

CONTENTS

Preface	xi
1 ARM® CORTEX® - M4 Development Systems	1
1.1 Introduction, 1	
1.1.1 Audio Interfaces, 2	
1.1.2 Texas Instruments TM4C123 LaunchPad and STM32F407 Discovery Development Kits, 2	
1.1.3 Hardware and Software Tools, 6	
Reference, 7	
2 Analog Input and Output	9
2.1 Introduction, 9	
2.1.1 Sampling, Reconstruction, and Aliasing, 9	
2.2 TLV320AIC3104 (AIC3104) Stereo Codec for Audio Input and Output, 10	
2.3 WM5102 Audio Hub Codec for Audio Input and Output, 12	
2.4 Programming Examples, 12	
2.5 Real-Time Input and Output Using Polling, Interrupts, and Direct Memory Access (DMA), 12	
2.5.1 I2S Emulation on the TM4C123, 15	
2.5.2 Program Operation, 15	
2.5.3 Running the Program, 16	
2.5.4 Changing the Input Connection to LINE IN, 16	
2.5.5 Changing the Sampling Frequency, 16	

- 2.5.6 Using the Digital MEMS Microphone on the Wolfson Audio Card, 20
- 2.5.7 Running the Program, 21
- 2.5.8 Running the Program, 23
- 2.5.9 DMA in the TM4C123 Processor, 26
- 2.5.10 Running the Program, 30
- 2.5.11 Monitoring Program Execution, 30
- 2.5.12 Measuring the Delay Introduced by DMA-Based I/O, 30
- 2.5.13 DMA in the STM32F407 Processor, 34
- 2.5.14 Running the Program, 35
- 2.5.15 Measuring the Delay Introduced by DMA-Based I/O, 35
- 2.5.16 Running the Program, 46
- 2.6 Real-Time Waveform Generation, 46
 - 2.6.1 Running the Program, 49
 - 2.6.2 Out-of-Band Noise in the Output of the AIC3104 Codec (tm4c123_sine48_intr.c), 49
 - 2.6.3 Running the Program, 53
 - 2.6.4 Running the Program, 62
 - 2.6.5 Running the Program, 69
- 2.7 Identifying the Frequency Response of the DAC Using Pseudorandom Noise, 70
 - 2.7.1 Programmable De-Emphasis in the AIC3104 Codec, 72
 - 2.7.2 Programmable Digital Effects Filters in the AIC3104 Codec, 72
- 2.8 Aliasing, 78
 - 2.8.1 Running the Program, 83
- 2.9 Identifying the Frequency Response of the DAC Using An Adaptive Filter, 83
 - 2.9.1 Running the Program, 84
- 2.10 Analog Output Using the STM32F407'S 12-BIT DAC, 91
 - References, 96

3 Finite Impulse Response Filters

97

- 3.1 Introduction to Digital Filters, 97
 - 3.1.1 The FIR Filter, 97
 - 3.1.2 Introduction to the z -Transform, 99
 - 3.1.3 Definition of the z -Transform, 100
 - 3.1.4 Properties of the z -Transform, 108
 - 3.1.5 z -Transfer Functions, 111
 - 3.1.6 Mapping from the s -Plane to the z -Plane, 111
 - 3.1.7 Difference Equations, 112
 - 3.1.8 Frequency Response and the z -Transform, 113
 - 3.1.9 The Inverse z -Transform, 114
- 3.2 Ideal Filter Response Classifications: LP, HP, BP, BS, 114
 - 3.2.1 Window Method of FIR Filter Design, 114

- 3.2.2 Window Functions, 116
- 3.2.3 Design of Ideal High-Pass, Band-Pass, and Band-Stop FIR Filters Using the Window Method, 120
- 3.3 Programming Examples, 123
 - 3.3.1 Altering the Coefficients of the Moving Average Filter, 132
 - 3.3.2 Generating FIR Filter Coefficient Header Files Using MATLAB, 137

4 Infinite Impulse Response Filters 163

- 4.1 Introduction, 163
 - 4.2 IIR Filter Structures, 164
 - 4.2.1 Direct Form I Structure, 164
 - 4.2.2 Direct Form II Structure, 165
 - 4.2.3 Direct Form II Transpose, 166
 - 4.2.4 Cascade Structure, 168
 - 4.2.5 Parallel Form Structure, 169
 - 4.3 Impulse Invariance, 171
 - 4.4 Bilinear Transformation, 171
 - 4.4.1 Bilinear Transform Design Procedure, 172
 - 4.5 Programming Examples, 173
 - 4.5.1 Design of a Simple IIR Low-Pass Filter, 173
- Reference, 216

5 Fast Fourier Transform 217

- 5.1 Introduction, 217
 - 5.2 Development of the FFT Algorithm with RADIX-2, 218
 - 5.3 Decimation-in-Frequency FFT Algorithm with RADIX-2, 219
 - 5.4 Decimation-in-Time FFT Algorithm with RADIX-2, 222
 - 5.4.1 Reordered Sequences in the Radix-2 FFT and Bit-Reversed Addressing, 224
 - 5.5 Decimation-in-Frequency FFT Algorithm with RADIX-4, 226
 - 5.6 Inverse Fast Fourier Transform, 227
 - 5.7 Programming Examples, 228
 - 5.7.1 Twiddle Factors, 233
 - 5.8 Frame- or Block-Based Programming, 239
 - 5.8.1 Running the Program, 242
 - 5.8.2 Spectral Leakage, 244
 - 5.9 Fast Convolution, 252
 - 5.9.1 Running the Program, 256
 - 5.9.2 Execution Time of Fast Convolution Method of FIR Filter Implementation, 256
- Reference, 261

6	Adaptive Filters	263
6.1	Introduction,	263
6.2	Adaptive Filter Configurations,	264
6.2.1	Adaptive Prediction,	264
6.2.2	System Identification or Direct Modeling,	265
6.2.3	Noise Cancellation,	265
6.2.4	Equalization,	266
6.3	Performance Function,	267
6.3.1	Visualizing the Performance Function,	269
6.4	Searching for the Minimum,	270
6.5	Least Mean Squares Algorithm,	270
6.5.1	LMS Variants,	272
6.5.2	Normalized LMS Algorithm,	272
6.6	Programming Examples,	273
6.6.1	Using CMSIS DSP Function <code>arm_lms_f32()</code> ,	280
	Index	299