

Contents

DEDICATION	v
AUTHORS	ix
PREFACE	xi
1. INTRODUCTION	1
2. RADIATION EFFECTS IN INTEGRATED CIRCUITS	9
2.1 RADIATION ENVIRONMENT OVERVIEW	9
2.2 RADIATION EFFECTS IN INTEGRATED CIRCUITS	13
2.2.1 <i>SEU Classification</i>	16
2.3 PECULIAR EFFECTS IN SRAM-BASED FPGAS	17
3. SINGLE EVENT UPSET (SEU) MITIGATION TECHNIQUES	29
3.1 DESIGN-BASED TECHNIQUES	31
3.1.1 <i>Detection Techniques</i>	32
3.1.2 <i>Mitigation Techniques</i>	33
3.1.2.1 Full Time and Hardware Redundancy	33
3.1.2.2 Error Correction and Detection Codes	39
3.1.2.3 Hardened Memory Cells	43
3.2 EXAMPLES OF SEU MITIGATION TECHNIQUES IN ASICs	54
3.3 EXAMPLES OF SEU MITIGATION TECHNIQUES IN FPGAS	61
3.3.1 <i>Antifuse based FPGAs</i>	62
3.3.2 <i>SRAM-based FPGAs</i>	65
3.3.2.1 SEU Mitigation Solution in high-level description	66
3.3.2.2 SEU Mitigation Solutions at the Architectural level	67
3.3.2.3 Recovery technique	69

4. ARCHITECTURAL SEU MITIGATION TECHNIQUES.....	73
5. HIGH-LEVEL SEU MITIGATION TECHNIQUES.....	83
5.1 TRIPLE MODULAR REDUNDANCY TECHNIQUE FOR FPGAS	84
5.2 SCRUBBING	88
6. TRIPLE MODULAR REDUNDANCY (TMR) ROBUSTNESS.....	91
6.1 TEST DESIGN METHODOLOGY	95
6.2 FAULT INJECTION IN THE FPGA BITSTREAM	96
6.3 LOCATING THE UPSET IN THE DESIGN FLOORPLANNING	98
6.3.1 <i>Bit column location in the matrix.</i>	99
6.3.2 <i>Bit row location in the matrix</i>	100
6.3.3 <i>Bit location in the CLB</i>	100
6.3.4 <i>Bit Classification</i>	101
6.4 FAULT INJECTION RESULTS.....	103
6.5 THE “GOLDEN” CHIP APPROACH	108
7. DESIGNING AND TESTING A TMR MICRO-CONTROLLER	111
7.1 AREA AND PERFORMANCE RESULTS	114
7.2 TMR 8051 MICRO-CONTROLLER RADIATION GROUND TEST RESULTS ..	116
8. REDUCING TMR OVERHEADS: PART I	123
8.1 DUPLICATION WITH COMPARISON COMBINED WITH TIME REDUNDANCY.....	124
8.2 FAULT INJECTION IN THE VHDL DESCRIPTION	132
8.3 AREA AND PERFORMANCE RESULTS	136
9. REDUCING TMR OVERHEADS: PART II.....	143
9.1 DWC-CED TECHNIQUE IN ARITHMETIC-BASED CIRCUITS	145
9.1.1 <i>Using CED based on hardware redundancy</i>	148
9.1.2 <i>Using CED based on time redundancy</i>	150
9.1.3 <i>Choosing the most appropriated CED block</i>	152
9.1.3.1 Multipliers.....	152
9.1.3.2 Arithmetic and Logic Unit (ALU).....	153
9.1.3.3 Digital FIR Filter	154
9.1.4 <i>Fault Coverage Results</i>	154
9.1.4 <i>Area and Performance Results</i>	158
9.2 DESIGNING DWC-CED TECHNIQUE IN NON-ARITHMETIC-BASED CIRCUITS	168
10. FINAL REMARKS	171
REFERENCES	175