

Contents

1	Introduction	1
1.1	Historical Introduction	1
1.1.1	Electromagnetic Transmission	3
1.1.2	The Vacuum Tube	8
1.1.3	The Invention of the Transistor	11
1.2	Wireless Sensor Networks	17
1.2.1	RFID Adoption	17
1.2.2	Challenges in RFID Design	18
1.2.3	The Pinballs Framework	18
1.2.4	Architecture of an RFID Tag	23
1.3	Focus and Outline of this Work	26
Part I Theoretical Background on Oscillators and Time References		
2	Oscillators and Time References	31
2.1	Introduction	31
2.2	The Phase Space Description of an Oscillator	32
2.2.1	The Phase Space Description	32
2.2.2	One-Dimensional Systems	32
2.2.3	Two-Dimensional Systems	34
2.2.4	The van der Pol Oscillator	36
2.2.5	n-Dimensional Systems	39
2.3	Minimum Requirements for a Time Reference	42
2.3.1	An Energy Reservoir and a Resistor	43
2.3.2	Two Different Energy Reservoirs	44
2.3.3	Harmonic Versus Relaxation Oscillators	46

2.4	Representation of an Oscillator Signal	47
2.4.1	Oscillator Signals in the Time Domain	47
2.4.2	Oscillator Signals in the Frequency Domain	49
2.5	Properties of an Oscillator	52
2.5.1	The Quality Factor	53
2.5.2	Stability of an Oscillator Signal	59
2.6	Conclusion.	59
3	Jitter and Phase Noise in Oscillators	61
3.1	Introduction	61
3.2	Noise Sources	62
3.2.1	Noise in a Resistor	63
3.2.2	Noise in a P-N Junction.	63
3.2.3	MOS Transistor Noise.	64
3.3	The Phase Noise Spectrum.	64
3.3.1	The Noise Model of Leeson.	65
3.4	The Phase Noise Theory of Hajimiri	68
3.4.1	Generation of the Phase Noise Spectrum	68
3.4.2	Extensions to the Theory of Hajimiri.	74
3.4.3	Calculation of the ISF	76
3.4.4	Evaluation of Hajimiri's Theory	78
3.5	Nonlinear Noise Theories.	79
3.5.1	The Lorentzian Spectrum.	79
3.5.2	The Gaussian Spectrum	80
3.5.3	Evaluation	81
3.6	Phase Noise Versus Jitter.	82
3.6.1	Definition of Jitter	82
3.6.2	Only White Noise Sources.	85
3.6.3	Colored Noise Sources	85
3.6.4	General Calculation Method.	86
3.7	The Q Factor and the Noise	87
3.7.1	The Theory of Leeson	87
3.7.2	The Theory of Hajimiri	87
3.8	Figures of Merit	88
3.8.1	The Phase Noise FoM.	88
3.9	Conclusion.	90
4	Long-term Oscillator Stability	91
4.1	Introduction	91
4.1.1	Causes of Frequency Drift	91
4.1.2	Organization of this Chapter.	92
4.2	Building Blocks of an Oscillator.	92
4.2.1	Linear Oscillator Systems	93

4.2.2	Nonlinear Oscillator Systems	94
4.2.3	Transistor Behavior.	100
4.2.4	Properties of the Feedback Network	102
4.2.5	How to Obtain a Stable Oscillator?	106
4.3	Figures of Merit for Long-term Stability	108
4.3.1	Temperature FoM	108
4.3.2	Supply Voltage FoM.	109
4.4	Oscillators for Low-Power Applications.	110
4.4.1	Harmonic Integrated Oscillators	113
4.4.2	Relaxation Integrated Oscillators.	121
4.4.3	Ring Oscillators	127
4.4.4	Other Implementations.	129
4.4.5	Comparison of the Different Topologies	133
4.5	Conclusion.	135

Part II Oscillator Designs for Temperature and Voltage Independence

5	Design of Two Wien Bridge Oscillators	139
5.1	Introduction	139
5.1.1	The Wien Bridge Oscillator	140
5.2	The Temperature-Independent Wien Bridge	141
5.2.1	Basic Amplifier Structure.	142
5.2.2	The Amplitude Regulator.	146
5.2.3	Complete Circuit	148
5.2.4	Phase Noise Performance.	148
5.2.5	Measurement Results.	155
5.2.6	Conclusion on the Temperature-Independent Wien Bridge Oscillator	158
5.3	The Supply Voltage-Independent Wien Bridge Oscillator.	159
5.3.1	The Oscillator Topology	160
5.3.2	The Proposed Oscillator.	161
5.3.3	The LDO Regulator	164
5.3.4	Temperature Dependency of the Voltage-Independent Oscillator.	167
5.3.5	Measurement Results.	169
5.3.6	Conclusion on the Voltage-Independent Oscillator	172
5.4	General Conclusion.	172
6	The Pulsed Oscillator Topology.	173
6.1	Introduction	173
6.2	The Pulsed-Harmonic Oscillator Topology	174
6.2.1	The Energy Tank	175

