minimum SWR / 309	
F.3.5	Relaxing Restrictions / 309	
F.4	Impedance Transformations in Cables / 310	
F.5	Smith Chart / 310	

<b>APPENDIX G TYPES OF POWER GAIN</b>	<b>313</b>
G.1 Available Gain / 313	
G.2 Maximum Available Gain / 313	
G.3 Transducer Gain / 314	
G.4 Insertion Gain / 315	
G.5 Actual Gain / 315	
<b>APPENDIX H FORMULAS RELATING TO IMs AND HARMONICS</b>	<b>317</b>
H.1 Second Harmonics / 317	
H.2 Second-Order IMs / 318	
H.3 Third Harmonics / 318	
H.4 Third-Order IMs / 319	
H.5 Definitions of Terms / 320	
<b>APPENDIX I CHANGING THE STANDARD IMPEDANCE</b>	<b>321</b>
I.1 General Case / 321	
I.2 Unilateral Module / 323	
<b>APPENDIX L POWER DELIVERED TO THE LOAD</b>	<b>325</b>
<b>APPENDIX M MATRIX MULTIPLICATION</b>	<b>327</b>
<b>APPENDIX N NOISE FACTORS – STANDARD AND THEORETICAL</b>	<b>329</b>
N.1 Theoretical Noise Factor / 329	
N.2 Standard Noise Factor / 331	
N.3 Standard Modules and Standard Noise Factor / 332	
N.4 Module Noise Factor in a Standard Cascade / 333	
N.5 How Can This Be? / 334	
N.6 Noise Factor of an Interconnect / 334	
N.6.1 Noise Factor with Mismatch / 335	
N.6.2 In More Usable Terms / 336	
N.6.3 Verification / 338	
N.6.4 Comparison with Theoretical Value / 340	
N.7 Effect of Source Impedance / 341	
N.8 Ratio of Power Gains / 342	
Endnote / 343	

<b>APPENDIX P</b>	<b>IM PRODUCTS IN MIXERS</b>	<b>345</b>
<b>APPENDIX S</b>	<b>COMPOSITE S PARAMETERS</b>	<b>349</b>
<b>APPENDIX T</b>	<b>THIRD-ORDER TERMS AT INPUT FREQUENCY</b>	<b>353</b>
<b>APPENDIX V</b>	<b>SENSITIVITIES AND VARIANCE OF NOISE FIGURE</b>	<b>355</b>
<b>APPENDIX X</b>	<b>CROSSOVER SPURS</b>	<b>359</b>
<b>APPENDIX Z</b>	<b>NONSTANDARD MODULES</b>	<b>363</b>
	Z.1 Gain of Cascade of Modules Relative to Tested Gain /	363
	Z.2 Finding Maximum Available Gain of a Module /	366
	Z.3 Interconnects /	367
	Z.4 Equivalent <i>S</i> Parameters /	367
	Z.5 <i>S</i> Parameters for Cascade of Nonstandard Modules /	368
	Endnote /	369
<b>REFERENCES</b>		<b>371</b>
	Endnote /	377
<b>INDEX</b>		<b>379</b>

