

CONTENTS

Chapter 1: Introduction.....	1
Chapter 2: Low Power Digital Circuit Design Concepts	3
2.1 Introduction	3
2.2 Device Characteristic.....	4
2.2.1 Basic Device Characteristics	4
2.2.2 Power Issue	6
2.2.3 Wire Delay.....	7
2.3 Circuit Design Concepts and Techniques	9
2.3.1 Buffering.....	9
2.3.2 Stack Effect	12
2.3.3 MTCMOS Design and Power Gating Technique.....	13
2.3.4 Transistor Size Optimum	14
2.3.5 Unbalanced Latch	15
2.3.6 Reducing Effective Capacitance Technique	15
2.4 Overview of Flip-Flops.....	16
2.5 Overview of First-In-First-Out Register File.....	17
2.6 Conclusion	18
Chapter 3: Low power Pulsed Latch Design.....	20
3.1 Introduction	20
3.2 Flip-Flop Characterization Metrics.....	21
3.2.1 Timing Metrics.....	21
3.2.2 Energy Metrics	23
3.2.3 Other Design Issue	23
3.3 Conventional Edge-Triggered Latch.....	23
3.3.1 Master – Slave Flip-Flop	24
3.3.2 Pulsed Triggered Latch.....	26
3.3.3 Low Power Flip-Flop	28
3.3.3.1 Reduced Clock Swing Flip-Flop	29
3.3.3.2 Conditional Capture Flip-Flop.....	31
3.4 Proposed Edge-Triggered Latch Design and Simulation Result.....	33
3.4.1 Proposed Flip-Flop	33
3.4.1.1 Static Power Reduction	33
3.4.1.2 Dynamic Power Reduction.....	33
3.4.1.3 Low Swing Conditional Capture Flip-Flop Design.....	35

3.4.2 Simulation Result and Comparisons.....	37
3.4.2.1 Basic Comparison of Design Metrics	37
3.4.2.2 Comparison with Different Application	39
3.4.3 Flip-Flop Design with MTCMOS Technique	40
3.5 Double Edge-Triggered Latch Design	42
3.5.1 Double Edge-Triggered Flip-Flop Design Methodology	43
3.5.2 New Double Edge-Triggered Latch Design	44
3.5.3 Simulation Results and Comparisons.....	45
3.5.4 DETFF Design with MTCMOS technique.....	47
3.6 Conclusion	48

Chapter 4: Low Power Clock Gating Techniques and Scan-Retention Mechanism

Mechanism.....	50
4.1 Introduction	50
4.2 Clock Gating Techniques	51
4.2.1 Basic Clock gating technique.....	51
4.2.2 Signal gating technique.....	54
4.2.3 Pipeline gating technique.....	55
4.2.4 Proposed Gating Circuit.....	56
4.3 Scan-Retention Mechanism	58
4.3.1 Scan Mechanism	58
4.3.2 Data Retention Mechanism.....	60
4.3.3 Scan-Retention Mechanism.....	62
4.3.4 Proposed Scan-Retention DETFF	63
4.4 Conclusion	67

Chapter 5: Low Power and Reconfigurable First-In-First-Out Register

File (FIFO) Design	68
5.1 Introduction	68
5.2 Proposed Reconfigurable FIFO Design	69
5.2.1 Overall FIFO Design Concept.....	69
5.2.2 Dual Port RAM cell Design	71
5.2.3 Sense Amplifier & Bias Circuit	72
5.2.4 Address Pointer Design	73
5.2.5 Initial Circuit Design	75
5.2.6 Flag Logic Design	76
5.2.7 Reconfigurable Power Gating Design.....	78
5.3 Simulation Result.....	78
5.3.1 Simulation Result and Waveforms.....	78
5.3.2 Simulation Result of the Reconfigurable Feature	82

5.3.3 Size Expansion of Proposed FIFO Register File	83
5.4 Conclusion	85
Chapter 6: Conclusions and Future Works	86
6.1 Conclusions	86
6.2 Future Works	87
References	88
Vita	103



LIST OF FIGURES

Chapter 2: Low Power Digital Circuit Design Concepts	
Figure 2.1 Evolution in Transistor count	4
Figure 2.2 Evolution in Complexity	5
Figure 2.3 Evolution in Speed / Performance.....	5
Figure 2.4 The growth trend in power.....	6
Figure 2.5 The trend of standby power of MOSFETs	7
Figure 2.6 Wire Models.....	7
Figure 2.7 Elmore delay model.....	8
Figure 2.8 Non-branched RC model	8
Figure 2.9 Step response of Elmore model with different N.....	9
Figure 2.10 Inverter buffer chain to drive a output loading.....	10
Figure 2.11 Optimize the parameter f.....	11
Figure 2.12 Inverter buffer chain design.....	12
Figure 2.13 Stack technique for inverter.....	12
Figure 2.14 Normalized results of the stack technique	13
Figure 2.15 Power gating diagram of MTCMOS	14
Figure 2.16 Unbalanced Latch cell.....	15
Chapter 3: Low power Pulsed Latch Design.....	
Figure 3.1 Definition of setup time and hold time	22
Figure 3.2 Master-Slave Flip-flop	24
Figure 3.3 The RACE condition in TGFF	25
Figure 3.4 Pulse Generator	26
Figure 3.5 Pulsed Latch Flip-flop.....	27
Figure 3.6 K-6 dual rail edge-triggered latch	28
Figure 3.7 Half swing flip-flop	29
Figure 3.8 Reduced clock swing flip-flop (RCSFF)	30
Figure 3.9 NAND-type Keeper flip-flop (NKDFF)	30
Figure 3.10 Flip-flop with internal clock gating: Clock-On-Demand Flip-flop.....	31
Figure 3.11 Different Conditional capture energy recovery flip-flop (DCCER)	32
Figure 3.12 Reduced Swing Inverter	34
Figure 3.13 Proposed Low Swing Inverter Chain.....	35
Figure 3.14 Normalized Comparison Between the Typical Inverter Chain and Low Swing Inverter Chain	35

