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About This Manual

The purpose of this book is to present integrated solutions for typical TMS320C54x design issues. It combines a description of specific programming topics with code examples. The text discusses basic programming topics for the '54x digital signal processor (DSP). The code examples were created and tested in real time using the '54x evaluation module (EVM) as a platform. You may use these examples in developing your applications.

How to Use This Manual

The book is divided into two parts: topic information, provided in Chapters 1–9, and complete code examples, provided in Chapter 10.

- Topic information, Chapters 1–9: These chapters give you a framework of knowledge for programming the '54x. Before creating code, beginners may want to read these chapters entirely to understand why these issues must be addressed in certain ways. Advanced users may want to read only the topics relevant to specific code applications.

- Complete code examples, Chapter 10: These examples elaborate on the code provided in Chapters 1–9. This code has been tested and can be run as is.

Notational Conventions

This document uses the following conventions.

- Program listings and program examples are shown in a special font.

Here is a sample program listing:

```
STL A, *AR1+ ; Int_RAM(I)=0
RSBX INTM ; Globally enable interrupts
B MAIN_PG ; Return to foreground program
```

- Throughout this book, the notation '54x refers to the TMS320C54x and the TMS320VC54x. The notations '541, '542, etc., refer to the TMS320C541, TMS320C542, etc. The notation 'LC548 refers to the TMS320LC548.
The following books describe the '54x and related support tools. To obtain a copy of any of these TI documents, call the Texas Instruments Literature Response Center at (800) 477-8924. When ordering, please identify the book by its title and literature number.

TMS320C54x DSP Reference Set (literature number SPRU210) is composed of four volumes of information, each with its own literature number for individual ordering.

TMS320C54x DSP Reference Set, Volume 1: CPU and Peripherals (literature number SPRU131) describes the TMS320C54x 16-bit, fixed-point, general-purpose digital signal processors. Covered are its architecture, internal register structure, data and program addressing, the instruction pipeline, DMA, and on-chip peripherals. Also includes development support information, parts lists, and design considerations for using the XDS510 emulator.

TMS320C54x DSP Reference Set, Volume 2: Mnemonic Instruction Set (literature number SPRU172) describes the TMS320C54x digital signal processor mnemonic instructions individually. Also includes a summary of instruction set classes and cycles.

TMS320C54x DSP Reference Set, Volume 3: Algebraic Instruction Set (literature number SPRU179) describes the TMS320C54x digital signal processor algebraic instructions individually. Also includes a summary of instruction set classes and cycles.

TMS320C54x DSP Reference Set, Volume 4: Applications Guide (literature number SPRU173) describes software and hardware applications for the TMS320C54x digital signal processor. Also includes development support information, parts lists, and design considerations for using the XDS510 emulator.

TMS320C54x, TMS320LC54x, TMS320VC54x Fixed-Point Digital Signal Processors (literature number SPRS039) data sheet contains the electrical and timing specifications for these devices, as well as signal descriptions and pinouts for all of the available packages.

TMS320C54x Assembly Language Tools User’s Guide (literature number SPRU102) describes the assembly language tools (assembler, linker, and other tools used to develop assembly language code), assembler directives, macros, common object file format, and symbolic debugging directives for the 'C54x generation of devices.
TMS320C5xx C Source Debugger User’s Guide (literature number SPRU099) tells you how to invoke the 'C54x emulator, EVM, and simulator versions of the C source debugger interface. This book discusses various aspects of the debugger interface, including window management, command entry, code execution, data management, and breakpoints. It also includes a tutorial that introduces basic debugger functionality.

TMS320C54x Code Generation Tools Getting Started Guide (literature number SPRU147) describes how to install the TMS320C54x assembly language tools and the C compiler for the 'C54x devices. The installation for MS-DOS™, OS/2™, SunOS™, Solaris™, and HP-UX™ 9.0x systems is covered.

TMS320C54x Evaluation Module Technical Reference (literature number SPRU135) describes the 'C54x EVM, its features, design details and external interfaces.

TMS320C54x Optimizing C Compiler User’s Guide (literature number SPRU103) describes the 'C54x C compiler. This C compiler accepts ANSI standard C source code and produces TMS320 assembly language source code for the 'C54x generation of devices.

TMS320C54x Simulator Getting Started (literature number SPRU137) describes how to install the TMS320C54x simulator and the C source debugger for the 'C54x. The installation for MS-DOS™, PC-DOS™, SunOS™, Solaris™, and HP-UX™ systems is covered.

TMS320 Third-Party Support Reference Guide (literature number SPRU052) alphabetically lists over 100 third parties that provide various products that serve the family of '320 digital signal processors. A myriad of products and applications are offered—software and hardware development tools, speech recognition, image processing, noise cancellation, modems, etc.

TMS320 DSP Development Support Reference Guide (literature number SPRU011) describes the TMS320 family of digital signal processors and the tools that support these devices. Included are code-generation tools (compilers, assemblers, linkers, etc.) and system integration and debug tools (simulators, emulators, evaluation modules, etc.). Also covered are available documentation, seminars, the university program, and factory repair and exchange.
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When making suggestions or reporting errors in documentation, please include the following information that is on the title page: the full title of the book, the publication date, and the literature number.
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# Contents

1 Introduction ................................................................. 1-1

*Presents an introduction to DSP systems, which consist of a DSP, optional external memory, and an analog front end. Describes the architecture of a typical DSP and an EVM.*

1.1 DSP Overview ......................................................... 1-2
1.2 '54x Evaluation Module (EVM) Overview .......................... 1-3
1.3 Memory Interface ..................................................... 1-4
1.4 '54x EVM External Memory Interface ............................. 1-6

2 System Start-Up .......................................................... 2-1

*Presents typical options when using on-chip ROM, external 16-bit memory (EPROM), or bootloading from an 8-bit EPROM. Describes start-up conditions and initialization.*

2.1 On-Chip ROM/External 16-Bit EPROM ............................. 2-2
2.2 Processor Initialization .............................................. 2-3

3 Analog I/O ............................................................... 3-1

*Describes the most common means by which data goes to and from the DSP. Discusses initialization of serial ports and the process of acquiring and transmitting data using interrupt service routines (ISRs).*

3.1 Synchronous Serial Port Devices .................................. 3-2
3.2 TLC320AC01 Analog Interface Circuit ............................ 3-5
3.3 Software Stack ....................................................... 3-19
3.4 Context Switching .................................................... 3-20
3.5 Interrupt Handling ................................................... 3-22
3.6 Interrupt Priority ..................................................... 3-25
3.7 Circular Addressing .................................................. 3-26
3.8 Buffered Serial Port .................................................. 3-28

4 Signal Processing .......................................................... 4-1

*Discusses digital filters that use both fixed and adaptive coefficients and real fast Fourier transforms.*

4.1 Finite Impulse Response (FIR) Filters ............................ 4-2
4.2 Infinite Impulse Response (IIR) Filters ............................ 4-9
4.3 Adaptive Filtering .................................................... 4-12
4.4 Fast Fourier Transforms (FFTs) .................................... 4-19
4.4.1 Memory Allocation for Real FFT Example .................... 4-19
4.4.2 Real FFT Example ................................................ 4-22
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Sections</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Resource Management</td>
<td>5.1 Memory Allocation, 5.2 Overlay Management, 5.3 Memory-to-Memory Moves, 5.4 Power Management</td>
<td>5-1</td>
</tr>
<tr>
<td>6</td>
<td>Arithmetic and Logical Operations</td>
<td>6.1 Division and Modulus Algorithm, 6.2 Sines and Cosines, 6.3 Square Roots, 6.4 Extended-Precision Arithmetic, 6.5 Floating-Point Arithmetic, 6.6 Logical Operations</td>
<td>6-1</td>
</tr>
<tr>
<td>7</td>
<td>Application-Specific Examples</td>
<td>7.1 Codebook Search for Excitation Signal in Speech Coding, 7.2 Viterbi Algorithm for Channel Decoding</td>
<td>7-1</td>
</tr>
<tr>
<td>8</td>
<td>Bootloader</td>
<td>8.1 Boot Mode Selection, 8.2 Host Port Interface (HPI) Boot Loading Sequence, 8.3 16-Bit/8-Bit Parallel Boot, 8.4 I/O Boot, 8.5 Standard Serial Boot, 8.6 Warm Boot</td>
<td>8-1</td>
</tr>
<tr>
<td>9</td>
<td>Host–Target Communication</td>
<td>9.1 Communication Channels, 9.2 Handshake and Data Transfer</td>
<td>9-1</td>
</tr>
</tbody>
</table>
### 10 Application Code Examples ........................................... 10-1

*Provides code examples from start-up initialization to signal processing developed for real-time operation on the '54x EVM.*

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.1 Running the Applications</td>
<td>10-2</td>
</tr>
<tr>
<td>10.2 Application Code</td>
<td>10-4</td>
</tr>
</tbody>
</table>

### A Design Considerations for Using XDS510 Emulator .......................... A-1

*Describes the JTAG emulator cable and how to construct a 14-pin connector on your target system and how to connect the target system to the emulator.*

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.1 Designing Your Target System’s Emulator Connector (14-Pin Header)</td>
<td>A-2</td>
</tr>
<tr>
<td>A.2 Bus Protocol</td>
<td>A-4</td>
</tr>
<tr>
<td>A.3 Emulator Cable Pod</td>
<td>A-5</td>
</tr>
<tr>
<td>A.4 Emulator Cable Pod Signal Timing</td>
<td>A-6</td>
</tr>
<tr>
<td>A.5 Emulation Timing Calculations</td>
<td>A-7</td>
</tr>
<tr>
<td>A.6 Connections Between the Emulator and the Target System</td>
<td>A-10</td>
</tr>
<tr>
<td>A.6.1 Buffering Signals</td>
<td>A-10</td>
</tr>
<tr>
<td>A.6.2 Using a Target-System Clock</td>
<td>A-12</td>
</tr>
<tr>
<td>A.6.3 Configuring Multiple Processors</td>
<td>A-13</td>
</tr>
<tr>
<td>A.7 Physical Dimensions for the 14-Pin Emulator Connector</td>
<td>A-14</td>
</tr>
<tr>
<td>A.8 Emulation Design Considerations</td>
<td>A-16</td>
</tr>
<tr>
<td>A.8.1 Using Scan Path Linkers</td>
<td>A-16</td>
</tr>
<tr>
<td>A.8.2 Emulation Timing Calculations for a Scan Path Linker (SPL)</td>
<td>A-18</td>
</tr>
<tr>
<td>A.8.3 Using Emulation Pins</td>
<td>A-20</td>
</tr>
<tr>
<td>A.8.4 Performing Diagnostic Applications</td>
<td>A-24</td>
</tr>
</tbody>
</table>

### B Development Support and Part Order Information ....................... B-1

*Provides device part numbers and support tool ordering information for the TMS320C54x and development support information available from TI and third-party vendors.*

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>B.1 Development Support</td>
<td>B-2</td>
</tr>
<tr>
<td>B.1.1 Development Tools</td>
<td>B-2</td>
</tr>
<tr>
<td>B.1.2 Third-Party Support</td>
<td>B-3</td>
</tr>
<tr>
<td>B.1.3 Technical Training Organization (TTO) TMS320 Workshops</td>
<td>B-4</td>
</tr>
<tr>
<td>B.1.4 Assistance</td>
<td>B-4</td>
</tr>
<tr>
<td>B.2 Part Order Information</td>
<td>B-5</td>
</tr>
<tr>
<td>B.2.1 Device and Development Support Tool Nomenclature Prefixes</td>
<td>B-5</td>
</tr>
<tr>
<td>B.2.2 Device Nomenclature</td>
<td>B-6</td>
</tr>
<tr>
<td>B.2.3 Development Support Tools</td>
<td>B-7</td>
</tr>
</tbody>
</table>

### C Glossary ................................................................. C-1

*Defines terms and abbreviations used throughout this book.*
Figures

1–1 Typical DSP System ................................................................. 1-2
1–2 Block Diagram of a '54x EVM ......................................................... 1-3
1–3 External Interfaces on the '541 ..................................................... 1-5
1–4 '54x EVM Interface to External SRAM for Program and Data Memory .............................................................................. 1-7
3–1 Interfacing a TLC320AC01C AIC to the '54x .................................... 3-2
3–2 Master- and Slave-to-'54x Interfaces ................................................. 3-3
3–3 System Stack .................................................................................... 3-19
3–4 BSP Control Extension Register (BSPCE) Diagram ................. 3-28
3–5 Autobuffering Process for Transmit ................................................ 3-32
3–6 Autobuffering Process for Receive .................................................. 3-33
4–1 Data Memory Organization in an FIR Filter ................................. 4-2
4–2 Block Diagram of an Nth-Order Symmetric FIR Filter .................. 4-5
4–3 Input Sequence Storage ................................................................. 4-6
4–4 Nth-Order Direct-Form Type II IIR Filter ........................................ 4-9
4–5 Biquad IIR Filter ............................................................................. 4-9
4–6 Adaptive FIR Filter Implemented Using the Least-Mean-Squares (LMS) Algorithm ................................................................. 4-12
4–7 System Identification Using Adaptive Filter .................................... 4-13
4–8 Memory Allocation for Real FFT Example ....................................... 4-20
4–9 Data Processing Buffer .................................................................. 4-21
4–10 Phase 1 Data Memory ................................................................. 4-23
4–11 Phase 2 Data Memory ................................................................. 4-25
4–12 Phase 3 Data Memory ................................................................. 4-27
4–13 Phase 4 Data Memory ................................................................. 4-29
6–1 32-Bit Addition ............................................................................. 6-18
6–2 32-Bit Subtraction .......................................................................... 6-20
6–3 32-Bit Multiplication ...................................................................... 6-22
6–4 IEEE Floating-Point Format ........................................................... 6-25
7–1 CELP-Based Speech Coder .............................................................. 7-2
7–2 Butterfly Structure of the Trellis Diagram ......................................... 7-5
7–3 Pointer Management and Storage Scheme for Path Metrics ........ 7-7
8–1 Boot Mode Selection Process .......................................................... 8-3
8–2 16-Bit EPROM Address Defined by SRC Field ......................... 8-5
8–3 Data Read for a 16-Bit Parallel Boot ................................................ 8-5
8–4 Data Read During 8-Bit Parallel Boot .............................................. 8-6
8–5 8-Bit/16-Bit Parallel Boot ............................................................... 8-7
8–6 Handshake Protocol ....................................................................... 8-8
<table>
<thead>
<tr>
<th>Page</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>8–7</td>
<td>8-Bit/16-Bit I/O Boot Mode</td>
</tr>
<tr>
<td>8–8</td>
<td>Serial Boot Mode</td>
</tr>
<tr>
<td>8–9</td>
<td>Warm Boot Address Specified in BRS Word</td>
</tr>
<tr>
<td>9–1</td>
<td>Host Control Register (HCR) Diagram</td>
</tr>
<tr>
<td>9–2</td>
<td>'54x EVM Port Usage</td>
</tr>
<tr>
<td>9–3</td>
<td>Target Control Register (TCR) Diagram</td>
</tr>
<tr>
<td>9–4</td>
<td>Handshake Protocol</td>
</tr>
<tr>
<td>9–5</td>
<td>Data Transfer Protocol</td>
</tr>
<tr>
<td>A–1</td>
<td>14-Pin Header Signals and Header Dimensions</td>
</tr>
<tr>
<td>A–2</td>
<td>Emulator Cable Pod Interface</td>
</tr>
<tr>
<td>A–3</td>
<td>Emulator Cable Pod Timings</td>
</tr>
<tr>
<td>A–4</td>
<td>Emulator Connections Without Signal Buffering</td>
</tr>
<tr>
<td>A–5</td>
<td>Emulator Connections With Signal Buffering</td>
</tr>
<tr>
<td>A–6</td>
<td>Target-System-Generated Test Clock</td>
</tr>
<tr>
<td>A–7</td>
<td>Multiprocessor Connections</td>
</tr>
<tr>
<td>A–8</td>
<td>Pod/Connector Dimensions</td>
</tr>
<tr>
<td>A–9</td>
<td>14-Pin Connector Dimensions</td>
</tr>
<tr>
<td>A–10</td>
<td>Connecting a Secondary JTAG Scan Path to a Scan Path Linker</td>
</tr>
<tr>
<td>A–11</td>
<td>EMU0/1 Configuration to Meet Timing Requirements of Less Than 25 ns</td>
</tr>
<tr>
<td>A–12</td>
<td>Suggested Timings for the EMU0 and EMU1 Signals</td>
</tr>
<tr>
<td>A–13</td>
<td>EMU0/1 Configuration With Additional AND Gate to Meet Timing Requirements of Greater Than 25 ns</td>
</tr>
<tr>
<td>A–14</td>
<td>EMU0/1 Configuration Without Global Stop</td>
</tr>
<tr>
<td>A–15</td>
<td>TBC Emulation Connections for n JTAG Scan Paths</td>
</tr>
<tr>
<td>B–1</td>
<td>TMS320C54x Device Nomenclature</td>
</tr>
</tbody>
</table>
## Tables

