

Contents

List of Figures	ix
List of Tables	xv
List of Symbols and Abbreviations	xvii
Preface	xxv
1. INTRODUCTION	1
1.1 Modern Telecommunications	1
1.1.1 A Short History	2
1.1.2 Digital Cellular Systems	4
1.2 Integrating a Transceiver	6
1.3 Frequency Synthesizer Types	8
1.3.1 The Table-Look-Up Synthesizer	8
1.3.2 The Direct Synthesizer	9
1.3.3 The Phase-Locked Loop Synthesizer	10
1.3.4 Combination of Techniques	11
1.4 The Presented Work	12
2. PHASE-LOCKED LOOP FREQUENCY SYNTHESIZERS	15
2.1 Introduction	15
2.2 Definition of Phase Noise	16
2.3 PLL Fundamentals	20
2.3.1 Noise Characteristics	21
2.3.2 Transient Characteristics	23
2.3.2.1 Tracking	23
2.3.2.2 Acquisition	24
2.4 PLL Building Blocks	25
2.4.1 Phase Detector	25
2.4.1.1 Multipliers	26
2.4.1.2 Exclusive OR Gate	26
2.4.1.3 Flip-Flop	26
2.4.1.4 Phase-Frequency Detector	26
2.4.2 Loop Filter	30
2.4.2.1 First-Order PLL	30
2.4.2.2 Second-Order PLL	31
2.4.2.3 Third-Order PLL	32

2.4.2.4	Charge-Pump PLL	34
2.4.3	Voltage-Controlled Oscillator	35
2.4.3.1	Crystal Oscillators	36
2.4.3.2	Relaxation Oscillators	38
2.4.3.3	Ring Oscillators	39
2.4.3.4	LC-Oscillators	40
2.4.3.5	OTA-C Oscillators	41
2.4.3.6	Other Configurations	41
2.4.4	Frequency Divider	41
2.4.4.1	Programmable Dividers or Counters	42
2.4.4.2	Prescalers	43
2.4.4.3	Fractional-N Synthesis	44
2.5	Conclusion	46
3.	VOLTAGE-CONTROLLED OSCILLATOR PHASE NOISE	49
3.1	Introduction	49
3.2	Oscillator Theory	50
3.2.1	Q : the Quality factor	52
3.2.2	Active Inductors	53
3.2.2.1	Circuit implementation	53
3.2.2.2	Noise in Active Inductors	54
3.2.3	Passive Inductors	55
3.3	Phase Noise of a Basic Oscillator with Passive Inductor	57
3.3.1	Parallel Resistance R_p	57
3.3.2	Inductor Series Resistance R_l	59
3.3.3	Capacitor Series Resistance R_c	60
3.3.4	Effective Resistance	61
3.3.5	Active Element G_M	61
3.3.6	Conclusion	62
3.4	Phase Noise of a Basic Oscillator with Active Inductor	63
3.4.1	Inductor Current Noise Source	64
3.4.2	Inductor Voltage Noise Source	64
3.4.3	Total Noise	65
3.4.4	Conclusion	66
3.4.5	Comparison with Bandpass Filters	67
3.5	Phase Noise in Crystal Oscillators	68
3.5.1	Parallel Resistance R_p	68
3.5.2	Other Parasitic Resistors	70
3.5.3	Effective Resistance and Capacitance	71
3.5.4	Active Element G_M	71
3.5.5	Noisy Inductor L_s	72
3.5.6	Case Study : the CMOS Pierce Crystal Oscillator	73
3.5.7	Conclusion	75
3.6	Enhanced LC-Tanks	78
3.7	Other Phase Noise Sources	80
3.7.1	FM-modulation	81
3.7.2	1/f Noise	83
3.8	State-of-the-Art Integrated VCOs	83
3.9	Conclusions	83
4.	BONDING WIRE INDUCTANCE VCOS	87
4.1	Introduction	89
		89