Figure 3.15 Proposed Low Swing Conditional Capture Flip-Flop (LSCCFF).....	36
Figure 3.16 Typical LSCCFF waveforms	37
Figure 3.17 Comparison of Power consumption in Different Switching Activity	38
Figure 3.18 Comparisons of Power Consumption in 8-bit counter	39
Figure 3.19 Comparisons of Power Consumption in Shift Register	40
Figure 3.20 LSCCFF in MTCMOS	41
Figure 3.21 Comparison of LSCCFF in dual V _t and single V _t	42
Figure 3.22 Classical DETFF Design	43
Figure 3.23 Pulsed Based Double edge-triggered Flip-flop	44
Figure 3.24 Conditional Precharge Double Edge-Triggered Flip-Flop (CPDFF)	44
Figure 3.25 Typical CPDFF waveforms	45
Figure 3.26 Comparison of DETFF	46
Figure 3.27 CPDFF with MTCMOS.....	47
Figure 3.28 Comparison of CPDFF in dual V _t and single V _t	48
Chapter 4: Low Power Clock Gating Techniques and Scan-Retention Mechanism	
Figure 4.1 Clock tree distribution	52
Figure 4.2 Clock tree distribution with clock gating	53
Figure 4.3 Clock gating methodology	53
Figure 4.4 Precision distribution of Add/sub.....	54
Figure 4.5 Pipeline gating approach.....	55
Figure 4.6 Basic superscalar pipeline.....	56
Figure 4.7 Proposed gating technique.....	57
Figure 4.8 Clock gating in each layer	57
Figure 4.9 Serial-scan test.....	59
Figure 4.10 Typical Scannable Master-Slave Flip-Flop	60
Figure 4.11 Operation of Ballon circuit	61
Figure 4.12 A balloon circuit applied to a DFF circuit.....	62
Figure 4.13 Scan-Retention Flip-Flop Mechanism.....	63
Figure 4.14 CPDFF with Scan-Retention Mechanism	64
Figure 4.15 Operation Waveform of Proposed scan-retention DETFF.....	65
Figure 4.16 Operation Waveform of Proposed scan-retention DETFF.....	66
Chapter 5: Low Power and Reconfigurable First-In-First-Out Register	

File (FIFO) Design	
Figure 5.1 Reconfigurable FIFO Cell View	70
Figure 5.2 FIFO Cell Overview	71
Figure 5.3 Dual Port RAM Cell	72
Figure 5.4 Bias Circuit & Current Mode Sense Amplifier	73
Figure 5.5 Address Pointer Design.....	74
Figure 5.6 Proposed Low Swing Conditional Capture Flip-Flop (LSCCFF)	74
Figure 5.7 Reconfigurable Address Pointer Design	75
Figure 5.8 Initial Circuit design	76
Figure 5.9 Reconfigurable Flag Logic Design	77
Figure 5.10 Reconfigurable Supply Voltage.....	78
Figure 5.11 The Waveform of Simulation Results.....	80
Figure 5.12 The operation of Single Chip mode.....	81
Figure 5.13 The Comparison of the FIFO cell with different size ...	82
Figure 5.14 The Operation of the Multi-Chip Parallel mode	83
Figure 5.15 The Operation of the Multi-Chip Serial mode.....	84



LIST OF TABLES

Chapter 2: Low Power Digital Circuit Design Concepts	
Table 2.1 Step response of lamped and distributed RC model.....	9
Table 2.2 The simulation Result of the Stack technique	13
Table 2.3 The comparison of different Vt device.....	14
Chapter 3: Low power Pulsed Latch Design.....	
Table 3.1 The Simulation Result of the Reduced swing inverter Chain	35
Table 3.2 Comparison of Flip-Flops	38
Table 3.3 Comparison of power in Different Application	39
Table 3.4 Comparison of LSCCFF in dual Vt and single Vt	41
Table 3.5 Comparison of DETFFs.....	46
Table 3.6 Comparison of CPDFF in dual Vt and single Vt	48
Chapter 4: Low Power Clock Gating Techniques and Scan-Retention Mechanism	
Chapter 5: Low Power and Reconfigurable First-In-First-Out Register File (FIFO) Design	
Table 5.1 The Simulation Results of the FIFO Cell	79
Table 5.2 The Comparison of the FIFO cell with different size	82