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3–1</td>
<td>BSP Control Extension Register (BSPCE) Bit Summary</td>
<td>3-29</td>
</tr>
<tr>
<td>7–1</td>
<td>Code Generated by the Convolutional Encoder</td>
<td>7-6</td>
</tr>
<tr>
<td>9–1</td>
<td>'54x EVM Host-Interface Register Usage</td>
<td>9-2</td>
</tr>
<tr>
<td>9–2</td>
<td>Host Control Register (HCR) Bit Summary</td>
<td>9-3</td>
</tr>
<tr>
<td>9–3</td>
<td>Target Control Register (TCR) Bit Summary</td>
<td>9-5</td>
</tr>
<tr>
<td>10–1</td>
<td>Target Files</td>
<td>10-4</td>
</tr>
<tr>
<td>10–2</td>
<td>Communication Interface Files</td>
<td>10-5</td>
</tr>
<tr>
<td>A–1</td>
<td>14-Pin Header Signal Descriptions</td>
<td>A-3</td>
</tr>
<tr>
<td>A–2</td>
<td>Emulator Cable Pod Timing Parameters</td>
<td>A-6</td>
</tr>
<tr>
<td>B–1</td>
<td>Development Support Tools Part Numbers</td>
<td>B-7</td>
</tr>
</tbody>
</table>
Examples

2–1 Vector Table Initialization — vectors.asm
2–2 Processor Initialization — init_54x.asm
3–1 Default Initialization of 'AC01
3–2 Initiation of a Secondary Communication Interval for Programming the 'AC01
3–3 Master-Slave Mode
3–4 Context Save and Restore for TMS320C54x
3–5 Receive Interrupt Service Routine
3–6 Interrupt Service Routine (ISR)
3–7 Circular Addressing Mode
3–8 BSP Transmit Initialization Routine
3–9 BSP Receive Initialization Routine
3–10 BSP initialization Routine
4–1 FIR Implementation Using Circular Addressing Mode With a Multiply and Accumulate (MAC) Instruction
4–2 Symmetric FIR Implementation Using FIRS Instruction
4–3 Two-Biquad Implementation of an IIR Filter
4–4 System Identification Using Adaptive Filtering Techniques
5–1 Memory Management
5–2 Stack Initialization for Assembly Applications
5–3 Stack Initialization for C Applications
5–4 Memory-to-Memory Block Moves Using the RPT Instruction
6–1 Unsigned/Signed Integer Division Examples
6–2 Generation of a Sine Wave
6–3 Generation of a Cosine Wave
6–4 Square Root Computation
6–5 64-Bit Addition
6–6 64-Bit Subtraction
6–7 32-Bit Integer Multiplication
6–8 32-Bit Fractional Multiplication
6–9 Add Two Floating-Point Numbers
6–10 Multiply Two Floating-Point Numbers
6–11 Divide a Floating-Point Number by Another
6–12 Pack/Unpack Data in the Scrambler/Descrambler of a Digital Modem
7–1 Codebook Search
7–2 Viterbi Operator for Channel Coding
8–1 Warm Boot Option
Examples

9–1 Handshake — Target Action ......................................................... 9-8
9–2 Handshake — Host Action .......................................................... 9-10
9–3 Data Transfer — Target Action ..................................................... 9-12
9–4 Data Transfer — Host Action ....................................................... 9-13
10–1 Vector Table Initialization ......................................................... 10-6
10–2 Memory Allocation for Entire Application ..................................... 10-10
10–3 Main Program That Calls Different Functions ............................. 10-16
10–4 Processor Initialization .............................................................. 10-22
10–5 Handshake Between Host and Target ......................................... 10-25
10–6 Initialization of Variables, Pointers, and Buffers ......................... 10-29
10–7 Initialization of Serial Port 1 ....................................................... 10-33
10–8 'AC01 Initialization ................................................................. 10-38
10–9 'AC01 Register Configuration ...................................................... 10-42
10–10 Receive Interrupt Service Routine ............................................. 10-46
10–11 Task Scheduling ................................................................. 10-51
10–12 Echo the Input Signal ............................................................. 10-56
10–13 Low-Pass FIR Filtering Using MAC Instruction ......................... 10-59
10–14 Low-Pass Symmetric FIR Filtering Using FIRS Instruction ............. 10-64
10–15 Low-Pass Biquad IIR Filter ..................................................... 10-69
10–16 Adaptive Filtering Using LMS Instruction ................................... 10-74
10–17 256-Point Real FFT Initialization ............................................ 10-84
10–18 Bit Reversal Routine ........................................................... 10-87
10–19 256-Point Real FFT Routine ................................................ 10-91
10–20 Unpack 256-Point Real FFT Output ....................................... 10-97
10–21 Compute the Power Spectrum of the Complex Output of the 256-Point Real FFT ................................. 10-103
10–22 Data Transfer from FIFO ...................................................... 10-106
10–23 Interrupt 1 Service Routine ................................................... 10-111
10–24 Function Calls on Host Side ................................................... 10-116
10–25 Main Function Call on Host Side ............................................ 10-118
10–26 Graphic Drivers Routine ..................................................... 10-121
10–27 Display the Data on the Screen ............................................. 10-123
10–28 Linker Command File for the Application ................................. 10-124
10–29 Memory Map of TMS320C541 ............................................... 10-127
A–1 Key Timing for a Single-Processor System Without Buffers .............. A-8
A–2 Key Timing for a Single- or Multiple-Processor System With Buffered Input and Output ........................................ A-8
A–3 Key Timing for a Single-Processor System Without Buffering (SPL) ........ A-19
A–4 Key Timing for a Single- or Multiprocessor-System With Buffered Input and Output (SPL) ........................ A-19
## Equations

<table>
<thead>
<tr>
<th>Equation</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7–1</td>
<td>Optimum Code Vector Localization</td>
<td>7-2</td>
</tr>
<tr>
<td>7–2</td>
<td>Cross Correlation Variable (ci)</td>
<td>7-3</td>
</tr>
<tr>
<td>7–3</td>
<td>Energy Variable (Gi)</td>
<td>7-3</td>
</tr>
<tr>
<td>7–4</td>
<td>Optimal Code Vector Condition</td>
<td>7-3</td>
</tr>
<tr>
<td>7–5</td>
<td>Polynomials for Convolutional Encoding</td>
<td>7-5</td>
</tr>
<tr>
<td>7–6</td>
<td>Branch Metric</td>
<td>7-6</td>
</tr>
</tbody>
</table>
The TMS320C54x is a fixed-point digital signal processor (DSP) in the TMS320 family. It provides many options for the design of telecommunication and wireless applications. It executes 50 million instructions per second (MIPS), providing high performance, low power consumption, and cost effectiveness.

The code examples in this book were tested in real time using a '54x Evaluation Module (EVM) platform. This chapter introduces you to DSP and EVM architecture and describes the '54x memory interface mechanism and the EVM’s interface with memory devices. Since the '54x EVM contains a '541 DSP, the chapter discusses the '541 specifically.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 DSP Overview</td>
<td>1-2</td>
</tr>
<tr>
<td>1.2 '54x Evaluation Module (EVM) Overview</td>
<td>1-3</td>
</tr>
<tr>
<td>1.3 Memory Interface</td>
<td>1-4</td>
</tr>
<tr>
<td>1.4 '54x EVM External Memory Interface</td>
<td>1-6</td>
</tr>
</tbody>
</table>
1.1 DSP Overview

The block diagram in Figure 1–1 represents a typical DSP system. It uses an analog interface, where an input signal is digitized and processed by the DSP and has an output terminal. The RAM and EPROM blocks make up the system's memory. These blocks sometimes replace with DSP on-chip memory. For a stand-alone system, an EPROM bootloads the code during system power-up. The emulation interface can access the '54x high-level language debuggers, factory-installed tests, and field diagnostics. The host can download program files or data through the emulation port. The host interface provides buffering, host I/O decode, and access control.

Figure 1–1. Typical DSP System
### 1.2 '54x Evaluation Module (EVM) Overview

The '54x EVM is a PC/AT™ plug-in half-card that consists of a '541 DSP, 128K × 16 words of fast SRAM, and a TLC320AC01 analog interface chip (AIC). It also includes a programmer interface and a mouse-driven, window-oriented C source debugger. It provides a platform for using real-time device evaluation, benchmarking, and system debugging to design embedded systems.

The EVM has all common software debugging features, including breakpoint, modify, load, and watch. User-defined windows can be set up to view device parameters. The '54x EVM comes with a full assembler/linker package and an expansion port for interfacing to peripherals. Other hosts, systems, and target boards can communicate with the EVM using the serial port connector, provided on the board. The EVM allows you to prototype application software and hardware. The example code provided in chapter 10 uses '54x EVM as the hardware platform along with a host interface and demonstrates the various applications using signal processing techniques.

Figure 1–2 shows the configuration of the '54x EVM. It interfaces to 128K words of zero wait-state static RAM. The EVM includes 64K words of zero wait-state program memory and 64K words of zero wait-state data memory. An external I/O interface supports 16 parallel I/O ports and a serial port. The host-target communication system provides a simple means to pass data between the target and host during real-time operation. The two channels, A and B, are single, 16-bit bidirectional registers, mapped into two I/O port locations. Channel B has a 64-word deep FIFO buffer. The analog interface circuit (AIC) interfaces to the '541 serial port. The codec is a TLC320AC01 AIC that provides a 14-bit A/D and D/A interface with 16 bits of dynamic range, and sampling rates up to 43.2 kHz. Two RCA connectors provide analog input and output for 'AC01.

![Figure 1–2. Block Diagram of a '54x EVM](image-url)
1.3 Memory Interface

The '54x has several types of memory interfaces. Each interface contains a 16-bit address bus and 16-bit data bus signal lines. These transfer information and control interface operation. All of the interfaces are independent of one another, and different operations can be performed simultaneously on each interface.

The external direct memory access (DMA) interface lets external devices cause the processor to give up the bus and control signals for DMA. The MSTRB signal is activated for program and memory accesses, and the IOSTRB signal is used for transactions with I/O ports (PORTR and PORTW instructions). The R/W signal controls the direction of accesses. The external ready input signal (READY) and the software-programmable wait-state generators allow the processor to interface with memory and I/O devices of varying speeds.

Two signals, HOLD and HOLDA, allow an external device to take control of the processor’s buses. The processor acknowledges receiving a HOLD signal from an external device by bringing HOLDA low. The PS signal initializes the internal '541 logic and executes the system-initialization software. The PS, DS, and I/O select signals are used to select any external program, data, or I/O access. The connection of X1 and X2/CLKIN determines the clock source that drives the clock generator. The clock mode that operates the clock generator is determined by the CLKMD(1–3) signals.

Figure 1–3 shows the external interfaces on the '541. The device contains two independent bidirectional serial ports: serial port 0 and serial port 1. The analog interface circuit interfaces directly to the serial ports of the '541. The external flag, BIO, is used to monitor the status of the peripheral devices. The XF pin signals external devices via software. The '541 has four external, maskable user interrupts that external devices can use to interrupt the processor and one external, nonmaskable interrupt (NMI). These provide a convenient means to perform periodic I/O or other functions.

The '541 can be interfaced with EPROMs and static RAMs. The speed, cost, and power limitations imposed by an application determine the selection of memory device. If speed and maximum throughput are important, the '541 can run with no wait states. In this case, memory accesses are performed in a single machine cycle. Slower memories can be accessed by introducing an appropriate number of wait states or slowing down the system clock.
Figure 1–3. External Interfaces on the '541

Data/address bus and control signals

System control

Reset

Clocks

X1
X2/CLKIN
CLKOUT
CLKMD(1–3)
MP/MC
CNT

D(15–0)
A(15–0)
PS
DS
IS
R/W
MSTRB
IOSTRB
READY
IAQ
MSC
RS

External DMA interface

External interrupt interface

External flags

Timer output

Serial port 0

Serial port 1
1.4  '54x EVM External Memory Interface

The '54x EVM includes 64K words of zero wait-state program memory and 64K words of zero wait-state data memory, providing a total of 128K words of external memory. The PS line controls accesses to data and program memory. Each time the DSP accesses external program memory, the PS line goes low, driving the A16 address line low and forcing access to memory locations 00000h – 0FFFFh. Data memory accesses have no effect on the PS line. During data memory accesses, the PS line remains high. This means that the EVM accesses memory locations from 100000h – 1FFFFh. These accesses are tabulated in the truth table below.

<table>
<thead>
<tr>
<th>Access</th>
<th>MSTRB</th>
<th>PS</th>
<th>DS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Program</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Data</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>No access</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 1–4 shows a diagram of program/data memory interfaces for the EVM.
Figure 1–4. '54x EVM Interface to External SRAM for Program and Data Memory
To successfully power up a system, you must have a clear understanding of reset signals, clock modes and sources, memory interfaces with and without wait states, and bank switching. Common methods to start up a program include using on-chip ROM, external 16-bit EPROM, and bootloading from an 8-bit EPROM. This chapter examines these start-up methods and parameters and gives examples of initialization software.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 On-Chip ROM/External 16-Bit EPROM</td>
<td>2-2</td>
</tr>
<tr>
<td>2.2 Processor Initialization</td>
<td>2-3</td>
</tr>
</tbody>
</table>
2.1 On-Chip ROM/External 16-Bit EPROM

The '54x program memory space can reside either on- or off-chip. On-chip memory can include RAM, ROM, and external SRAM; off-chip memory can include 16-bit EPROM. There are two common methods to execute a program: running from memory (which uses on-chip ROM or 16-bit external EPROM) or using the bootloader either serially or in parallel from a 16- or an 8-bit EPROM.

The system can run using a 16-bit external EPROM or on-chip ROM. With on-chip ROM, internal memory is enabled. The EVM uses 128K words of external memory, which includes 64K words each of program and data memory. If a program resides in the external memory space, the program space includes part of the 64K of program memory. The EVM has external SRAM that can emulate either on-chip ROM or external EPROM. Executing the code from on-chip ROM requires no wait states, whereas executing from external EPROM requires some wait states, depending upon the speed of the DSP and the speed of the EPROM. In either case, the program starts executing from the reset vector, FF80h.

Program memory in on-chip ROM is configured internally, since the processor is in microcomputer mode when the MP/MC pin is low. For 16-bit EPROM, the program space is external. The processor is configured in microprocessor mode when MP/MC is high.
2.2 Processor Initialization

At power-up, the state of the '54x processor is partially defined, since all the bits in both status control registers are established. Thus, the processor is in a predefined condition at reset. Some of the conditions in these registers can be changed, depending upon the system configuration and the application. The reset signal puts the processor in a known state. In a typical DSP system, the processor must be initialized for proper execution of an application.

Starting up the system from on-chip ROM or 16-bit EPROM is done by resetting the processor. In both cases, the processor is reset by applying a low level to the RS pin. Reset causes the processor to fetch the reset vector. Upon reset, the IPTR bits of the PMST register are all set to 1, mapping the vectors to page 511 in program memory space. This means that the reset vector always resides at program memory location 0FF80h. This location usually contains a branch instruction to direct program execution to the system initialization routine.

After a reset, the processor initializes the following internal functions:

- Stack pointer (SP)
- Memory-mapped peripheral control registers (SWWSR and BSCR)
- Status registers (ST0 and ST1)
- Control register (PMST)

Some of the reset bits in the status and control registers can be changed during initialization. The '54x has a software stack and the stack pointer must be initialized. The data page pointer, which is initialized to page 0 during reset, must also be configured during initialization. The predefined and the remaining bits in ST0, ST1, and PMST are initialized so that the processor starts executing the code from a defined state.

Software wait-state generators interface external memory devices to the processor. Programmable bank switching determines the bank size. The software wait-state register (SWWSR) and the bank-switching control register (BCSR) are initialized.

