## Contents

1.	Inti	roduction	1
	1.1		1
	1.2		3
		1.2.1 Classification by Granularity	3
			5
			6
	1.3	DSP Technology Requirements	9
			0
	1.4	Design Implementation	1
		1.4.1 FPGA Structure 1	5
			8
		1.4.3 Case Study: Frequency Synthesizer	1
	Exe	rcises	5
2.	Cor	mputer Arithmetic	9
	2.1		9
	2.2		0
		±	0
			3
			4
	2.3	8	5
		·	7
			2
	2.4		3
		v ±	7
	2.5		8
		/	0
			3
		· ·	5
	2.6		6
			0
	Eve		, K

3.	Fin	ite Im	pulse Response (FIR) Digital Filters	. 79
	3.1		l Filters	
	3.2		Theory	
	J	3.2.1	FIR Filter with Transposed Structure	
		3.2.2	Symmetry in FIR Filters	
		3.2.3	Linear-Phase FIR Filters	
	3.3		ning FIR Filters	
	0.0	3.3.1	Direct Window Design Method	
		3.3.2	Equiripple Design Method	
	3.4		ant Coefficient FIR Design	
	0.1	3.4.1	Direct FIR Design	
		3.4.2	FIR Filter with Transposed Structure	
		3.4.3	<del>-</del>	
	Exe			
	Line	icibob .		
4.	Infi	nite Ir	npulse Response (IIR) Digital Filters	. 115
	4.1		heory	
	4.2	IIR C	oefficient Computation	. 121
		4.2.1	Summary of Important IIR Design Attributes	. 123
	4.3	IIR F	ilter Implementation	
		4.3.1	Finite Wordlength Effects	. 128
		4.3.2	Optimization of the Filter Gain Factor	. 129
	4.4	Fast I	IR Filter	
		4.4.1	Time Domain Interleaving	. 131
		4.4.2	Clustered and Scattered Look-Ahead Pipelining	
		4.4.3	IIR Decimator Design	. 136
		4.4.4	Parallel Processing	. 136
		4.4.5	IIR Design Using RNS	. 139
	$\mathbf{Exe}$	rcises .		
<b>5</b> .	Mu		Signal Processing	
	5.1	$\operatorname{Decim}$	nation and Interpolation	
		5.1.1	Noble Identities	. 144
		5.1.2	Sampling Rate Conversion by Rational Factor	
	5.2	Polyp	hase Decomposition	
		5.2.1	Recursive IIR Decimator	
		5.2.2		
	5.3	Hoger	nauer CIC Filters	. 15
		5.3.1	Single-Stage CIC Case Study	. 155
		5.3.2	Multistage CIC Filter Theory	
		5.3.3	Amplitude and Aliasing Distortion	. 162
		5.3.4	Hogenauer Pruning Theory	. 164
		5.3.5	CIC RNS Design	. 170
	5.4	Multis	stage Decimator	. 172

			Iultistage Decimator Design Using Goodman-Carey	
			alfband Filters	
	5.5		cy Sampling Filters as Bandpass Decimators	
	5.6		nks	
		5.6.1 U	niform DFT Filter Bank	179
		5.6.2 T	wo-Channel Filter Banks	183
	5.7	Wavelets		197
		5.7.1 T	he Discrete Wavelet Transformation	200
	Exe	rcises		205
6.	Fou	rier Traı	nsforms	209
	6.1	The Disc	rete Fourier Transform Algorithms	210
		6.1.1 Fe	ourier Transform Approximations Using the DFT	210
		6.1.2 P	roperties of the DFT	212
		6.1.3 T	he Goertzel Algorithm	215
		6.1.4 T	he Bluestein Chirp-z Transform	216
		6.1.5 T	he Rader Algorithm	219
		6.1.6 T	he Winograd DFT Algorithm	225
	6.2	The Fast	Fourier Transform (FFT) Algorithms	227
		6.2.1 T	he Cooley-Tukey FFT Algorithm	228
		6.2.2 T	he Good-Thomas FFT Algorithm	239
			he Winograd FFT Algorithm	
			omparison of DFT and FFT Algorithms	
	6.3		Related Transforms	
			omputing the DCT Using the DFT	
			ast Direct DCT Implementation	
	Exe			
7.	$\mathbf{Ad}$	anced T	opics	257
	7.1		ılar and Number Theoretic Transforms (NTTs)	
	•		rithmetic Modulo $2^b \pm 1$	
			fficient Convolutions Using NTTs	
			ast Convolution Using NTTs	
			Iultidimensional Index Maps and the Agarwal-Burrus	
			TT	265
			omputing the DFT Matrix with NTTs	
			idex Maps for NTTs	
			sing Rectangular Transforms to Compute the DFT	
	7.2		ontrol and Cryptography	
	1.2		asic Concepts from Coding Theory	
			lock Codes	
			onvolutional Codes	
			ryptography Algorithms for FPGAs	
	7.3		ion and Demodulation	
	1.5		asic Modulation Concepts	
		1.0.1 D	asic modulation Concepts	OIO

	7.3.2 Incoherent Demodulation
	7.3.3 Coherent Demodulation
	Exercises
Re	ferences
Α.	Verilog Source Code
В.	VHDL and Verilog Coding
	B.1 List of Examples
	B.2 Library of Parameterized Modules (LPM)
	B.2.1 The Parameterized Flip-flop Megafunction (lpm_ff) 390
	B.2.2 The Parameterized Adder/Subtractor Megafunction
	(lpm_add_sub)
	B.2.3 The Parameterized Multiplier Megafunction
	(lpm_mult)
	B.2.4 The Parameterized ROM Megafunction (lpm_rom) 403
$\mathbf{C}.$	Glossary
D.	<b>CD-ROM File: "1readme.ps"</b>
Ind	lex