6.3	Transient Behavior of the Energy Tank	176
6.3.1	The n -th Order Transfer Function	177
6.3.2	Realistic Second-Order Tanks	179
6.4	Behavior of the Pulsed LC Oscillator	183
6.4.1	Sensitivity to PW and MoI	186
6.4.2	Energy Losses During Oscillation	188
6.5	Phase Noise in the Pulsed LC Oscillator	189
6.5.1	Noise Injection During the Free-Running Period	189
6.5.2	Noise Injection During the Applied Pulse	193
6.5.3	Impact of the Different Noise Sources	194
6.6	Implementation of the Pulsed LC Oscillator	196
6.6.1	Design of the LC Tank	196
6.6.2	Design of the Differential Amplifier	198
6.6.3	The Counter	200
6.6.4	The Pulse Generator	200
6.7	Measurement Results	202
6.8	Conclusion	207
7	Injection-Locked Oscillators	209
7.1	Introduction	209
7.2	Injection Locking of an Oscillator	211
7.2.1	Lock Range of the Oscillator	211
7.2.2	Dynamic Behavior of the Locking Process	216
7.2.3	Frequency Beating	220
7.3	Phase Noise in the Injection-Locked Oscillator	222
7.3.1	Noise Model Using a Decreased Tank Impedance	223
7.3.2	A PLL-Based Noise Model	225
7.4	The Wirelessly-Locked Oscillator in 130 nm	229
7.4.1	The Oscillator Topology	229
7.4.2	Techniques to Increase the Lock Range	233
7.4.3	Measurement Results	236
7.4.4	Conclusion on the 130-nm Injection-Locked Oscillator	237
7.5	The 40-nm Injection-Locked Receiver	238
7.5.1	The Clock Circuit	240
7.5.2	The Receiver Circuit	247
7.5.3	Measurement and Simulation Results	250
7.6	Conclusion	256
8	Oscillator-Based Sensor Interfaces	257
8.1	Introduction	257
8.2	PLL-Based Sensor Interfaces	258
8.2.1	Implementation of the PLL	258

8.3	The PWM-Based Sensor Interface	260
8.3.1	The Coupled Sawtooth Oscillator	261
8.3.2	Use in Combination with a Sensor	263
8.3.3	Transmission of the Output Signal	265
8.4	Jitter in the Coupled Sawtooth Oscillator	266
8.4.1	Jitter due to Sensor Noise	267
8.4.2	Jitter from the Differential Pair	270
8.4.3	Jitter due to the Current Source	272
8.4.4	Noise Propagation to the Sensor Interface Output	273
8.4.5	A/D-Converter FoM	277
8.5	Implementation of the Sensor Interface	278
8.5.1	Implementation in 130 nm CMOS	278
8.5.2	Implementation in 40 nm CMOS	282
8.5.3	Measurement Results.	288
8.6	Conclusion.	292

Part III Wireless Sensor Nodes

9	Design of a Low-Power Wireless RFID Tag	295
9.1	Introduction	295
9.2	Architecture of the Wireless Tag.	296
9.2.1	The Clock and Receiver Circuit	297
9.2.2	The UWB Transmitter.	298
9.2.3	The Sensor Interface	299
9.2.4	The Digital Logic	300
9.3	Measurement Results.	302
9.4	Conclusion.	305
10	Conclusion	307
10.1	Comparison to the State of the Art	308
10.1.1	The Wien Bridge Implementations	308
10.1.2	The Pulsed-Harmonic Oscillator	309
10.1.3	The Injection-Locked Oscillators.	311
10.1.4	The Sensor Interface	311
10.1.5	The Wireless Tag	312
10.1.6	General Conclusions	312
10.2	Main Contributions	313
10.3	Suggestions for Future Work	314

Appendix A: Definitions and Conventions Used Throughout the Work	317
Appendix B: Influence of a Nonlinear Amplifier	331
Appendix C: Measurement Issues for Jitter and Phase Noise.	341
Appendix D: Comparison to the State of the Art.	353
References.	361
Index	377

Temperature- and Supply Voltage-Independent Time
References for Wireless Sensor Networks

De Smedt, V.; Gielen, G.; Dehaene, W.

2015, LIV, 382 p. 195 illus., 68 illus. in color., Hardcover

ISBN: 978-3-319-09002-3