Example 2–1 initializes the vector table. Example 2–2, on page 2-6, initializes the '54x, where the processor branches to main_start upon reset.
Example 2–1. Vector Table Initialization — vectors.asm

; TEXAS INSTRUMENTS INCORPORATED
.mmregs
.include "init_54x.inc"
.include "main.inc"
.ref SYSTEM_STACK
.ref main_start
.ref receive_int1
.ref host_command_int1

;---------------------------------------------------------------
;            Functional Description
;---------------------------------------------------------------
; This function initializes the vector table of 541 device
;---------------------------------------------------------------

.sect "vectors"
.reset: BD main_start ; RESET vector
        STM #SYSTEM_STACK, SP

nmi:   RETE
        NOP
        NOP
        NOP
        ; NMI

; software interrupts
sint17 .space 4*16
sint18 .space 4*16
sint19 .space 4*16
sint20 .space 4*16
sint21 .space 4*16
sint22 .space 4*16
sint23 .space 4*16
sint24 .space 4*16
sint25 .space 4*16
sint26 .space 4*16
sint2 .space 4*16
sint28 .space 4*16
sint29 .space 4*16
sint30 .space 4*16
int0:  RETE
        NOP
        NOP
        NOP
        ; INTO

int1: BD host_command_int1 ; Host interrupt
        PSHM ST0
        PSHM ST1
        ; INT1

int2: RETE
        NOP
        NOP
        NOP

int:  RETE
        NOP
        NOP
        NOP
        ; TIMER
Example 2–1. Vector Table Initialization — vectors.asm (Continued)

rint0: RETE ; Serial Port Receive
        NOP ; Interrupt 0
        NOP
        NOP

xint0: RETE ; Serial Port Transmit
        NOP ; Interrupt 0
        NOP
        NOP

rint1: BD receive_int1 ; Serial Port Receive
        PSHM ST0 ; Interrupt 1
        PSHM ST1

xint1: RETE ; Serial Port Transmit
        NOP ; Interrupt 1
        NOP
        NOP

int3: RETE
        NOP
        NOP
        NOP
        ; INT3
        .end
Example 2—2. Processor Initialization — init_54x.asm

; TEXAS INSTRUMENTS INCORPORATED
.mmregs
.include "init_54x.inc"
.include "main.inc"
.ref d_frame_flag
.ref RCV_INT1_DP
.ref aic_init, serial_init, init_54, init_bffr_ptr_var
.ref task_handler, evm_handshake, fifo_host_transfer
STACK .usect "stack", K_STACK_SIZE
SYSTEM_STACK .set K_STACK_SIZE+STACK
.def main_start
.def SYSTEM_STACK
;
; Functional Description
; This is the main function that calls other functions.
;******************************************************************************

main_start:
CALL init_54 ; initialize ST0,ST1 PMST and
; other registers
.if K_HOST_FLAG = 1
CALL evm_handshake ; EVM host handshake
.endif
CALL init_bffr_ptr_var ; init tables, vars, bffrs, ptr
CALL serial_init ; initialize serial_port 1
CALLD aic_init ; Configures AC01
LD #0,DP
NOP

******************************************************************************
* After enabling interrupts from the above, the real processing starts here
* After collecting 256 samples from AC01 a flag (d_frame_flag is set).
* Handles the task initiated by the user and transfers the data to the
* host. Keeps the sequence forever !!!!!
******************************************************************************
start_loop
LD #RCV_INT1_DP,DP ; restore the DP
loop:
BITF d_frame_flag, 1 ; if 256 samples are received
BC loop, NTC ; if not just loop back
CALL task_handler ; handles task scheduling
CALL fifo_host_transfer ; EVM HOST interface
B loop
.end
Example 2–2. Processor Initialization — init_54x.asm (Continued)

* Filename: Main.inc
* Includes all the constants that are used in the entire application
K_0 .set 0 ; constant
K_FIR_INDEX .set 1 ; index count
K_FIR_BFFR .set 16 ; FIR buffer size
K_neg1 .set –1h ; index count
K_BIQUAD .set 2 ; there are 2 bi-quad sections
K_IIR_SIZE .set 10 ; each bi-quad has 5 coeffs
K_STACK_SIZE .set 200 ; stack size
K_FRAME_SIZE .set 256 ; PING/PONG buffer size
K_FRAME_FLAG .set 1 ; set after 256 collected
H_FILT_SIZE .set 128 ; H(z) filter size
ADPT_FILT_SIZE .set 128 ; W(z) filter size
K_mu .set 0h ; initial step constant
K_HOST_FLAG .set 1 ; Enable EVM_HOST interface
K_DEFAULT_AC01 .set 1h ; default AC01 init
* This include file sets the FFT size for the ’54x Real FFT code
* Note that the Real FFT size (i.e. the number of points in the
* original real input sequence) is 2N; whereas the FFT size is
* the number of complex points formed by packing the real inputs,
* which is N. For example, for a 256-pt Real FFT, K_FFT_SIZE
* should be set to 128 and K_LOGN should be set to 7.
K_FFT_SIZE .set 128 ; # of complex points (=N)
K_LOGN .set 7 ; # of stages (=logN/log2)
K_ZERO_BK .set 0
K_TWID_TBL_SIZE .set 128 ; Twiddle table size
K_DATA_IDX_1 .set 2 ; Data index for Stage 1
K_DATA_IDX_2 .set 4 ; Data index for Stage 2
K_DATA_IDX_3 .set 8 ; Data index for Stage 3
K_FLY_COUNT_3 .set 4 ; Butterfly counter for Stage 3
K_TWID_IDX_3 .set 32 ; Twiddle index for Stage 3

FILENAME: INIT54x.INC
* This include file contains all the initial values of ST0, ST1, PMST, SWRSR, BSCR registers
;ST0 Register Organization
<table>
<thead>
<tr>
<th>15</th>
<th>13</th>
<th>12</th>
<th>11</th>
<th>10</th>
<th>9</th>
<th>8</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARP</td>
<td>TC</td>
<td>C</td>
<td>OVA</td>
<td>OVB</td>
<td>DP</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*****************************************************************************
K_ARP .set 000b<<13 ; ARP can be addressed from 000b -111b
   ; reset value
K_TC .set 1b<<12 ; TC = 1 at reset
K_C .set 1b<<11 ; C = 1 at reset
K_OVA .set 1b<<10 ; OVA = 0 at reset, Set OVA
K_OVB .set 1b<< 9 ; OVB = 0 at reset, Set OVB
K_DP .set 000000000b<<0; DP is cleared to 0 at reset
K_ST0 .set K_ARP|K_TC|K_C|K_OVA|K_OVB|K_DP
Example 2–2. Processor Initialization — *init_54x.asm* (Continued)

```assembly
; ST1 Register Organization
* | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 0 |
* | BRAF | CPL | XF | HM | INTM | 0 | OVM | SXM | C16 | FRCT | CMPT | ASM |
* ––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––
K_BRAF .set 0b << 15 ; BRAF = 0 at reset
K_CPL .set 0b << 14 ; CPL = 0 at reset
K_XF .set 1b << 13 ; XF = 1 at reset
K_HM .set 0b << 12 ; HM = 0 at reset
K_INTM .set 1b << 11 ; INTM
K_ST1_HIGH .set K_BRAF|K_CPL|K_XF|K_HM|K_INTM|K_ST1_RESR|K_OVM|K_SXMK_ST1_LOW
K_ST1_LOW .set K_C16|K_FRCT|K_CMPT|K_ASM
K_ST1 .set K_ST1_HIGH|K_ST1_LOW

*PMST Register Organization
* | 15 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
* | IPTR | MP/MC | OVLY | AVIS | DROM | CLKOFF | Reserved |
* ––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––
K_IPTR .set 111111111b << 07 ; 111111111b at reset
K_MP_MC .set 1b << 06 ; 1 at reset
K_OVLY .set 0b << 05 ; OVLY = 0 at reset
K_AVIS .set 0b << 04 ; AVIS = 0 at reset
K_DROM .set 0b << 03 ; DROM = 0 at reset
K_CLKOFF .set 0b << 02 ; CLKOFF = 0 at reset
K_PMST_RESR .set 00b << 0 ; reserved
; for 548 bit 0 = SMUL
; saturation on multiply
; bit 1 = SST = saturation on store
K_PMST.set K_IPTR|K_MP_MC|K_OVLY|K_AVIS|K_DROM|K_CLKOFF|K_PMST_RESR
```

PRELIMINARY
Example 2–2. Processor Initialization — init_54x.asm (Continued)

*SWWSR Register Organization
  | 15 | 14 12|11 9|8 6| 5 3 | 2 0 |
  | Reserved | I/O | Data | Data | Program | Program |

******************************************************************************
K_SWWSR_IO .set 2000h ; set the I/O space
******************************************************************************

*Bank Switching Control Register (BSCR) Organization
  | 15 12 | 11 | 10 2 | 1 | 0 |
  | BNKCMP | PS–DS | Reserved | BH | EXIO |

******************************************************************************
K_BNKCMP .set 0000b << 12 ; bank size = 64K
K_PS_DS .set 0b << 11
K_BSCR_RESR .set 000000000b <<2 ; reserved space
K_BH .set 0b << 1 ; BH = 0 at reset
K_EXIO .set 0b << 0 ; EXIO = 0 at reset
K_BSCR .set K_BNKCMP|K_PS_DS|K_BSCR_RESR|K_BH|K_EXIO

; TEXAS INSTRUMENTS INCORPORATED
.mnreg
.include "init_54x.inc"
.def init_54

; Functional Description
; Initializes the processor from a reset state

.sect "main_prg"
init_54: ; Init.the s/w wait state reg.for 2 wait states for I/O operations
  STM #K_SWWSR_IO, SWWSR ; 2 wait states for I/O operations
  STM #K_BSCR, BSCR ; wait states for Bank Switch

; initialize the status and control registers
  STM #K_ST0, ST0
  STM #K_ST1, ST1
  RETD
  STM #K_PMST, PMST
.end
Most DSP systems transfer data through peripherals. These peripherals include parallel and serial ports. This chapter describes how the serial ports are initialized and how the TLC320AC01 ('AC01) analog interface circuit (AIC) interfaces to the '54x serial port. This chapter also describes the various issues involved such as stack, context switching, interrupt priorities, and different addressing modes for collecting the samples during the interrupt processing.
3.1 Synchronous Serial Port Devices

Several '54x devices implement a variety of types of flexible serial port interfaces. These serial port interfaces provide full duplex, bidirectional, communication with serial devices such as codecs, serial analog to digital (A/D) converters, and other serial systems. The serial port interface signals are directly compatible with many industry-standard codecs and other serial devices. The serial port may also be used for interprocessor communication in multiprocessor applications. When the serial ports are in reset, the device can be configured to shut off the serial port clocks. This allows the device to run in a low-power mode of operation.

Three signals are necessary to connect the '54x to the serial port, as shown in Figure 3–1. On the transmitting device, the transmit data signal (DX) sends the data, the transmit frame synchronization signal (FSX) initiates the transfer at the beginning of the packet, and the transmit clock signal (CLKX) clocks the bit transfer.

The corresponding pins on the receiving device are the received serial data signal (DR), the receive frame synchronization signal (FSR) and, the receive clock signal (CLKR), respectively. At reset, CLKX, CLKR, DR, FSX, and FSR become inputs and DX is set for high impedance. Figure 3–1 shows the '54x interface to an 'AC01 that uses the serial port to transfer the data to and from the DSP. The SCLK signal clocks the serial data into and out of the device.

*Figure 3–1. Interfacing a TLC320AC01C AIC to the '54x*
Figure 3–2 shows the master and slave-to-DSP interface. In the master-slave mode, the master 'AC01, generates its own shift clock and frame sync signals and generates all delayed frame-sync signals to support slave devices. The slave receives the shift clock and frame-sync signals from the master device.

Figure 3–2. Master- and Slave-to-'54x Interfaces

The serial port operates through three memory-mapped registers: the serial port control register (SPC), the data transmit register (DXR), and the data receive register (DRR). The configuration of the serial port is changed by writing to the SPC register. The system configuration is as follows:

- **Word length:** The serial port must be programmed to use 16-bit data, since communications between the 'AC01 AIC and the host DSP use 16 bits. This means clearing the format bit, FO, to a logic 0.

- **Frame synchronization:** The system operates in burst mode with frame synchronization signals generated externally by the 'AC01. This means the frame synchronization mode bit, FSM, must be set to a logic 1. A frame sync pulse is required on the frame sync transmit and receive pins (FSX and FSR, respectively) for the transmission and reception of every word.
It also means that the FSX pin has to be configured as an input pin by clearing the transmit mode bit, TXM, to a logic 0.

Clock: The clock is generated externally by the 'AC01 and is supplied to the DSP on the CLKX pin. This means clearing the clock mode bit, MCM, to a logic 0.

To reset the serial port, two writes to the SPC register must occur. The first must write 0s to the transmit reset (XRST) and receive reset (RRST) bits and the desired configuration to all the other bits. The second must write 1s to the XRST and RRST bits and write the desired configuration to all the other bits. The SPC register is written as 0000 0000 1100 1000 to pull the serial port out of reset. This is shown in Example 3–1 on page 3-7.
3.2 TLC320AC01 Analog Interface Circuit

The 'AC01 is an audio-band processor. It integrates a band-pass switched-capacitor antialiasing input filter, 14-bit A/D and D/A converters, a low-pass switched-capacitor output reconstruction filter, sinx/x compensation, and a serial port for data and control transfers. The A/D and D/A channels operate synchronously, and data is transferred in 2s-complement format. It has nine internal registers that can be programmed for an application.

There are three basic modes of operation:

1) Stand-alone analog interface mode: The 'AC01 generates the shift clock and frame synchronization signals for data transfers; it is the only AIC used.

2) Master-slave mode: One 'AC01 serves as the master, generating the master shift clock and frame synchronization signals; the other 'AC01s serve as slaves.

3) Linear codec mode: The shift clock and frame synchronization signals are externally generated by the host.

Software control of the AIC allows you to program the sampling frequency, cut-off frequencies for the low- and high-pass filters, and analog input and output gains at any time. No programming is needed when the default values of the 'AC01 are satisfactory.

Data transfers between the DSP and the 'AC01 are categorized as primary and secondary serial communications. During primary communication, the 14 most significant bits (MSBs), bits 2 through 15, specify sample data. If the two least significant bits (LSBs), bits 1 and 0, are 11, a subsequent 16 bits of control information is received by the 'AC01 as part of the secondary serial communication interval. This control information programs one of the nine internal registers.

During the secondary communication interval, the bits transmitted to the 'AC01 are defined as follows:

- Bits 15 and 14, which control phase shifting in certain applications, are usually 0s.
- Bit 13 decides whether the data is written to or read from a register.
- Bits 12 through 8 define the address of the register to be programmed.
- Bits 7 through 0 contain the data to be stored in a register for write operations.

The bits received from the 'AC01 during the secondary communication interval are 0s for bits 15 through 8, and the value of the register data for bits 7 through 0.
The three programs that follow show the use of the 'AC01 in different circumstances: Example 3–1 assumes that the user is satisfied with the default configuration of the 'AC01 and proceeds to receive and send data, Example 3–2 on page 3-12 shows how to program the 'AC01 for a particular configuration before data transfer, and Example 3–3 on page 3-17 demonstrates serial communications while in a master-slave configuration. All three programs consist of a main routine which, apart from initializing the serial port and the interrupt, also resets the 'AC01.

Example 3–1 initiates a reset of the 'AC01, initializes the serial port, and sets up interrupts. To reset the 'AC01 properly, it must be held in reset for at least one MCLK cycle. With the 'AC01 operating at 10.368 MHz, one MCLK cycle equals 96.45 ns. In all the examples, the total time spent between initiating a reset and pulling the 'AC01 out of reset is 12 cycles. For a '54x DSP operating at 40 MHz, one cycle is 25 ns. This means that the 'AC01 spends 300 ns in reset. This is roughly three times the specification’s recommended value and is safe, since it allows a proper reset.

If a 50-MHz DSP is used, one cycle equals 20 ns; the same code keeps the 'AC01 in reset for 240 ns. This is also safe, since it is approximately 2.5 times the specification’s recommended value.

The 'AC01 can operate at a minimum clock frequency of 5.184 MHz. This implies that it must be held in reset for at least one MCLK cycle, or 192.9 ns. Assuming a processor speed of 50 MHz, the 'AC01 spends 12 cycles multiplied by 20 ns = 240 ns in reset.

A safe margin holds the 'AC01 in reset for at least twice the specification’s recommended time. To allow the necessary time in reset, use a dedicated timer function or insert useful instructions to fill the time slot. After the 'AC01 is reset, the main program sits in a loop, waiting for a serial port interrupt.