4.2	Bonding Wire Inductors	99
4.2.1	Inductance Calculation	99
4.2.2	Bonding Wire Test VCO	99
4.2.3	Inductance Variation	93
4.2.4	Parasitics	95
4.2.4.1	Bonding Pad Parasitics	98
4.2.4.2	Inductor Series Resistance	98
4.2.4.3	Substrate Loss	103
4.2.4.4	Magnetic Coupling	104
4.3	Enhanced Bonding Wire LC-tank	106
4.4	Amplifier Design	106
4.4.1	Circuit Schematic	111
4.4.2	Bipolar or CMOS ?	111
4.4.3	Circuit Sizing	112
4.5	Measurement Results	113
4.6	Conclusions	114
5.	PLANAR-INDUCTOR VCOS	118
5.1	Introduction	121
5.2	Planar Inductors	121
5.2.1	First-Order Inductance Calculation	122
5.2.2	Finite-Element Simulations	125
5.2.2.1	Metal Losses	126
5.2.2.2	Substrate Losses	128
5.2.2.3	Inductor Design Model	132
5.2.3	Hollow Coil Design Guidelines	134
5.3	Planar-LC VCO Design on a Heavily Doped Substrate	135
5.3.1	Coil Geometry	136
5.3.2	Amplifier Design	137
5.3.3	Measurement Results	139
5.4	Planar-LC VCO Design on a Lowly Doped Substrate	140
5.4.1	Coil Geometry	142
5.4.2	Amplifier Design	144
5.4.3	Measurement Results	149
5.4.3.1	900-MHz Design	151
5.4.3.2	1.8-GHz Design	151
5.5	Conclusions	156
6.	HIGH-FREQUENCY CMOS PRESCALERS	156
6.1	Introduction	161
6.2	Phase-Switching Dual-Modulus Prescaler Architecture	161
6.2.1	Conventional Topology	162
6.2.2	Phase-Switching Topology	164
6.2.3	Variations on the Basic Topology	166
6.3	A Dual-Modulus Divide-by-128/129 Prescaler in 0.7- μ m CMOS	168
6.3.1	Circuit Design	168
6.3.1.1	Full-Frequency Divide-by-2	168
6.3.1.2	Half-Frequency Divide-by-2	172
6.3.1.3	Phase-Selection	173
6.3.1.4	Low-Frequency Divide-by-32	176
6.3.2	Measurement Results	176
6.4	An Eight-Modulus Prescaler in 0.4- μ m CMOS	177

4.2	Bonding Wire Inductors	90
4.2.1	Inductance Calculation	90
4.2.2	Bonding Wire Test VCO	93
4.2.3	Inductance Variation	95
4.2.4	Parasitics	98
4.2.4.1	Bonding Pad Parasitics	98
4.2.4.2	Inductor Series Resistance	103
4.2.4.3	Substrate Loss	104
4.2.4.4	Magnetic Coupling	106
4.3	Enhanced Bonding Wire LC-tank	106
4.4	Amplifier Design	111
4.4.1	Circuit Schematic	111
4.4.2	Bipolar or CMOS ?	112
4.4.3	Circuit Sizing	113
4.5	Measurement Results	114
4.6	Conclusions	118
5.	PLANAR-INDUCTOR VCOS	121
5.1	Introduction	121
5.2	Planar Inductors	122
5.2.1	First-Order Inductance Calculation	125
5.2.2	Finite-Element Simulations	126
5.2.2.1	Metal Losses	128
5.2.2.2	Substrate Losses	132
5.2.2.3	Inductor Design Model	134
5.2.3	Hollow Coil Design Guidelines	135
5.3	Planar-LC VCO Design on a Heavily Doped Substrate	136
5.3.1	Coil Geometry	137
5.3.2	Amplifier Design	139
5.3.3	Measurement Results	140
5.4	Planar-LC VCO Design on a Lowly Doped Substrate	142
5.4.1	Coil Geometry	144
5.4.2	Amplifier Design	149
5.4.3	Measurement Results	151
5.4.3.1	900-MHz Design	151
5.4.3.2	1.8-GHz Design	156
5.5	Conclusions	156
6.	HIGH-FREQUENCY CMOS PRESCALERS	161
6.1	Introduction	161
6.2	Phase-Switching Dual-Modulus Prescaler Architecture	162
6.2.1	Conventional Topology	162
6.2.2	Phase-Switching Topology	164
6.2.3	Variations on the Basic Topology	166
6.3	A Dual-Modulus Divide-by-128/129 Prescaler in 0.7- μ m CMOS	168
6.3.1	Circuit Design	168
6.3.1.1	Full-Frequency Divide-by-2	168
6.3.1.2	Half-Frequency Divide-by-2	172
6.3.1.3	Phase-Selection	173
6.3.1.4	Low-Frequency Divide-by-32	176
6.3.2	Measurement Results	176
6.4	An Eight-Modulus Prescaler in 0.4- μ m CMOS	177

8.4.1	Circuit Design	178
8.4.2	Measurements	181
8.5	Conclusions	183
7.	A FULLY INTEGRATED CMOS PLL FREQUENCY SYNTHESIZER	
7.1	Introduction	187
7.2	Phase-Frequency Detector	187
7.3	Loop Filter	190
7.3.1	Charge Pump	190
7.3.2	Filter Impedance	190
7.3.3	Active or Passive Filter ?	193
7.4	Noise Aspects	195
7.4.1	Charge Pump Noise	197
7.4.2	Filter Impedance Noise	197
7.4.3	4-th Order PLL	198
7.5	Improved Loop filter	199
7.5.1	Filter topology	201
7.5.2	Transfer Functions	202
7.5.2.1	Open Loop Gain	205
7.5.2.2	Charge Pump Noise	206
7.5.2.3	Loop Filter Noise	207
7.5.3	Filter Optimization	208
7.6	Linearization	208
7.7	Measurements	212
7.7.1	Phase Noise Performance	217
7.7.2	Transient Characteristics	220
7.8	Conclusions	222
8.	GENERAL CONCLUSIONS	223
	Bibliography	227
	Index	233
		245