

Contents

List of Figures	xi
List of Tables	xv
Preface	xvii
Acknowledgements	xix
1 Introduction	1
1.1 Passive Elements	1
1.2 Figures of Merit of Varactors	3
1.2.1 Quality Factor	3
1.2.2 Tuning Range	4
1.2.3 Self-resonant Frequency (f_R)	4
1.2.4 Effective Silicon Area	5
1.2.5 Absolute Capacity Value	5
1.3 Principal Types of Varactor Manufacture	5
1.3.1 Discrete Varactors	5
1.3.2 MEMS Varactors	6
1.3.3 BST Varactors	7
1.3.4 Integrated Varactors Using Standard Technologies	8
References	8
2 PN-junction Varactors	11
2.1 The Operating Principle of a PN-junction Varactor	11
2.1.1 Electrical Phenomena in a PN-junction Varactor	13
2.2 Different Architectures of PN-junction Varactors	15
2.2.1 Different Configurations of PN-junction Varactors	17
2.3 Influence of Bias Voltage on the Behaviour of a PN-junction Varactor	19
2.4 Influence of Geometric Parameters on the Behaviour of a PN-junction Varactor	20
2.4.1 Influence in the Variation of the Number of Islands	20
2.4.2 Influence of the Size of the Islands	21

2.4.3	Influence of the Distance Between Islands	23
2.4.4	Variation of the Size of the N Well	24
2.5	Influence of the Working Frequency on the Results	25
2.5.1	Influence of the Frequency on the Quality of a Varactor	25
2.5.2	Influence of the Frequency on the Capacitance of a Varactor	26
2.6	Comparison Between the Different Types of PN-junction Varactors	28
2.6.1	Comparison According to the Effective Silicon Area	28
2.6.2	Comparison According to the Quality Factor	29
	References	30
3	MOS Varactors	31
3.1	Operating Principles of an NMOS Varactor	31
3.1.1	Operating Ranges of the NMOS Varactor	32
3.1.2	Electrical Phenomena of an NMOS Varactor in Accumulation Mode	35
3.1.3	Electrical Phenomena of an NMOS Varactor in Depletion Mode	36
3.2	NMOS Varactors	38
3.2.1	Operating Ranges of the NMOS Varactor	38
3.3	Influence of the Operating Mode on an NMOS Varactor	41
3.4	Influence of Bias Voltage on the Behaviour of an NMOS Accumulation Varactor	44
3.5	Influence of Geometric Parameters on the Behaviour of an NMOS Varactor	45
3.5.1	Influence of the Variation of the Varactor Size	45
3.5.2	Influence of the Varactor Gate Length on its Performance	46
3.5.3	Influence of the Varactor Gate Width on its Performance	49
3.6	Influence of the Working Frequency on the Results	50
	References	51
4	Measurement Techniques for Integrated Varactors	53
4.1	Test System	53
4.2	Equipment Required for the On-Wafer Testing of Integrated Varactors	54
4.2.1	Test Probes	54
4.2.2	Connectivity	54
4.3	Calibrating the Test System	55
4.4	Test Structures	56
4.4.1	Choosing the Test Structure Configuration	56

4.4.2	Design of the Test Structures	57
4.4.3	Effects Introduced by the Test Structures	59
4.5	Test Structure DE-embedding Techniques	61
4.5.1	Single-Short Structure	62
4.5.2	Single-Open Structure	63
4.5.3	Thru Structure	64
4.6	Characterization of Integrated Varactors	66
4.7	Test System Verification	67
4.7.1	Error Introduced by Positioning the Test Probes on the Pads	67
4.7.2	Error Introduced by the Calibration Reference Tolerances	68
4.7.3	Error Introduced by the Test Probes Heating up	69
4.7.4	Error Introduced by the Degradation of the Components	70
4.7.5	Analysis of the Results	72
	References	72
5	Modeling Varactors	73
5.1	Introduction to the Modeling of Varactors	73
5.2	Modeling PN-junction Varactors	74
5.2.1	Value of Parameter L_1	76
5.2.2	Value of Parameter C_1	76
5.2.3	Value of Parameter R_1	77
5.2.4	Value of Parameter L_2	77
5.2.5	Value of Parameter C_2	77
5.2.6	Value of Parameter R_2	78
5.3	Modeling NMOS Varactors	78
5.3.1	Value of Parameter L_G	80
5.3.2	Value of Parameter C_{ox}	80
5.3.3	Value of Parameter C_{Si}	81
5.3.4	Value of Parameter C_{GD}	81
5.3.5	Value of Parameter R_1	82
5.3.6	Value of Parameter R_{N2}	82
5.3.7	Value of Parameter C_{NS}	82
5.3.8	Value of Parameter L_D/S	83
6	Design Rules for Integrated Varactors	85
6.1	Design Rules for PN-junction Integrated Varactors	85
6.2	Design Rules for NMOS Integrated Varactors	86
6.3	Comparison between Accumulation NMOS Varactors and PN-junction Varactors	86
	References	88

7 Design of a Demonstrator: Integrated VCO	89
7.1 Circuits Including Varactors	89
7.1.1 Influence of the Figures of Merit of the Varactor	90
7.1.2 Choosing the Demonstrator	96
7.2 General Considerations	96
7.2.1 Introduction	96
7.2.2 VCO Specifications	97
7.2.3 Active Circuit	100
7.2.4 Analysis of the CMOS Oscillator	103
7.3 Voltage-controlled Oscillator	106
7.3.1 Design of the Tank Circuit	106
7.3.2 Design of the Oscillator	113
7.3.3 VCO Measurements	115
7.3.4 PLL Measurements	119
References	122
Appendix 1: Geometric Characteristics of Varactors	123
A1.1 Chip with the Varactors used in this Book	123
A1.2 Geometrical Characteristics of the PN-junction Varactors	123
A1.2.1 Interdigit Varactors	123
A1.2.2 Island Varactors	123
A1.2.3 Matrix Varactors	125
A1.3 Geometrical Characteristics of MOS Varactors	126
Appendix 2: Validation of the Predictions Provided by Equations of Chapter 5	129
A2.1 PN-junction Varactor	129
A2.1.1 Inductance L_1	130
A2.1.2 Capacitance C_1	130
A2.1.3 Resistance R_1	132
A2.1.4 Inductance L_2	133
A2.1.5 Capacitance C_2	134
A2.1.6 Resistance R_2	134
A2.2 NMOS Varactors	135
A2.2.1 Inductance L_G	135
A2.2.2 Capacitance C_{ox}	136
A2.2.3 Capacitance C_{Si}	137
A2.2.4 Capacitance C_{GD}	139
A2.2.5 Resistance R_1	140
A2.2.6 Resistance R_{N2}	141
A2.2.7 Capacitance C_{NS}	141
A2.2.8 Inductance $L_{D/S}$	141

Appendix 3: Measurement of Oscillator's Performance	143
A3.1 Design of the Layout	143
A3.2 Measurement Set-up	148
A3.3 Oscillator and PLL Measurement	150
A3.3.1 Analysis and Calculation of the Loop Filter	150
A3.3.2 Printed Circuit Board Design	150
A3.3.3 Measurement Set-up	152
Glossary	155
Index	157