Example 3–1 initializes the serial port and uses the default initialization of the 'AC01, which is in the master mode and transfers the data upon a receive interrupt. It is not necessary to initiate a secondary communication interval to program the 'AC01. The serial port is configured between the cycles that the AIC is in reset.
Example 3–1. Default Initialization of ’AC01

;TEXAS INSTRUMENTS INCORPORATED

.include “interrupt.inc”
.include init_ser.inc”

AIC_VAR_DP .usect “aic_vars”,0
aic_in_rst .usect “aic_vars”,1
aic_out_of_rst .usect “aic_vars”,1

.def serial_init

;–––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––
; Functional Description
; This routine initializes the serial port 1 of 541. The serial port is put
; in reset by writing 0's to RRST and XRST bits and pulled out of reset by
; writing 1's to both RRST and XRST bits. This routine also puts the AC01
; in reset and after 12 cycles the AC01 is pulled out of reset. The serial
; port initialization is done during the 12 cycle latency of the AC01 init.
;–––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––

.sect “ser_cnfg”

serial_init:
LD #AIC_VAR_DP,DP ; initialize DP for aic_reset
ST #K_0, aic_in_rst ; bit 15 = 0 of TCR resets AIC
PORTW aic_in_rst,K_TRGCR_ADDR ;write to address 14h (TCR)

*********************************************************************************
*We need at least 12 cycles to pull the AIC out of reset.
*********************************************************************************

STM #K_SERIAL_RST, SPC1 ;reset the serial port with
;0000 0000 0000 1000
STM #K_SERIAL_OUT_RST, SPC1 ;bring ser.port out of reset
;0000 0000 1100 1000
RSBX INTM
LD #0,DP
ORM #((K_RINT1|K_INT1),IMR ; Enable RINT1,INT1
; 0000 0000 0100 0010
LD #AIC_VAR_DP,DP ; restore DP
STM #(K_RINT1),IFR ; clear RINT1
STM #K_0,DXR1 ; 0000 0000 0100 0000

; Pull the AC01 out of reset - the AC01 requires that it be held in reset for
; 1 MCLK, which is equivalent to 96.45ns (based on an MCLK of 10.368MHz)
ST #K_8000, aic_out_of_rst ; bit 15 = 1 brings AIC from reset
RETD
PORTW aic_out_of_rst, K_TRGCR_ADDR ;AIC out of reset

.end

* This include file includes the SPC1 register configuration

*************************************************************************
Example 3–1. Default Initialization of 'AC01 (Continued)

* FILENAME: “INIT_SER.INC”
; SPC Register Organization

<table>
<thead>
<tr>
<th>15</th>
<th>14</th>
<th>13</th>
<th>12</th>
<th>11</th>
<th>10</th>
<th>9</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>FREE</td>
<td>SOFT</td>
<td>RSRFULL</td>
<td>XSREMTY</td>
<td>XRDY</td>
<td>RRDY</td>
<td>IN1</td>
<td>IN0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>RRST</td>
<td>XRST</td>
<td>TXM</td>
<td>MCM</td>
<td>FSM</td>
<td>FO</td>
<td>DLB</td>
<td>RES</td>
</tr>
</tbody>
</table>

* This include file includes the SPC1 register configuration

<table>
<thead>
<tr>
<th>Bit</th>
<th>Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Reserved</td>
<td>Always read as 0</td>
</tr>
<tr>
<td>1</td>
<td>DLB</td>
<td>Digital loop back: 0 -&gt; Disabled, 1 _ . Enabled</td>
</tr>
<tr>
<td>2</td>
<td>FO</td>
<td>Format bit: 0 -&gt; data transferred as 8 bit bytes, 1 -&gt; 16 bit words</td>
</tr>
<tr>
<td>3</td>
<td>FSM</td>
<td>Frame sync pulse: 0 -&gt; serial port in continuous mode, 1 -&gt; FSM is required</td>
</tr>
<tr>
<td>4</td>
<td>MCM</td>
<td>Clock mode bit: 0 -&gt; CLKX obtained from CLKX pin 1-&gt; CLKX obtained from CLKX</td>
</tr>
<tr>
<td>5</td>
<td>TXM</td>
<td>Transmit mode bit: 0 -&gt; Frame sync pulses generated externally and supplied on FSX pin, 1-&gt; Internally generated frame sync pulses out on FSX pin</td>
</tr>
<tr>
<td>6</td>
<td>XRST</td>
<td>Transmit reset bit: 0 -&gt; reset the serial port, 1-&gt; bring serial port out of reset</td>
</tr>
<tr>
<td>7</td>
<td>RRST</td>
<td>Receive reset bit: 0 -&gt; reset the serial port, 1-&gt; bring serial port out of reset</td>
</tr>
<tr>
<td>8</td>
<td>IN0</td>
<td>Read–only bit reflecting the state of the CLKR pin</td>
</tr>
<tr>
<td>9</td>
<td>IN1</td>
<td>Read–only bit reflecting the state of the CLKX pin</td>
</tr>
<tr>
<td>10</td>
<td>RRDY</td>
<td>Transition from 0 to 1 indicates data is ready to be read</td>
</tr>
<tr>
<td>11</td>
<td>XRDY</td>
<td>Transition from 0 to 1 indicates data is ready to be sent</td>
</tr>
<tr>
<td>12</td>
<td>XSREMTY</td>
<td>Transmit shift register empty (Read–only) 0 -&gt; transistor has experienced underflow, 1-&gt; has not experienced underflow</td>
</tr>
<tr>
<td>13</td>
<td>RSRFUL</td>
<td>Receive shift register full flag (Read–only): 0 -&gt; Receiver has experienced overrun, 1-&gt; receiver has not experienced overrun</td>
</tr>
<tr>
<td>14</td>
<td>SOFT</td>
<td>Soft bit – 0 -&gt; immediate stop, 1-&gt; stop after word completion</td>
</tr>
<tr>
<td>15</td>
<td>FREE</td>
<td>Free run regardless of SOFT bit</td>
</tr>
</tbody>
</table>
Example 3–1. Default Initialization of 'AC01 (Continued)

; The system has the following configuration:
; Uses 16-bit data => FO = 0
; Operates in burst mode => FSM = 1
; CLKX is derived from CLKX pin => MCM = 0
; Frame sync pulses are generated externally by the AIC => TXM = 0
; Therefore, to reset the serial port, the SPC field would have
; 0000 0000 0000 1000
; To pull the serial port out of reset, the SPC field would have
; 0000 0000 1100 1000

K_0 .set 00000000b << 8 ; bits 15-8 to 0 at reset
K_RRST .set 0b << 7 ; First write to SPC1 is 0
; second write is 1
K_XRST .set 0b << 6 ; First write to SPC1 is 0
; second write is 1
K_TXM .set 0b << 5
K_MCM .set 0b << 4
K_FSM .set 1b << 3 ; Frame Sync mode
K_ZERO .set 000b << 0
K_SERIAL_RST .set K_0|K_RRST|K_XRST|K_TXM|K_MCM|K_FSM|K_ZERO
; first write to SPC1 register
K_RRST1 .set 1b << 7 ; second write to SPC1
K_XRST1 .set 1b << 6 ; second write to SPC1
K_SERIAL_OUT_RST .set K_0|K_RRST1|K_XRST1|K_TXM|K_MCM|K_FSM|K_ZERO
K_TRGCR_ADDR .set 14h ; Target/Status I/O address
K_0 .set 0h
K_8000 .set 8000h ; set bit 15 to pull AIC out
; of reset

* FILENAME: INTERRUPT.INC

; 541 Interrupt Mask Register (IMR) Organization

<table>
<thead>
<tr>
<th>15</th>
<th>9</th>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserved</td>
<td>INT3</td>
<td>XINT1</td>
<td>RINT1</td>
<td>XINT0</td>
<td>RINT0</td>
<td>TINT</td>
<td>INT2</td>
<td>INT1</td>
<td>INT0</td>
<td></td>
</tr>
</tbody>
</table>

* This file includes the IMR and IFR configuration

K_IMR_RESR .set 00000000b << 9 ; reserved space
K_INT3 .set 1b << 8 ; disable INT3
K_XINT1 .set 1b << 7 ; disable transmit interrupt 1
K_RINT1 .set 1b << 6 ; enable receive interrupt 1
K_XINT0 .set 1b << 5 ; disable transmit interrupt 0
K_RINT0 .set 1b << 4 ; disable receive interrupt
K_TINT .set 1b << 3 ; disable timer interrupt
K_INT2 .set 1b << 2 ; disable INT2
K_INT1 .set 1b << 1 ; disable INT1
K_INT0 .set 1b << 1 ; enable INT0
Example 3–2 on page 3-12 demonstrates initiation of a secondary communication interval for programming the 'AC01. The configuration of the 'AC01 can be changed via its nine internal registers. To understand this, consider registers 1 and 2 in the 'AC01.

The data content of register 1, also referred to as the register A, determines the divisions of the master clock frequency that produce the internal filter clock, FCLK. The default value of this register is 18 (decimal). The filter clock frequency is calculated using the equation:

\[ FCLK \text{ frequency} = \frac{\text{master clock frequency}}{(\text{register A contents})} \]

This means that for an MCLK of 10.368 MHz, the default value of the filter clock frequency is

\[ FCLK = 288 \text{ kHz} \]

This FCLK determines the –3 dB corner frequency of the low-pass filter which is given by:

\[ f_{LP} = \frac{FCLK}{40} \]

The default value of \( f_{LP} \) is equal to 7.2 kHz.

The data content of register 2 of the 'AC01, also referred to as register B, determines the division of FCLK to generate the conversion clock, and is given by the equation:

\[ \text{Conversion frequency} = \frac{FCLK}{\text{(register B contents)}} \]

The default value of register B is equal to 18 (decimal). Hence, the default value of the conversion (sampling) frequency is equal to:

\[ 288 \text{ kHz} / 18 = 16 \text{ kHz} \]

This register also determines the –3 dB corner frequency of the high-pass filter, which is given by:

\[ f_{HP} = \frac{\text{sampling frequency}}{200} \]

Hence, the default value of \( f_{HP} \) is equal to 80 Hz.

For a system that processes speech signals, the following parameters are desirable:

- Sampling frequency \( f_s = 8.0 \text{ kHz} \)
- Low-pass filter corner frequency, \( f_{LP} = 3.6 \text{ kHz} \)
Assume that the 'AC01 uses a master clock frequency, MCLK, of 10.368 MHz. The 'AC01’s parameters are:

\[ f_{LP} = \frac{FCLK}{40} \text{ gives } FCLK = 144 \text{ kHz} \]

\[ FCLK = \frac{MCLK}{\text{(register A } \times 2)} \text{ gives register A} = 36 \text{ (decimal)} \]

\[ f_s = \frac{FCLK}{B} \text{ gives register B} = 18 \text{ (decimal)} \]

This also means that with the specified sampling frequency, the –3 dB corner frequency of the high-pass filter changes to \(8.0 \text{ kHz} / 200 = 48 \text{ Hz}\).

After the 'AC01 has been reset in the main program, it makes a call to the routine wrt_cnfg, which programs the new values of registers A and B as calculated above. To prevent the occurrence of an interrupt while programming the 'AC01, wrt_cnfg disables all interrupts until the end of programming. After each word has been sent to the serial port, the code waits for the data to be copied from the data transmit register to the transmit shift register before it sends the next data. After the 'AC01 has been programmed, the main routine waits for an interrupt. The service routines that transfer data between the memory buffers and the serial port transmit and receive registers remain the same.
Example 3–2. Initiation of a Secondary Communication Interval for Programming the ‘AC01

;TEXAS INSTRUMENTS INCORPORATED
.include "interrupt.inc"
.include "init_ser.inc"
AIC_VAR_DP .usect "aic_vars",0
aic_in_rst .usect "aic_vars",1
aic_out_of_rst .usect "aic_vars",1
.def serial_init

;–––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––
; Functional Description
; This routine initializes the serial port 1 of 541. The serial port is put
; in reset by writing 0’s to RRST and XRST bits and pulled out of reset by
; writing 1’s to both RRST and XRST bits. This routine also puts the AC01
; in reset and after 12 cycles the AC01 is pulled out of reset. The serial
; port initialization is done during the 12 cycle latency of the AC01 init.
;–––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––

.sect "ser_cnfg"
serial_init:
LD #AIC_VAR_DP,DP ; initialize DP for aic_reset
ST #K_0, aic_in_rst ; bit 15 = 0 of TCR resets AIC
PORTW aic_in_rst,K_TRGCR_ADDR ;write to address 14h (TCR)
*********************************************************************************
*We need at least 12 cycles to pull the AIC out of reset.
*********************************************************************************
STM #K_SERIAL_RST, SPC1 ;reset the serial port with
;0000 0000 0000 1000
STM #K_SERIAL_OUT_RST, SPC1 ;bring ser.port out of reset
;0000 0000 1100 1000
RSBX INTM
LD #0,DP
ORM #(K_RINT1|K_INT1),IMR ; Enable RINT1,INT1
; 0000 0000 0100 0010
LD #AIC_VAR_DP,DP ; restore DP
STM #(K_RINT1),IFR ; clear RINT1
STM #K_0,DXR1 ; 0000 0000 0100 0000
; Pull the AC01 out of reset - the AC01 requires that it be held in reset for
; 1 MCLK, which is equivalent to 96.45ns (based on an MCLK of 10.368MHz)
ST #K_8000, aic_out_of_rst ; bit 15 = 1 brings AIC from reset
RETD
PORTW aic_out_of_rst, K_TRGCR_ADDR ;AIC out of reset
.end
; TEXAS INSTRUMENTS INCORPORATED
.include "interrupt.inc"
.ref wrt_cnfg ; initializes AC01
.def aic_init

;–––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––
; Functional Description
; This routine disables IMR and clears any pending interrupts before
; initializing AC01. The wrt_cnfg function configures the AC01
;–––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––
Example 3–2. Initiation of a Secondary Communication Interval for Programming the `AC01(Continued)

aic_init:
    CALLD wrt_cnfg ; initialize AC01
    ANDM #(~K_RINT1|K_INT1),IMR ; disable receive_int1,INT1
    ORM #(K_RINT1|K_INT1),IMR ; enable the RINT1, INT1
    RETD
    STM #(K_RINT1),IFR ; service any pending interrupt
.end

**********************************************************************
* This file includes the AC01 registers initialization
* All registers have 2 control bits that initiates serial communication
* There are 2 communication modes - primary and secondary communications
* During primary communication the control bits D00 and D01 are 11 to request
* for a secondary communication. In the secondary serial communications the
* control bits D15 and D14 perform same control function as primary.
* The R/W~ bit at reset is set to 0 placing the device in write mode.
**********************************************************************

K_NOP_ADDR .set 0 << 8
K_REG_0 .set K_NOP_ADDR
K_A_ADDR .set 1 << 8 ; REG 1 address
K_REG_1 .set 36
K_B_ADDR .set 2 << 8 ; REG 2 address
K_REG_2 .set 18
K_AA_ADDR .set 3 << 8 ; Register 3 address
K_AA_REG .set 0
K_REG_3 .set K_AA_ADDR|K_AA_REG ; ; no shift
K_GAIN_ADDR .set 4 << 8 ; Register 4 address
K_MONITOR_GAIN .set 00b << 4 ; Monitor output gain = squelch
K_ANLG_IN_GAIN .set 01b << 2 ; Analog input gain = 0dB
K_ANLG_OUT_GAIN .set 01b << 0 ; Analog output gain = 0dB
K_REG_4 .set K_GAIN_ADDR|K_MONITOR_GAIN|K_ANLG_IN_GAIN|K_ANLG_OUT_GAIN
K_ANLG_CNFG_ADDR .set 5 << 8 ; Register 5 address
K_ANLG_RESRV .set 0 << 3 ; Must be set to 0K_HGH_FILTER
K_ENBL_IN .set 01b << 0 ; Enables IN+ and IN–
K_REG_5 .set K_ANLG_CNFG_ADDR|K_ANLG_RESRV|K_HGH_FILTER|K_ENBL_IN
K_DGTL_CNFG_ADDR .set 6 << 8 ; Register 6 address
K_ADC_DAC .set 0 << 5 ; ADC and DAC is inactive
K_FSD_OUT .set 0 << 4 ; Enabled FSD output
K_16_BIT_COMM .set 0 << 3 ; Normal 16-bit mode
K_SECND_COMM .set 0 << 2 ; Normal secondary communication
K_SOFT_RESET .set 0 << 1 ; Inactive reset
K_POWER_DWN .set 0 << 0 ; Power down external
K_REG_HIGH_6 .set K_DGTL_CNFG_ADDR|K_ADC_DAC|K_FSD_OUT|K_16_BIT_COMM
K_REG_LOW_6 .set K_SECND_COMM|K_SOFT_RESET|K_POWER_DWN
K_REG_6 .set K_REG_HIGH_6|K_REG_LOW_6
K_FRME_SYN_ADDR .set 7 << 8 ; Register 7 address
K_FRME_SYN .set 0 << 8 ;
K_REG_7 .set K_FRME_SYN_ADDR|K_FRME_SYN
K_FRME_NUM_ADDR .set 8 << 8 ; Register 8 address
K_FRME_NUM .set 0 << 8 ;
Example 3–2. Initiation of a Secondary Communication Interval for Programming the 'AC01

