Table of Contents

1. Introduction	1
2. Overview of Analog and Digital Controllers in Switching Voltage	
Regulators	7
A. Operation of a Switching Regulator	8
B. Switching Converter with an Analog Controller	11
C. Switching Converter with a Digital Controller	14
2.1. A Comparison of Digital and Analog Implementations	17
A. Number of components needed for implementation	17
B. Production yield	18
C. Design flow and development time	19
D. External Influences	21
E. Flexibility and Additional Processing Options	22
2.2. Digital Controllers in Power Electronics Applications	
	23
2.2.1. Research and Developments in Digital Control for Power Electronics	23
2.2.2. Digital Controller Technology in Power Electronics Applications Today	27
2.3 Research Motivation	29
3. Models and Minimal Hardware Requirements of Functional	
Blocks in Digital Controller	30
3.1. Functional Blocks of a Digitally Controlled Switching Converter	31
3.1.1. Analog-to-Digital Converter	32
A. Sample and Hold	33
B. Quantization and Coding	37
C. Processing Delay	38
3.1.1.1. Analog-to-digital converter model	39
A. Low-frequency gain	39
B. High-frequency model	40
3.1.2, Digital Pulse Width Modulator (DPWM)	41
A. Operation of analog pulse width modulator	41
B. Operation of digital pulse width modulator (DPWM)	42
3.1.2.1. Digital pulse width modulator model	44
A. Phase Characteristic	44
B. Gain of DPWM	45
3.1.3. Modeling of Switching Converters	47
3.1.4. Model of a Digitally Controlled Switching Converter	47
3.2. Minimal Hardware Requirements	50
3.2.1. Resolution of the Analog-to-Digital Converter	50
3.2.2 Resolution of the Digital Pulse Width Modulator	52
3.2.2. Dynamic Conditions for Limit Cycle Elimination	55
A. Derivation of describing functions for common nonlinearities	58
B. Describing Functions as a Tool For Limit Cycle Prediction	66
3.3. Dynamic Conditions for Limit Cycle Oscillations in a Digitally	
Controlled Switching Converter	71
3.3.1. Conditions for Existence of Limit Cycle Oscillations	80
4.Compensator Design and VLSI Implementation of a High-	
Frequency Digital Controller	87
4. 1. Look-Up Table Based Digital Compensator	87
4.1.1. Size and resolution of the look-up table based processing unit	89

A. The number of words in the look-up tables	90
B. The number of bits for the look-up table words	90
4.2. Digital Controller Chip Set for Isolated DC-DC Power Supplies	100
4.2.1. High-frequency, high-resolution digital pulse width modulator	
(DPWM) with programmable switching frequency	100
4.2.2. Functional Description of the Digital Controller IC Set for Isolated	
DC-DC Power Supplies	103
A. Serial Transmitter	106
B. Serial receiver	108
C. Compensator	110
4.2.3. Test system and experimental results	111
5. Digital Control of Power Factor Correctors	115
5.1. Rectifier with power factor correction (PFC)	116
A. Operation of the power factor correction rectifier	117
B. Approaches to digital control of PFC rectifiers	118
5.2. Digital PFC Controller	119
A. Selection of the switching frequency and resolution of the DPWM	120
B. Selection of the sampling instants	121
C. Current loop regulator design	121
D. Design of a low-bandwidth voltage loop	122
5.3. Digital Controllers with Improved Dynamic Response of the	125
Voltage Loop	
A. Approaches to fast voltage loop design in PFC rectifiers	126
5.3.1. Method 1: Fast Voltage Loop Based on a Self-Tuning Comb Filter	126
(STCF)	129
A. Modified comb filter	133
B. Voltage loop with the modified comb filter	134
C. Self-tuning comb filter	136
D. Self-tuning comb filter implementation	138
E. Design of a high-bandwidth voltage loop F. Experimental Results	139
5.3.2. Method 2:"Dead-Zone" Digital Controller	146
A. Dead-zone controller	147
B. Self-adjustable dead-zone controller	149
C. Test System and Experimental Results	151
6. Conclusions	155
7. References	160
7. ALEXII FUNED	
Appendix A (Spectrum of a Sampled Signal)	165
Appendix B (Matlab Routines)	168
Appendix C (Verilog Codes)	171