K_REG_8 .set K_FRME_NUM_ADDR|K_FRME_NUM
; primary word with D01 and D00 bits set to 11 will cause a
; secondary communications interval to start when the frame
; sync goes low next
K_SCND_CNTL.set 1b << 0 ; Secondary comm.bits
AIC_REG.START_LIST .sect "aic_reg" ; includes the aic table
    .word AIC_REG.END_LIST-AIC_REG.START_LIST-1
    .word K_REG_1
    .word K_REG_2
    .word K_REG_3
    .word K_REG_4
    .word K_REG_5
    .word K_REG_6
    .word K_REG_7
    .word K_REG_8
AIC_REG.END_LIST
K_XRDY .set 0800h ; XRDY bit in SPC1
; TEXAS INSTRUMENTS INCORPORATED
.mmregs
.include "interrupt.inc"
.ref wrt_cnfg ; initializes AC01
.def aic_init

; Functional Description
; This routine disables IMR and clears any pending interrupts before
; initializing AC01. The wrt_cnfg function configures the AC01

.aic_init:
    CALLD wrt_cnfg ; initialize AC01
    ANDM #(~K_RINT1),IMR ; disable receive_int1
    ORM #(K_RINT1|K_INT1),IMR ; enable the RINT1, INT1
    RETD
    STM #(K_RINT1),IFR ; service any pending interrupt
.end

; TEXAS INSTRUMENTS INCORPORATED
.mmregs
.include "aic_cfg.inc"
aic_reg.tble .usect "aic_vars",10
.def wrt_cnfg

; Functional Description
; Writes new configuration data into the AC01. Assuming a system
; which processes speech signals and * requires the following parameters
; Low pass filter cut-off frequency = 3.6 kHz
; Sampling rate = 8000 Hz
; Assume the Master clock MCLK = 10.368 MHz
; This example demonstrates how to program these parameters -
; the registers affected are:
; Register A which determines the division of the MCLK frequency
; to generate the internal filter clock FCLK.
; It also determines the -3 dB corner frequency of the low-pass filter
Example 3–2. Initiation of a Secondary Communication Interval for Programming the AC01 (Continued)

Register B which determines the division of FCLK to generate the sampling (conversion) frequency. It also determines the -3dB corner frequency of the high-pass filter.

```
.asg AR1, AIC_REG_P
.sect "aic_cnfgr"

wrt_cnfgr:
  STM #aic_reg_tbl, AIC_REG_P ; init AR1
  RPT #AIC_REG_END_LIST-AIC_REG_START_LIST
  MVPD #AIC_REG_START_LIST,*AIC_REG_P+ ; move the table
  STM #aic_reg_tbl, AIC_REG_P ; init AR1
  STM #K_REG_0, DXR1 ; primary data word –
  ; a jump start!

wait_xrdy
  BITF SPC1, K_XRDY ; test XRDY bit in SPC1
  BC wait_xrdy, NTC ; loop if not set
  STM #K_SCND_CONTRL, DXR1 ; send primary word with
  ; D01-D00 = 11 to ; signify secondary communication

  LD *AIC_REG_P+, A
  STLM A, DXR1

wait_xrdy1
  BITF SPC1, K_XRDY ; test XRDY bit in SPC1
  BC wait_xrdy1, NTC ; loop if not set
  LD *AIC_REG_P+, A ; Read the register contents
  STLM A, DXR1

wait_xrdy2
  BITF SPC1, K_XRDY ; test XRDY bit in SPC1
  BC wait_xrdy2, NTC ; loop if not set
  STM #K_SCND_CONTRL, DXR1 ; set to read the next register

aic_cfg_complte ; contents

wait_xrdy3
  BITF SPC1, K_XRDY ; test XRDY bit in SPC1
  BC wait_xrdy3, NTC ; loop if not set

RET
```
Example 3–3 on page 3-17 uses two 'AC01s in master-slave configuration. After the 'AC01s have been reset, the Ac01s make a call to the routine wrt_cnfg. This routine programs the low- and high-pass filter cutoff frequencies, the number of slave devices attached, and sets up the frame-sync delay register. During the programming mode, the master and its slaves are programmed with the same control information. The last register programmed is frame-sync delay, which determines the lag between the frame-sync and delayed frame-sync signals. The minimum value for the frame-sync delay register is 18 (decimal). This is because every data transfer requires 16 clock periods, and the output data, DOUT, is placed in the high-impedance state on the 17th rising edge of the clock.

Example 3–3 uses a minimum value of 18, which means that the time delay between the frame sync and the delayed frame sync is equal to 18 multiplied by the period of SCLK. With SCLK = 2.592 MHz based on an MCLK of 10.368 MHz, the time delay is 6.94 μs. The hardware schematic indicates that the delayed frame-sync signal from the master is the frame-sync signal for the slave. The master, therefore, generates a frame-sync signal for itself and a delayed frame-sync signal for its slave. It then synchronizes the host serial port for data transfers to itself and its slaves. All interrupts on the host are disabled during the time the 'AC01s are programmed. This disallows the host from receiving or sending any data to or from the 'AC01s.

The output data (DOUT) from the 'AC01 operating in the master mode is available at the falling edge of the master frame-sync signal. In the primary communication interval, this data represents the 14-bit A/D conversion result. The two least significant bits (LSBs), D01 and D00, determine whether the data is generated by the master or its slave as follows:

<table>
<thead>
<tr>
<th></th>
<th>D01</th>
<th>D00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master mode</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Slave mode</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

In the secondary communication interval, the data available at DOUT represents the contents of the register read with the eight MSBs set to 0 and the read/write bit set to logic 1 during the primary interval. If no register read is requested, the second word is all 0s.

The output data at DOUT from the 'AC01 operating in slave mode is available at either the falling edge of the external frame sync signal (which is the delayed frame sync from the master) or the rising edge of the external SCLK signal, whichever comes first.
When the AC01 receives an interrupt, the service routine first determines whether the received data is from the master or the slave by checking the LSBs of the received data at bit positions D01 and D00. If the LSBs are 00, the received data is stored in a memory buffer, which holds all data received from the master. The service routine also sends data from a memory buffer, which holds all data going to the master. If the LSBs of the received data are 01, data is received from and sent to the slave AC01, using dedicated memory buffers. This can be used with double buffering or circular buffers to allow the ISR to notify the main routine. This occurs when new input data is available for processing and/or space is available to accept processed data for output to or from the master and the slave.

**Example 3–3. Master-Slave Mode**

```plaintext
* This file includes the AC01 registers initialization
* All registers have 2 control bits that initiates serial communication
* There are 2 communication modes - primary and secondary communications
* During primary communication the control bits D00 and D01 are 11 to request for a secondary communication. In the secondary serial communications the control bits D15 and D14 perform same control function as primary.
* The R/W~ bit at reset is set to 0 placing the device in write mode.
* DS7–DS00 → Number of SCLK’s between FS~ and FSD~. When slaves are used, this should be the last register to be programmed The minimum value for this register should be decimal 18. This means that the time interval between the FS~ and FSD~ with an SCLK ~ frequency of 2.592 MHz (with an MCLK of 10.368 MHz) is 18 1/2.592 MHz = 6.94 us
; DS7–DS00 → # of frame sync signals generated by AC01
; Therefore, number of frame sync signals number of slave = devices + 1
; In programming the AC01 REG7 is the last register to be programmed if the configuration is master slave mode configuration

K_NOP_ADDR .set 0 << 8
K_REG_0 .set K_NOP_ADDR
K_A_ADDR .set 1 << 8 ; REG 1 address
K_REG_1 .set 36
K_K_ADDR .set 7 << 8
K_B_ADDR .set 2 << 8 ; REG 2 address
K_B_REG .set 18
K_REG_2 .set K_B_ADDR|K_B_REG ; Sampling rate = 8KHz
K_AA_ADDR .set 3 << 8 ; Register 3 address
K_AA_REG .set 0
K_REG_3 .set K_AA_ADDR|K_AA_REG ; no shift
K_GAIN_ADDR .set 4 << 8 ; Register 4 address
K_MONITOR_GAIN .set 00b << 4 ; Monitor output gain = squelch
K_ANLG_IN_GAIN .set 01b << 2 ; Analog input gain = 0dB
K_ANLG_OUT_GAIN .set 01b << 0 ; Analog output gain = 0dB
K_REG_4 .set K_GAIN_ADDR|K_MONITOR_GAIN|K_ANLG_IN_GAIN|K_ANLG_OUT_GAIN
K_ANLG_CNFS_ADDR .set 5 << 8 ; Register 5 address
K_ANLG_RESRV .set 0 << 3 ; Must be set to 0
K_HGH_FILTER .set 0 << 2 ; High pass filter is enabled
K_ENBL_IN .set 01b << 0 ; Enables IN+ and IN‐
```
Example 3-3. Master-Slave Mode (Continued)

K_REG_5 .set K_ANLG_CNFRD_ADDR|K_ANLG_RESRV|K_HGH_FILTER|K_ENBL_IN
K_DGTL_CNFRD_ADDR .set 6 << 8 ; Register 6 address
K_ADC_DAC .set 0 << 5 ; ADC and DAC is inactive
K_FSD_OUT .set 0 << 4 ; Enabled FSD output
K_16_BIT_COMM .set 0 << 3 ; Normal 16-bit mode
K_SECND_COMM .set 0 << 2 ; Normal secondary communication
K_SOFT_RESET .set 0 << 1 ; Inactive reset
K_POWER_DWN .set 0 << 0 ; Power down external
K_REG_HIGH_6 .set K_DGTL_CNFRD_ADDR|K_ADC_DAC|K_FSD_OUT|K_16_BIT_COMM
K_REG_LOW_6 .set K_SECND_COMM|K_SOFT_RESET|K_POWER_DWN
K_REG_6 .set K_REG_HIGH_6|K_REG_LOW_6
K_FRME_SYN_ADDR .set 7 << 8 ; Register 7 address
K_FRME_SYN .set 18 << 8 ;
K_REG_7 .set K_FRME_SYN_ADDR|K_FRME_SYN
K_FRME_NUM_ADDR .set 8 << 8 ; Register 8 address
K_FRME_NUM .set 2 << 8 ;
K_REG_8 .set K_FRME_NUM_ADDR|K_FRME_NUM
; primary word with D01 and D00 bits set to 11 will cause a
; secondary communications interval to start when the frame
; sync goes low next
K_SCND_CONTRL .set 11b << 0 ; Secondary comm.bits
AIC_REG_START_LIST .sect "aic_reg" ; includes the aic table
   .word AIC_REG_END_LIST-AIC_REG_START_LIST-1
   .word K_REG_1
   .word K_REG_2
   .word K_REG_3
   .word K_REG_4
   .word K_REG_5
   .word K_REG_6
   .word K_REG_8
   .word K_REG_7 ; this should be the last
   ; register to be programmed
AIC_REG_END_LIST
K_XRDY .set 0800h ; XRDY bit in SPC1
3.3 Software Stack

A ’54x device has a software stack whose location is determined by the contents of the stack pointer (SP). When using the software stack, you must accommodate anticipated storage requirements. The system stack fills from high to low memory addresses, as shown in Figure 3–3. The SP always points to the last element pushed onto the stack. A push performs a predecrement and a pop performs a postincrement of the system stack pointer. The stack is used during subroutine calls and returns and inside the subroutine as temporary storage.

The CALL, CALLD, CC, CCD, CALA, and CALAD instructions push the value of the program counter (PC) onto the stack. The RET and RETD instructions pops the stack and places its value into the program counter. The contents of any memory-mapped register can be pushed onto and popped from the stack, using the PSHM and POPM instructions. Two additional instructions, PSHD, and POPD, are included in the instruction set so that data memory values can be pushed onto and popped from the stack.

Figure 3–3. System Stack
3.4 Context Switching

Before you execute a routine, you must save its context and restore the context after the routine has finished. This procedure is called context switching, and involves pushing the PC onto the stack. Context switching is useful for subroutine calls, especially when making extensive use of the auxiliary registers, accumulators, and other memory-mapped registers.

Due to system and CPU requirements, the order of saving and restoring can vary. Some repeat instructions, such as RPTB, are interruptible. To nest repeat block instructions, you must ensure that the block-repeat counter (BRC), block-repeat start address (RSA), and block-repeat end address (REA) registers are saved and restored.

You must also ensure that the block-repeat active flag (BRAF) is properly set. Since the block-repeat flag can be deactivated by clearing the BRAF bit of the ST1 register, the order in which you push the block-repeat counter and ST1 is important. If the BRC register is pushed onto the stack prior to ST1, any PC discontinuity in RPTB can give a wrong result, since BRAF is cleared in ST1. Thus, you must restore BRC before restoring the ST1 register.

A context save complements the restored contents. To ensure the integrity of the code, determine what contents must be restored so that no sequencing is lost.
Example 3–4. Context Save and Restore for TMS320C54x

.title "CONTEXT SAVE/RESTORE on SUBROUTINE or INTERRUPT"

CONTEXT_SAVE .macro
PSHM AG ;Save 8 guard bits of accA
PSHM AH ;Save upper 16 bits of accA
PSHM AL ;Save lower 16 bits of accA
PSHM BG ;Save 8 guard bits of accB
PSHM BH ;Save upper 16 bits of accB
PSHM BL ;Save lower 16 bits of accB
PSHM TRN ;Save transition register
PSHM T ;Save temporary register
PSHM AR7 ;Save AR7
PSHM AR6 ;Save AR6
PSHM AR5 ;Save AR5
PSHM AR4 ;Save AR4
PSHM AR3 ;Save AR3
PSHM AR2 ;Save AR2
PSHM AR1 ;Save AR1
PSHM AR0 ;Save AR0
PSHM ST0 ;Save ST0
PSHM ST1 ;Save ST1
PSHM BK ;Save circular size register
PSHM IMR ;Save interrupt mask register
PSHM BRC ;Save block repeat counter
PSHM REA ;Save block repeat end address
PSHM RSA ;Save block repeat start address
PSHM PMST ;Save PMST register
.endm

CONTEXT_RESTORE .macro
POPM PMST ;Restore PMST register
POPM RSA ;Restore block repeat start address
POPM REA ;Restore block repeat end address
POPM BRC ;Restore block repeat counter
POPM IMR ;Restore interrupt mask register
POPM BK ;Restore circular size register
POPM ST1 ;Restore ST1
POPM ST0 ;Restore ST0
POPM AR0 ;Restore AR0
POPM AR1 ;Restore AR1
POPM AR2 ; Restore AR2
POPM AR3 ; Restore AR3
POPM AR4 ; Restore AR4
POPM AR5 ; Restore AR5
POPM AR6 ; Restore AR6
POPM AR7 ; Restore AR7
POPM T ; Restore temporary register
POPM TRN ; Restore transition register
POPM BL ; Restore lower 16 bits of accB
POPM BH ; Restore upper 16 bits of accB
POPM BG ; Restore 8 guard bits of accB
POPM AL ; Restore lower 16 bits of accA
POPM AH ; Restore upper 16 bits of accA
POPM AR7 ; Restore AR7
POPM AR6 ; Restore AR6
POPM AR5 ; Restore AR5
POPM AR4 ; Restore AR4
POPM AR3 ; Restore AR3
POPM AR2 ; Restore AR2
POPM AR1 ; Restore AR1
POPM AR0 ; Restore AR0
POPM ST0 ; Restore ST0
POPM ST1 ; Restore ST1
.endm
3.5 Interrupt Handling

The '54x CPU supports 16 user-maskable interrupts. The vectors for interrupts not used by a '54x device can function as software interrupts, using the INTR and TRAP instructions. TRAP and INTR allow you to execute any of the 32 available ISRs. You can define other locations in the interrupt vector table. The INTR instruction sets the INTM bit to 1, clears the corresponding interrupt flag to 0, and makes the IACK signal active, but the TRAP instruction does not. INTR and TRAP are nonmaskable interrupts.

When a maskable interrupt occurs, the corresponding flag is set to 1 in the interrupt flag register (IFR). Interrupt processing begins if the corresponding bit in IMR register is set to 1 and the INTM bit in the ST1 register is cleared. The IFR register can be read and action taken if an interrupt occurs. This is true even when the interrupt is disabled. This is useful when not using an interrupt-driven interface, such as in a subroutine call when INT1 has not occurred.

When interrupt processing begins, the PC is pushed onto the stack and the interrupt vector is loaded into the PC. Interrupts are then disabled by setting INTM = 1. The program continues from the address loaded in the PC. Since all interrupts are disabled, the program can be processed without any interruptions, unless the ISR reenables them. Except for very simple ISRs, it is important to save the processor context during execution of the routine.

During the time the ‘AC01 is reset, the DSP initializes the serial port and sets up the interrupt. To set up the interrupts, it performs the following operations:

- Enables unmasked interrupts by clearing the interrupt mode bit (INTM)
- Clears prior receive interrupts by writing the current contents of the appropriate receive interrupt flag in the IFR back to the IFR
- Enables receive interrupts by setting the appropriate receive interrupt flag in the interrupt mask register (IMR)

The initialization of the IMR and IFR registers and the INTM bit is included in the serial port and the ‘AC01 initialization.

Example 3–5 processes the receive interrupt 1 service routine. The routine collects 256 samples in the first buffer and changes the address to the second buffer for the next 256 samples while processing the first buffer.
Example 3–5. Receive Interrupt Service Routine

; TEXAS INSTRUMENTS INCORPORATED
.include "INTERROPT.INC"
.include "main.inc"

RCV_INT1_DP .usect "rcv_vars",0
d_index_count .usect "rcv_vars",1 ; save/restore input bfr ptr
d_xmt_out_ptr .usect "rcv_vars",1 ; save/restore output bfr ptr
d_frame_flag .usect "rcv_vars",1
input_data .usect "inpt_buf",K_FRAME_SIZE*2 ; input data array
output_data .usect "outdata",K_FRAME_SIZE*2 ; output data array

.receive_int1
.d_frame_flag
RCV_INT1_DP
input_data, output_data
d_xmt_out_ptr
d_rcv_in_ptr

;––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––
; Functional Description
; This routine services receive interrupt1. Accumulator A, AR2 and AR3
; are pushed onto the stack since AR2 and AR3 are used in other applications.
; A 512 buffer size for both input and output.
; After every 256 collection of input samples a flag is set to process the
; data. No circular buffering scheme is used here.
; After collecting 256 samples in the 1st bfr, then the second buffer
; address is loaded and collect data in the second buffer while processing
; the first buffer and vice versa.
;–––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––

.asg AR2, GETFRM_IN_P ; get frame input data pointer
.asg AR3, GETFRM_OUT_P ; get frame output data pointer
.asg AR2, SAVE_RSTORE_AR2
.asg AR3, SAVE_RSTORE_AR3
.sect "main_prg"

.receive_int1:
PSHM AL
PSHM AH
PSHM AG
PSHM BL
PSHM BH
PSHM BG

; AR2, AR3 are used in other routines, they need to be saved and restored
; since receive interrupt uses AR2 and AR3 as pointers
PSHM SAVE_RSTORE_AR2 ; Since AR2 and AR3 are used
PSHM SAVE_RSTORE_AR3 ; in other routines, they need
PSHM BRC
LD #RCV_INT1_DP, DP ; init. DP
MVDK d_rcv_in_ptr, GETFRM_IN_P ; restore input bfr ptr
MVDK d_xmt_out_ptr, GETFRM_OUT_P ; restore output bfr ptr
ADDM #1, d_index_count ; increment the index count
LD #K_FRAME_SIZE, A
SUB d_index_count, A
BC get_samples, AGT ; check for a frame of samples
Example 3–5. Receive Interrupt Service Routine (Continued)

```Assembly
frame_flag_set
    ADDM #1,d_int_count
    ST #K_FRAME_FLAG,d_frame_flag ; set frame flag
    ST #0,d_index_count ; reset the counter
    LD #input_data+K_FRAME_SIZE,A ; second input bffr starting addr
    LD #output_data+K_FRAME_SIZE,B ; second output bffr starting addr
    BITF d_int_count,2 ; check for 1st/2nd bffr
    BC reset_buffer,NTC
    SUB #K_FRAME_SIZE,A ; 1st input address
    SUB #K_FRAME_SIZE,B ; 1st output address
    ST #K_0,d_int_count
reset_buffer
    STLM A,GETFRM_IN_P ; input buffer address
    STLM B,GETFRM_OUT_P ; output buffer address
get_samples
    LDM DRR1,A ; load the input sample
    STL A,*GETFRM_IN_P+ ; write to buffer
    LD *GETFRM_OUT_P+,A ; if not true, then the filtered
    AND #0fffch,A ; signal is send as output
    STLM A,DXR1 ; write to DXR1
    MVKD GETFRM_IN_P,d_rcv_in_ptr ; save input buffer ptr
    MVKD GETFRM_OUT_P,d_xmt_out_ptr ; save out bffr ptr
    POPM BRC
    POPM SAVE_RSTORE_AR3 ; restore AR3
    POPM SAVE_RSTORE_AR2 ; restore AR2
    POPM BG
    POPM BH
    POPM BL
    POPM AG
    POPM AH
    POPM AL
    POPM SI
    POPM ST0
    RETE ; return and enable interrupts
.end
```
3.6 Interrupt Priority

Interrupt prioritization allows interrupts that occur simultaneously to be serviced in a predefined order. For instance, infrequent but lengthy ISRs can be interrupted frequently. In Example 3-6, the ISR for the INT1 bit includes context save and restore macros. When the routine has finished processing, the IMR is restored to its original state. Notice that the RETE instruction not only pops the next program counter address from the stack, but also clears the INTM bit to 0. This enables all interrupts that have their IMR bit set.

Example 3–6. Interrupt Service Routine (ISR)

```
.title "Interrupt Service Routine"
.mmregs
int1:
    CONTEXT_STORE       ; push the contents of accumulators and registers on stack
    STM #K_INT0,IMR     ; Unmask only INT0~
    RSBX INTM           ; Enable all Interrupts

    ; Main Processing for Receive Interrupt 1

    SSBX INTM           ; Disable all interrupts
    CONTEXT_RESTORE     ; pop accumulators and registers
    RETE                ; return and enable interrupts
.end
```

There is a potential conflict between the INTM bit disable and context restore. If an interrupt 0 (INT0) occurs during context restore, the macro CONTEXT_RESTORE is executed before servicing INT0. This can trigger an INT0. If INTM is cleared during the context restore, it branches to the INT0 service routine. If you reenable the interrupts when INTM returns from INT0, a conflict occurs, because INTM is set to 0 and its original contents are lost. To preserve the contents of the INTM bit, do not enable the interrupts when INTM returns from the INT0 service routine. During interrupt priorities, preserve the INTM and IMR bits for the system requirements.
3.7 Circular Addressing

Circular addressing is an important feature of the '54x instruction set. Algorithms for convolution, correlation, and FIR filters can use circular buffers in memory. In these algorithms, the circular buffers implement a sliding window that contains the most recent data. As new data comes in, it overwrites the oldest data. The size, the bottom address, and the top address of the circular buffer are specified by the block size register (BK) and a user-selected auxiliary register (ARn). A circular buffer size of R must start on a K-bit boundary (that is, the K LSBs of the starting address of the circular buffer must be 0), where K is the smallest integer that satisfies $2^K > R$.

Circular addressing can be used for different functions of an application. For example, it can be used for collecting the input samples in a block. It can also be used in processing samples in blocks and data in the output buffer. In Example 3–7, a frame of 256 samples is collected from the serial port to process the data using the circular addressing mode. The output from the processed block is sent to the D/A converter through the serial port register using circular buffers. A ping-pong buffering scheme is used. While processing the first buffer, samples are collected in the second buffer, and vice versa. The real-time operation of the system is not disturbed and no data samples are lost.

Example 3–7. Circular Addressing Mode

```asm
; TEXAS INSTRUMENTS INCORPORATED

.mnreg
.include "INTERRUPT.INC"
.include "main.inc"

RCV_INT1_DP .usect "rcv_vars",0
d_index_count .usect "rcv_vars",1

d_rcv_in_ptr .usect "rcv_vars",1 ; save/restore input bffr ptr
d_xmt_out_ptr .usect "rcv_vars",1 ; save/restore output bffr ptr
d_frame_flag .usect "rcv_vars",1

input_data .usect "inpt_buf",K_FRAME_SIZE*2 ; input data array
output_data .usect "outdata",K_FRAME_SIZE*2 ; output data array

.receive_int1
.d_frame_flag
.RCV_INT1_DP
.input_data, output_data
.d_xmt_out_ptr
.d_rcv_in_ptr

; Functional Description
; This routine services receive interrupt1. Accumulator A, AR2 and AR3
; are pushed onto the stack since AR2 and AR3 are used in other applications.
; A 512 buffer size of both input and output uses circular addressing.
; After every 256 collection of input samples a flag is set to process the
; data. A PING/PONG buffering scheme is used such that upon processing
;
; PING buffer, samples are collected in the PONG buffer and vice versa.
```

3-26
Example 3–7. Circular Addressing Mode (Continued)

```assembly
.asg AR2,GETFRM_IN_P ; get frame input data pointer
.asg AR3,GETFRM_OUT_P ; get frame output data pointer
.asg AR2,SAVE_RSTORE_AR2
.asg AR3,SAVE_RSTORE_AR3
.sect "main_prg"

receive_int1:
PShm AL
PShm AH
PShm AG
PShm BL
PShm BH
PShm BG

; AR2, AR3 are used in other routines, they need to be saved and restored
; since receive interrupt uses AR2 and AR3 as pointers
PShm SAVE_RSTORE_AR2 ; Since AR2 and AR3 are used
PShm SAVE_RSTORE_AR3 ; in other routines, they need
PShm BRC
STM #2*K_FRAME_SIZE,BK ; circular buffer size of in,out
arrays
LD #RCV_INT1_DP,DP ; init. DP
MVDK d_rcv_in_ptr,GETFRM_IN_P ; restore input circular bffr ptr
MVDK d_xmt_out_ptr,GETFRM_OUT_P ; restore output circular bffr ptr
ADDM #1,d_index_count ; increment the index count
LD #K_FRAME_SIZE,A
SUB d_index_count,A
BC get_samples,AGT ;check for a frame of samples
frame_flag_set
ST #K_FRAME_FLAG,d_frame_flag ; set frame flag
ST #0,d_index_count ; reset the counter
get_samples
LDM DRR1,A ; load the input sample
STL A,*GETFRM_IN_P+% ; write to buffer
LD *GETFRM_OUT_P+%A ; if not true, then the filtered
AND #0fffch,A ; signal is send as output
STLM A,DXR1 ; write to DXR1
MVKD GETFRM_IN_P,d_rcv_in_ptr ; save input circular buffer ptr
MVKD GETFRM_OUT_P,d_xmt_out_ptr ; save out circular bffr ptr
POPM BRC
POPM SAVE_RSTORE_AR3 ; restore AR3
POPM SAVE_RSTORE_AR2 ; restore AR2
POPM BG
POPM BH
POPM BL
POPM AG
POPM AH
POPM AL
POPM ST1
POPM ST0
RETE ; return and enable interrupts
.end
```
3.8 Buffered Serial Port

The buffered serial port (BSP) is made up of a full-duplex, double-buffered serial port interface, which functions in a similar manner to the '54x standard serial port, and an autobuffering unit (ABU). The serial port section of the BSP is an enhanced version of the '54x standard serial port. The ABU is an additional section of logic which allows the serial port section to read/write directly to '54x internal memory independent of the CPU. This results in a minimum overhead for serial port transfers and faster data rates. The full duplex BSP serial interface provides direct communication with serial devices such as codecs, serial A/D converters, and other serial devices with a minimum of external hardware. The double-buffered BSP allows transfer of a continuous communication stream in 8-, 10-, 12- or 16-bit data packets. This section uses the '542 device to verify the BSP functionality.

The autobuffering process occurs between the ABU and the 2K-word block of ABU memory. Each time a serial port transfer occurs, the data involved is automatically transferred to or from a buffer in the 2K-word block of memory under control of the ABU. No interrupts are generated with each word transfer in autobuffering mode. Interrupts are generated to the CPU each time one of the half-boundaries is crossed. When autobuffering capability is disabled (standard mode), transfers with the serial port are performed under user control (software). When autobuffering is enabled, word transfers can be done directly between the serial port and '54x internal memory using the ABU embedded address generators. The ABU has its own set of circular addressing registers with corresponding address generation units. The length and starting addresses of the buffers are user programmable. A buffer empty/full interrupt can be posted to the CPU.

The six MSBs in the BSP control extension register (BSPCE) configure the ABU. Bits 14 and 11 are read only and the remaining bits are read/write. Figure 3–4 shows the bit positions of BSPCE and Table 3–1 provides a summary of each bit.

Figure 3–4. BSP Control Extension Register (BSPCE) Diagram

<table>
<thead>
<tr>
<th>15</th>
<th>14</th>
<th>13</th>
<th>12</th>
<th>11</th>
<th>10</th>
<th>9</th>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4–0</th>
</tr>
</thead>
<tbody>
<tr>
<td>HALTR</td>
<td>RH</td>
<td>BRE</td>
<td>HALTX</td>
<td>XH</td>
<td>BXE</td>
<td>PCM</td>
<td>FIG</td>
<td>FE</td>
<td>CLKP</td>
<td>FSP</td>
<td>CLKDV</td>
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<tr>
<td>R/W</td>
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<td>R/W</td>
<td>R/W</td>
<td>R/W</td>
<td>R/W</td>
<td>R/W</td>
</tr>
</tbody>
</table>

PRELIMINARY
### Table 3–1. BSP Control Extension Register (BSPCE) Bit Summary

<table>
<thead>
<tr>
<th>Bit</th>
<th>Name</th>
<th>Function</th>
</tr>
</thead>
</table>
| 15  | HALTR      | Autobuffing Receive Halt. This control bit determines whether autobuffing receive is halted when the current half of the buffer has been received.  

  - **HALTR = 0** Autobuffing continues to operate when the current half of the buffer has been received.  
  - **HALTR = 1** Autobuffing is halted when the current half of the buffer has been received. When this occurs, the BRE bit is cleared to 0 and the serial port continues to operate in standard mode. |

| 14  | RH         | Receive Buffer Half Received. This read-only bit indicates which half of the receive buffer has been filled. Reading RH when the RINT interrupt occurs (seen either as a program interrupt or by polling IFR) is a convenient way to identify which boundary has just been crossed.  

  - **RH = 0** The first half of the buffer has been filled and that receptions are currently placing data in the second half of the buffer.  
  - **RH = 1** The second half of the buffer has been filled and that receptions are currently placing data in the first half of the buffer. |

| 13  | BRE        | Autobuffing Receive Enable. This control bit enables autobuffing receive.  

  - **BRE = 0** Autobuffing is disabled and the serial port interface operates in standard mode.  
  - **BRE = 1** Autobuffing is enabled for the receiver. |

| 12  | HALTX      | Autobuffing Transmit Halt. This control bit determines whether autobuffing transmit is halted when the current half of the buffer has been transmitted.  

  - **HALTX = 0** Autobuffing continues to operate when the current half of the buffer has been transmitted.  
  - **HALTX = 1** Autobuffing is halted when the current half of the buffer has been transmitted. When this occurs, the BXE bit is cleared to 0 and the serial port continues to operate in standard mode. |

| 11  | XH         | Transmit Buffer Half Transmitted. This read-only bit indicates which half of the transmit buffer has been transmitted. Reading XH when the XINT interrupt occurs (seen either as a program interrupt or by polling IFR) is a convenient way to identify which boundary has just been crossed.  

  - **XH = 0** The first half of the buffer has been transmitted and transmissions are currently taking data from the second half of the buffer.  
  - **XH = 1** The second half of the buffer has been transmitted and transmissions are currently taking data from the first half of the buffer. |
### Table 3–1. BSP Control Extension Register (BSPCE) Bit Summary (Continued)

<table>
<thead>
<tr>
<th>Bit</th>
<th>Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>BXE</td>
<td>Autobuffering Transmit Enable. This control bit enables the autobuffering transmit.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>BXE = 0</code> Autobuffering is disabled and the serial port operates in standard mode.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>BXE = 1</code> Autobuffering is enabled for the transmitter.</td>
</tr>
<tr>
<td>9</td>
<td>PCM</td>
<td>Pulse Code Modulation Mode. This control bit puts the serial port in pulse code modulation (PCM) mode. The PCM mode only affects the transmitter. BDXR-to-BXSR transfer is not affected by the PCM bit value.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>PCM = 0</code> Pulse code modulation mode is disabled.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>PCM = 1</code> Pulse code modulation mode is enabled. In PCM mode, BDXR is transmitted only if its most significant (2(^{15})) bit is set to 0. If this bit is set to 1, BDXR is not transmitted and BDX is put in high impedance during the transmission period.</td>
</tr>
<tr>
<td>8</td>
<td>FIG</td>
<td>Frame Ignore. This control bit operates only in transmit continuous mode with external frame and in receive continuous mode.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>FIG = 0</code> Frame sync pulses following the first frame pulse restart the transfer.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>FIG = 1</code> Frame sync pulses following the first frame pulse that initiates a transfer operation are ignored.</td>
</tr>
<tr>
<td>7</td>
<td>FE</td>
<td>Format Extension. The FE bit in conjunction with FO in the SPC register specifies the word length. When FO FE = 00, the format is 16-bit words; when FO FE = 01, the format is 10-bit words; when FO FE = 10, the format is 8-bit words; and when FO FE = 11, the format is 12-bit words. Note that for 8-, 10-, and 12-bit words, the received words are right justified and the sign bit is extended to form a 16-bit word. Words to transmit must be right justified.</td>
</tr>
<tr>
<td>6</td>
<td>CLKP</td>
<td>Clock Polarity. This control bit specifies when the data is sampled by the receiver and transmitter.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>CLKP = 0</code> Data is sampled by the receiver on BCLKR falling edge and sent by the transmitter on BCLKX rising edge.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>CLKP = 1</code> Data is sampled by the receiver on BCLKR rising edge and sent by the transmitter on BCLKX falling edge.</td>
</tr>
<tr>
<td>5</td>
<td>FSP</td>
<td>Frame Sync Polarity. This control bit specifies whether frame sync pulses (BFSX and BFSR) are active high or low.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>FSP = 0</code> Frame sync pulses (BFSX and BFSR) are active high.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>FSP = 1</code> Frame sync pulses (BFSX and BFSR) are active low.</td>
</tr>
</tbody>
</table>
Table 3–1. BSP Control Extension Register (BSPCE) Bit Summary (Continued)

<table>
<thead>
<tr>
<th>Bit</th>
<th>Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>4–0</td>
<td>CLKDV</td>
<td>Internal Transmit Clock Division factor. When the MCM bit of BSPC is set to 1, CLKX is driven by an on-chip source having a frequency equal to $1/(CLKDV+1)$ of CLKOUT. CLKDV range is 0–31. When CLKDV is odd or equal to 0, the CLKX duty cycle is 50%. When CLKDV is an even value (CLKDV=2p), the CLKX high and low state durations depend on CLKP. When CLKP is 0, the high state duration is $p+1$ cycles and the low state duration is $p$ cycles; when CLKP is 1, the high state duration is $p$ cycles and the low state duration is $p+1$ cycles.</td>
</tr>
</tbody>
</table>

The autobuffering process for transmit is illustrated in Figure 3–5 and for receive in Figure 3–6. When a process is activated upon request from the serial port (XRDY = 1 or RRDY = 1), four actions are performed:

1) '54x internal memory access,
2) address register update,
3) decision for interrupt,
4) autodisabling management.

An interrupt is generated whenever the first or second half-of-buffer is processed. The RH and XH bits in BSPCE allow you to know which half has been processed when an interrupt boundary is found. For further details on BSP operation, refer to the TMS320C54x DSP Reference Set, Volume 1: CPU and Peripherals.
Figure 3–5. Autobuffering Process for Transmit

\[
\begin{align*}
XRDY = 1 & & \\
& & \text{DXR = Mem (AXR); memory access} \\
& & \text{AXRL = +1 ; increment address} \\
& & \text{If (AXRL=BKXL>>1) OR (AXRL=BKL) Then} \\
& & \quad \text{Generate XINT; Buffer boundary} \\
& & \quad \text{If (AXRL=BKXL>>1) Then} \\
& & \quad \quad XH = 0 ; \text{first half emptied} \\
& & \quad \text{Else} \\
& & \quad \quad AXL = 0 ; \text{buffer wrap around} \\
& & \quad \quad XH = 1 ; \text{second half emptied} \\
& & \text{Endif} \\
& & \text{If (HALTX = 1) Then} \\
& & \quad \text{BXE =0 ; disconnect ABU} \\
& & \text{Endif} \\
& & \text{Endif} \\
\end{align*}
\]
**Figure 3–6. Autobuffering Process for Receive**

```
RRDY = 1
& BRWE = 1
& RRST = 1

Mem (ARR) = DRR ;memory access
ARRL = +1 ;increment address
If (ARRL=BKRL>>1) OR (ARRL=BKRL) Then
  Generate RINT; Buffer boundary
  If (ARRL=BKRL>>1) Then
    RH = 0 ;first half filled
  Else
    ARL = 0 ;buffer wrap around
    RH = 1 ;second half filled
  Endif
  If (HALTR = 1) Then ;auto disabling
    BRE =0 ;disconnect ABU
  Endif
Endif
Endif
```
**Initialization Examples**

In order to start or restart BSP operation in standard mode, the same steps are performed in software as with initializing the serial port (see *TMS320C54x DSP Reference Set, Volume 1: CPU and Peripherals*), in addition to which, the BSPCE register must be initialized to configure any of the enhanced features desired. To start or restart the BSP in autobuffering mode, a similar set of steps must also be performed, in addition to which, the autobuffering registers must be initialized.

As an illustration of the proper operation of a buffered serial port, Example 3–8 and Example 3–9 define a sequence of actions. The ’542 peripheral configuration has been used as a reference for these examples. The examples show the actions for initializing the BSP for autobuffering mode operation. In both cases, assume that transmit and receive interrupts are used to service the ABU interrupts.

Example 3–8 initializes the serial port for transmit operations only, with burst mode, external frame sync, and external clock selected. The selected data format is 16 bits, with frame sync and clock polarities selected to be high true. Transmit autobuffering is enabled by setting the BXE bit in the BSPCE, and HALTX has been set to 1, which causes transmission to halt when half of the defined buffer is transmitted.

Example 3–9 initializes the serial port for receive operations only. Receive autobuffering is enabled by setting the BRE and HALTR bits in the BSPCE to 1.

The complete initialization code is shown in Example 3–10 on page 3-36.
**Example 3–8. BSP Transmit Initialization Routine**

<table>
<thead>
<tr>
<th>Action</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Reset and initialize the serial port by writing 0008h to SPC.</td>
<td>This places both the transmit and receive portions of the serial port in reset and sets up the serial port to operate with externally generated FSX and CLKX signals and FSX required for transmit/receive of each 16-bit word.</td>
</tr>
<tr>
<td>2) Clear any pending serial port interrupts by writing 0020h to IFR.</td>
<td>Eliminate any interrupts that may have occurred before initialization.</td>
</tr>
<tr>
<td>3) Enable the serial port interrupts by ORing 0020h with IMR.</td>
<td>Enable transmit interrupts.</td>
</tr>
<tr>
<td>4) Enable interrupts globally (if necessary) by clearing the INTM bit in ST1.</td>
<td>Interrupts must be globally enabled for the CPU to respond.</td>
</tr>
<tr>
<td>5) Initialize the ABU transmit by writing 1400h to BSPCE.</td>
<td>This causes the autobuffering mode to stop when the current half-of-buffer has been transmitted.</td>
</tr>
<tr>
<td>6) Write the buffer start address to AXR.</td>
<td>Identify the transmit buffer register address.</td>
</tr>
<tr>
<td>7) Write the buffer size to BKX.</td>
<td>Identify the buffer size of the ABU.</td>
</tr>
<tr>
<td>8) Start the serial port by writing 0048h to SPC.</td>
<td>This takes the transmit portion of the serial port out of reset and starts operations with the conditions defined in steps 1 and 5.</td>
</tr>
</tbody>
</table>

**Example 3–9. BSP Receive Initialization Routine**

<table>
<thead>
<tr>
<th>Action</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Reset and initialize the serial port by writing 0000h to SPC.</td>
<td>This places both the transmit and receive portions of the serial port in reset and sets up the serial port to operate with externally generated FSR and CLKR signals and FSR required for transmit/receive of each 16-bit word.</td>
</tr>
<tr>
<td>2) Clear any pending serial port interrupts by writing 0010h to IFR.</td>
<td>Eliminate any interrupts that may have occurred before initialization.</td>
</tr>
<tr>
<td>3) Enable the serial port interrupts by ORing 0010h with IMR.</td>
<td>Enable receive interrupts.</td>
</tr>
<tr>
<td>4) Enable interrupts globally (if necessary) by clearing the INTM bit in ST1.</td>
<td>Interrupts must be globally enabled for the CPU to respond.</td>
</tr>
<tr>
<td>5) Initialize the ABU transmit by writing A000h to BSPCE.</td>
<td>This causes the autobuffering mode to stop when the current half-of-buffer has been received.</td>
</tr>
<tr>
<td>6) Write the buffer start address to ARR.</td>
<td>Identify the receive buffer register address.</td>
</tr>
<tr>
<td>7) Write the buffer size to BKR.</td>
<td>Identify the buffer size of the ABU.</td>
</tr>
<tr>
<td>8) Start the serial port by writing 0088h to SPC.</td>
<td>This takes the receive portion of the serial port out of reset and starts operations with the conditions defined in steps 1 and 5.</td>
</tr>
</tbody>
</table>
Example 3–10. BSP initialization Routine

```assembly
.mmregs
K_STACK_SIZE .set 100
STACK .usect "stack", K_STACK_SIZE
SYSTEM_STACK .set STACK_K_STACK_SIZE
.def SYSTEM_STACK
 .ref main_start
 .ref bsp_receive_int
 .ref bsp_transmit_int
.sect "vectors"
reset: BD main_start ; RESET vector
 STM #SYSTEM_STACK, SP
nmi: RETE
 NOP
 NOP
 NOP ; NMI
 ; software interrupts
sint17 .space 4*16
sint18 .space 4*16
sint19 .space 4*16
sint20 .space 4*16
sint21 .space 4*16
sint22 .space 4*16
sint23 .space 4*16
sint24 .space 4*16
sint25 .space 4*16
sint26 .space 4*16
sint27 .space 4*16
sint28 .space 4*16
sint29 .space 4*16
sint30 .space 4*16
int0: RETE
 NOP
 NOP
 NOP ; INT0
int1: RETE
 NOP
 NOP
 NOP ; INT1
int2: RETE
 NOP
 NOP
 NOP
 tint: RETE
 NOP
 NOP
 NOP ; TIMER
brint: BD bsp_receive_int ; Buffered serial port receive intr
 PSHM ST0
 PSHM ST1
 bxint: BD bsp_transmit_int ; Buffered serial port transmit intr
 PSHM ST0
 PSHM ST1
 trint: RETE
 NOP
 NOP ; TDM serial port transmit intr
```

3-36
Example 3–10. BSP initialization Routine (Continued)

NOP NOP

txint: RETE ; TDM serial port transmit interrupt
NOP NOP NOP

int3: RETE NOP NOP ; INT3
NPOP NOP

hpiint: RETE ; HPI interrupt
NOP NOP NOP

.end

.include "interrupt.inc"
.include "init_ser.inc"

K_AUTO_BFFR_SIZE .set 8
rtop_bffr .usect "auto_rcv",K_AUTO_BFFR_SIZE ; starting address of receive bfr
xtop_bffr .usect "auto_xmt",K_AUTO_BFFR_SIZE ; starting address of transmit bfr
.def rtop_bffr
.def xtop_bffr
.def serial_init

; This routine initializes the BSP of 542. The serial port is put
; in reset by writing 0’s to RRST and XRST bits and pulled out of reset by
; writing 1’s to both RRST and XRST bits. The BSPCE register is init such
; that autobuffer is enabled. Also HALTX and HALTR are enabled to halt the
; autobuffering scheme whenever half buffer is either received or transmitted
;
;---------------------------------------------------------------

.sect "ser_cnfg"

serial_init:

*********************************************************************************
* We need at least 12 cycles to pull the AIC out of reset.
*********************************************************************************

RSBX XF ; Put the AC01 in reset
STM #K_SERIAL_RST, BSPC ; reset the serial port with
; 0000 0000 0000 1000
STM #K_ABUC,BSPCE ; enable auto-buffer
STM #K_SERIAL_OUT_RST, BSPC ; bring ser.port out of reset with
; 0000 0000 1100 1000
RSBX INTM ; Enable interrupts
LD #0,DP
ORM #(K_BXINT|K_BRINT),IMR ; Enable both BSP receive
; transmit interrupt
; 0000 0000 0011 0000
STM #(K_BXINT|K_BRINT),IFR ; clear BXINT,BRINT

; Pull the AC01 out of reset - the AC01 requires that it be held in reset for
; 1 MCLK, which is equivalent to 96.45ns (based on an MCLK of 10.368MHz)
SSBX XF ; Pull AC01 out of reset
RET

.end
Example 3–10. BSP initialization Routine (Continued)

*************************************************************************
* FILENAME: SERIAL_INIT.INC”
* This include file includes the BSPC register configuration
; SPC Register Organization
*************************************************************************

; Bit Name Function
; 0 Reserved Always read as 0
; 1 DLB Digital loop back : 0 -> Disabled, 1 __. Enabled
; 2 FO Format bit: 0 -> data transferred as 8 bit bytes,
; 1 -> 16 bit words
; 3 FSM Frame sync pulse: 0 -> serial port in continuous mode,
; 1 -> FSM is required
; 4 MCM Clock mode bit: 0 -> CLKX obtained from CLUX pin
; 1-> CLUX obtained from CLUX
; 5 TXM Transmit mode bit: 0 -> Frame sync pulses generated externally
; 1-> Internally generated frame sync
; 6 XRST Transmit reset bit:0 -> reset the serial port,
; 1-> bring serial port out of reset
; 7 RRST Receive reset bit: 0 -> reset the serial port,
; 1-> bring serial port out of reset
; 8 IN0 Read-only bit reflecting the state of the CLKR pin
; 9 IN1 Read-only bit reflecting the state of the CLUX pin
; 10 RRDY Transition from 0 to 1 indicates data is ready to be read
; 11 XRDY Transition from 0 to 1 indicates data is ready to be sent
; 12 XSREMPY Transmit shift register empty (Read-only)
; 0 -> transmitter has experienced underflow,
; 1-> has not experienced underflow
; 13 RSRFUL Receive shift register full flag  (Read-only):
; 0 -> Receiver has experienced overrun,
; 1-> receiver has not experienced overrun
; 14 SOFT Soft bit - 0 -> immediate stop, 1-> stop after word completion
; 15 FREE Free run bit: 0 -> behaviour depends on SOFT bit,
; 1-> free run regardless of SOFT bit

K_0 .set 00000000b << 8 ; bits 15-8 to 0 at reset
K_RRST .set 0b << 7 ; First write to BSPC is 0
; second write is 1
K_XRST .set 0b << 6 ; First write to BSPC is 0
; second write is 1
K_TXM .set 0b << 5
K_MCM .set 0b << 4
K_FSM .set 1b << 3 ; Frame Sync mode
K_ZERO .set 000b << 0
K_SERIAL_RST .set K_0|K_RRST|K_XRST|K_TXM|K_MCM|K_FSM|K_ZERO
; first write to BSPC register
Example 3–10. BSP initialization Routine (Continued)

```c
K_RRST1 .set 1b << 7 ; second write to BSPC
K_XRST1 .set 1b << 6 ; second write to BSPC
K_SERIAL_OUT_RST .set K_0|K_RRST1|K_XRST1|K_TXM|K_MCM|K_FSM|K_ZERO
; second write to SPC1 register
K_TRGCR_ADDR .set 14h ; Timer Control Register I/O
; address
K_0 .set 0h
K_8000 .set 8000h ; set bit 15 to pull AIC out
; of reset

; BSPCE Register Organization

* | 15  | 14 | 13 | 12   | 11 | 10 | 9  | 8  | 7  |  6 |  5 | 4      0 |
* |–––––|––––|––––|––––––|––––|––––|––––|––––|––––|––––|–––––|––––––––––|
* |HALTR| RH | BRE| HALTX| XH | BXE| PCM| FIG| FE |CLKP| FSP |  CLKDIV  |
* |––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––|

K_CLKDV .set 00000 << 0 ; External clock
K_FSP .set 0 << 5 ; Frame sync pulses are active
; high at reset 0
K_CLKP .set 0 << 6 ; CLKP = 0 at reset
K_FE .set 0 << 7 ; 16 bit format
K_FIG .set 0 << 8 ; at reset =0
K_PCM .set 0 << 9 ; no PCM mode
K_BXE .set 1 << 10 ; enable transmit auto-buffer
; mode
K_HALTX .set 1 << 12 ; auto-buffer is halted after
; half buffer has been trans
; mitted
K_BRE .set 1 << 13 ; enable receive auto-buffer
K_HALTR .set 1 << 15 ; auto-buffer is halted after
; half buffer has been received
K_SPIC .set K_CLKDV|K_FSP|K_CLKP|K_FG|K_PCM
K_ABUC .set K_SPIC|K_BXE|K_HALTX|K_BRE|K_HALTR
K_XH .set 0800h ; transmit half buffer check
K_RH .set 4000h ; receive half buffer check

* FILENAME: INTERRUPT.INC
* This file includes the IMR and IFR configuration
* 542Interrupt Mask Register (IMR) Organization

* | 15  | 10 |  9 |  8  |  7  |  6 |  5 |  4 |  3 |  2 |  1 |  0 |
* |–––––|––––|––––|––––––|––––|––––|––––|––––|––––|––––|––––|––––|
* |Reserved| HPIINT|INT3| XINT1| RINT1|XINT0 | RINT0| RINT| TINT | INT2| INT1| INT0|
* |–––––––––––––––––––––––––––––––––––|

K_IMR_RESR .set 0000000b << 9 ; reserved space
K_HPIINT .set 1b << 8 ; disable HPI interrupt
K_TXINT .set 1b << 7 ; enable TDM transmit 1
K_TRINT .set 1b << 6 ; enable TDM receive 1
K_BXINT .set 1b << 5 ; enable BSP transmit
; interrupt
K_BXINT .set 1b << 4 ; enable BSP receive intr
K_TINT .set 1b << 3 ; enable timer interrupt
K_INT2 .set 1b << 2 ; enable INT2
K_INT1 .set 1b << 1 ; enable INT1
```
Example 3–10. BSP initialization Routine (Continued)

K_INT0 .set 1b << 0 ; enable INT0
.include "interrupt.inc"
.include "init_ser.inc"
.ref rtop_bffr
.ref wrt_cnfg ; initializes AC01
.def aic_init
;
5.2 Functional Description
; This routine disables IMR and clears any pending interrupts before
; initializing AC01. The wrt_cnfg function configures the AC01

sect "aic_cnfg"
aic_init:
  CALLD wrt_cnfg ; initialize AC01
  ANDM #~(K_BXINT|K_BRINT),IMR ; disable receive_int1
  LD #rtop_bffr,A
  STLM A,AXR ; PING/PONG buffering scheme
  STLM A,ARR ; is used
  STM #8,BKX ; transmit circular size
  STM #8,BKR ; receive circular size
  ORM #(K_BXINT|K_BRINT),IMR ; enable the RINT1, INT1
  RETD
  STM #(K_BXINT|K_BRINT),IFR ; service any pending interrupt
.end
.include "aic_cfg.inc"
def wrt_cnfg

; Writes new configuration data into the AC01. Assuming a system
; which processes speech signals and * requires the following parameters
; Low pass filter cut–off frequency = 3.6 kHz
; Sampling rate = 8000 Hz
; Assume the Master clock MCLK = 10.368 MHz
; This example demonstrates how to program these parameters –
; the registers affected are:
; Register A which determines the division of the MCLK frequency
; to generate the internal filter clock FCLK.
; It also determines the –3 dB corner frequency of the low–pass filter
; Register B which determines the division of FCLK to generate
; the sampling (conversion) frequency
; It also determines the –3DB corner frequency of the high–pass filter

.asg AR1,AIC_REG_P
.sect "aic_cnfg"
wrt_cnfg:
  STM #aic_reg_tble,AIC_REG_P ;init AR1
  RPT #AIC_REG_END_LIST–AIC_REG_START_LIST
  MVPD #AIC_REG_START_LIST,*AIC_REG_P+ ; move the table
  STM #aic_reg_tble,AIC_REG_P ;init AR1
  STM #K_REG_0,BDXR;primary data word – a jump start!
.wait_xrdy
  BITF BSPC,K_XRDY ;test XRDY bit in BSPC
  BC wait_xrdy,NTC ;loop if not set
  STM #K_SCND_CONTRL,BDXR ;send primary word with D01–D00 = 11 to
  ;signify secondary communication
  LD *AIC_REG_P+,A
Example 3–10. BSP initialization Routine (Continued)

```
STLM A,BRC ;gives the # of registers to be
NOP ;initialized
RPTB aic_cfg_complte-1
wait_xrdy1
BITF BSPC,K_XRDY ;test XRDY bit in BSPC
BC wait_xrdy1,NTC ;loop if not set
LD *AIC_REG_P+,A ;Read the register contents
STLM A, BDXR
wait_xrdy2
BITF BSPC,K_XRDY ;test XRDY bit in BSPC
BC wait_xrdy2,NTC ;loop if not set
STM #K_SCND_CONTRL,BDXR ;set to read the next register
aic_cfg_complte ;contents
RET
```

**********************************************************************
* FILENAME: AIC_CFG.INC
* This file includes the AC01 registers initialization
* All registers have 2 control bits that initiates serial communication
* There are 2 communication modes - primary and secondary communications
* During primary communication the control bits D00 and D01 are 11 to request
* for a secondary communication. In the secondary serial communications the
* control bits D15 and D14 perform same control function as primary.
* The R/W~ bit at reset is set to 0 placing the device in write mode.
**********************************************************************

K_NOP_ADDR .set 0 << 8
K_REG_0 .set K_NOP_ADDR
K_A_ADDR .set 1 << 8 ; REG 1 address
K_A_REG .set 36
K_REG_1 .set K_A_ADDR|K_A_REG ; FCLK = 144KHz => A =24h
K_B_ADDR .set 2 << 8 ; REG 2 address
K_B_REG .set 18
K_REG_2 .set K_B_ADDR|K_B_REG ; Sampling rate = 8KHz
K_AA_ADDR .set 3 << 8 ; Register 3 address
K_AA_REG .set 0
K_REG_3 .set K_AA_ADDR|K_AA_REG ; ; no shift
K_GAIN_ADDR .set 4 << 8 ; Register 4 address
K_MONITOR_GAIN .set 00b << 4 ; Monitor output gain = squelch
K_ANLG_IN_GAIN .set 01b << 2 ; Analog input gain = 0dB
K_ANLG_OUT_GAIN .set 01b << 0 ; Analog output gain = 0dB
K_REG_4 .set K_GAIN_ADDR|K_MONITOR_GAIN|K_ANLG_IN_GAIN|K_ANLG_OUT_GAIN
K_ANLG_CNFR_ADDR .set 5 << 8 ; Register 5 address
K_ANLG_RESRV .set 0 << 3 ; Must be set to 0
K_HGH_FILTER .set 0 << 2 ; High pass filter is enabled
K_ENBL_IN .set 01b << 0 ; Enables IN+ and IN-
K_REG_5 .set K_ANLG_CNFR_ADDR|K_ANLG_RESRV|K_HGH_FILTER|K_ENBL_IN
K_DGTL_CNFR_ADDR .set 6 << 8 ; Register 6 address
K_ADC_DAC .set 0 << 5 ; ADC and DAC is inactive
K_FSD_OUT .set 0 << 4 ; Enabled FSD output
K_16_BIT_COMM .set 0 << 3 ; Normal 16-bit mode
K_SECND_COMM .set 0 << 2 ; Normal secondary communication
K_SOFT_RESET .set 0 << 1 ; Inactive reset
K_POWER_DWN .set 0 << 0 ; Power down external
K_REG_HIGH_6 .set K_DGTL_CNFR_ADDR|K_ADC_DAC|K_FSD_OUT|K_16_BIT_COMM
Example 3–10. BSP initialization Routine (Continued)

```
K_REG_LOW_6.set K_SECND_COMM|K_SOFT_RESET|K_POWER_DWN
K_REG_6.set K_REG_HIGH_6|K_REG_LOW_6
K_FRME_SYN_ADDR.set 7 << 8; // Register 7 address
K_FRME_SYN.set 0 << 8;
K_REG_7.set K_FRME_SYN_ADDR|K_FRME_SYN
K_FRME_NUM_ADDR.set 8 << 8; // Register 8 address
K_FRME_NUM.set 0 << 8;
K_REG_8.set K_FRME_NUM_ADDR|K_FRME_NUM
; primary word with D01 and D00 bits set to 11 will cause a secondary
; communications interval to start when the frame sync goes low next
K_SCND_CONTRL.set 11b << 0; // Secondary communication request
AIC_REG_START_LIST.sect "aic_reg"; includes the aic table
    .word AIC_REG_END_LIST-AIC_REG_START_LIST-1
    .word K_REG_1
    .word K_REG_2
    .word K_REG_3
    .word K_REG_4
    .word K_REG_5
    .word K_REG_6
    .word K_REG_7
    .word K_REG_8
AIC_REG_END_LIST
aic_reg_tble. usect "aic_vars",10
K_XRDY.set 0800h; // XRDY bit in BSPC
.mmregs
.include "INTERRUPT.INC"
.include "init_ser.inc"
def bsp_receive_int
def bsp_transmit_int
; bsp transmit and receive interrupt service routine
; This routine performs BSP receive interrupt and transmit interrupt in
; autobuffering mode. Since HALTX and HALTR = 1, the autobuffering mode
; is disabled thus BXE and BRE =1 to continue in autobuffering mode.
;-------------------------------------------------------------
.sect "main_prg"
bsp_receive_int:
    LD #0,DP
    ORM #K_BRE,BSPCE; enable the auto-buffer mode
    POPM ST1
    POPM ST0
    RETE; return and enable interrupts
******************************************************************************
bsp_transmit_int:
    LD #0,DP
    ORM #K_BXE,BSPCE; enable the auto-buffer mode
    POPM ST1
    POPM ST0
    RETE; return and enable interrupts
.end
```
Example 3–10.  BSP initialization Routine (Continued)

.mmregs
.include “init_54x.inc”
.include “main.inc”
.include “init_ser.inc”
.ref d_auto_bffr_flag,d_auto_bffr_reg,rtop_bffr
.ref RCV_INT1_DP
.ref aic_init,serial_init,init_54,init_bffr_ptr_var
.def main_start
.sect “main_prg”

main_start:
CALL init_54 ; initialize ST0,ST1 PMST and other registers
CALL init_bffr_ptr_var ; init tables,vars,bffrs,ptr
CALL serial_init ; initialize serial_port 1
.if K_DEFAULT_AC01 = 1
CALLD aic_init ; Configures AC01
LD #0,DP
NOP
.else
LD #rtop_bffr,A ; sampling rate = 16KHz
STLM A,AXR ; init. the buffers
STLM A,ARR
STM #8,BKX ; transmit circular size
STM #8,BKR ; receive circular size
.endif

start_loop
LD #RCV_INT1_DP,DP ; restore the DP

loop:
BITF d_auto_bffr_flag,1 ; check if auto-buffering scheme is enabled
BC loop,NTC
ST #0,d_auto_bffr_flag
LD #rtop_bffr,A ; PING buffer address
MVKD BSPCE,d_auto_bffr_reg ; load the status of SPCE
BITF d_auto_bffr_reg,K_RH ; check if first is emptied
BC half_buffer_empty,NTC
ADD #K_AUTO_BFFR_SIZE/2,A ; PONG buffer

half_buffer_empty
STLM A, AXR ; like PING/PONG buffer scheme
B loop
.end
Certain features of the '54x architecture and instruction set facilitate the solution of numerically intensive problems. Some examples include filtering, encoding techniques in telecommunication applications, and speech recognition. This chapter discusses digital filters that use both fixed and adaptive coefficients and fast Fourier transforms.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1 Finite Impulse Response (FIR) Filters</td>
<td>4-2</td>
</tr>
<tr>
<td>4.2 Infinite Impulse Response (IIR) Filters</td>
<td>4-9</td>
</tr>
<tr>
<td>4.3 Adaptive Filtering</td>
<td>4-12</td>
</tr>
<tr>
<td>4.4 Fast Fourier Transforms (FFTs)</td>
<td>4-19</td>
</tr>
</tbody>
</table>
4.1 Finite Impulse Response (FIR) Filters

Digital filters are a common requirement for digital signal processing systems. There are two types of digital filters: finite impulse response (FIR) and infinite impulse response (IIR). Each of these can have either fixed or adaptive coefficients.

If an FIR filter has an impulse response, \( h(0), h(1), ..., h(N-1) \), and \( x(n) \) represents the input of the filter at time \( n \), the output \( y(n) \) at time \( n \) is given by the following equation:

\[
y(n) = h(0)x(n) + h(1)x(n-1) + h(2)x(n-2) + ... + h(N-1)x[n-(N-1)]
\]

Figure 4–1 illustrates a method using circular addressing to implement an FIR filter. To set up circular addressing, initialize BK to block length \( N \). The locations for \( d\_data\_buffer \), and impulse responses, \( COFF\_FIR \), must start from memory locations whose addresses are multiples of the smallest power of 2 that is greater than \( N \). For instance, if \( N = 11 \), the first address for \( d\_data\_buffer \) must be a multiple of 16. Thus, the lowest four bits of the beginning address must be 0.

**Figure 4–1. Data Memory Organization in an FIR Filter**

In Example 4–1, \( N \) is 16 and the circular buffer starts at an address whose four LSBs are 0.
Example 4–1. FIR Implementation Using Circular Addressing Mode With a Multiply and Accumulate (MAC) Instruction

; TEXAS INSTRUMENTS INCORPORATED
.include "main.inc"
.TEXAS INSTRUMENTS INCORPORATED
; the 16 tap FIR coefficients
.COFF_FIR_START .sect "coff_fir" ; filter coefficients
.word 6Fh
.word 0F3h
.word 269h
.word 50Dh
.word 8A9h
.word 0C99h
.word 0FF8h
.word 11EBh
.word 11EBh
.word 0FF8h
.word 0C99h
.word 8A9h
.word 0C99h
.word 0FF8h
.word 0C99h
.word 8A9h
.word 0C99h
.COFF_FIR_END
.FIR_DP .usect  "fir_vars",0
d_filin .usect  "fir_vars",1
d_filout .usect  "fir_vars",1
fir_coff_table .usect  "fir_coff",20
d_data_buffer .usect  "fir_bfr",40 ; buffer size for the filter
.def fir_init ; initialize FIR filter
.def fir_task ; perform FIR filtering

;–––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––
; Functional Description
; This routine initializes circular buffers both for data and coeffs.
;–––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––
.asg AR0, FIR_INDEX_P
.asg AR4,FIR_DATA_P
.asg AR5,FIR_COFF_P
.sect  "fir_prog"
.fir_init:
.STM  #fir_coff_table,FIR_COFF_P
.RPT  #K_FIR_BFFR-1 ; move FIR coeffs from program
.MVPD #COFF_FIR_START,*FIR_COFF_P+ ; to data
.STM  #K_FIR_INDEX,FIR_INDEX_P
.STM  #d_data_buffer,FIR_DATA_P ; load cir_bfr address for the
                ; recent samples
.RPTZ A,#K_FIR_BFFR
.STL  A,*FIR_DATA_P+ ; reset the buffer
.STM  #d_data_buffer#K_FIR_BFFR-1#,FIR_DATA_P
.RETD
.STM  #fir_coff_table, FIR_COFF_P
Example 4–1. FIR Implementation Using Circular Addressing Mode with a Multiply and Accumulate (MAC) Instruction (Continued)

;-----------------------------------------------
; Functional Description
;
; This subroutine performs FIR filtering using MAC instruction.
; accumulator A (filter output) = h(n)*x(n-i) for i = 0,1...15
;-----------------------------------------------
.asg AR6,INBUF_P
.asg AR7,OUTBUF_P
.asg AR4,FIR_DATA_P
.asg AR5,FIR_COFF_P
.sect "fir_prog"

fir_task:
; LD #FIR_DP,DP
STM #K_FRAME_SIZE–1,BRC ; Repeat 256 times
RPTBD fir_filter_loop–1
STM #K_FIR_BFFR,BK ; FIR circular bffr size
LD *INBUF_P+, A ; load the input value

fir_filter:
STL A,*FIR_DATA_P+% ; replace oldest sample with newest
RPTZ A,(K_FIR_BFFR-1)
MAC *FIR_DATA_P+0%,*FIR_COFF_P+0%,A ; filtering
STH A, *OUTBUF_P+ ; replace the oldest bffr value

fir_filter_loop
RET
In a second method, two features of the '54x device facilitate implementation of the FIR filters: circular addressing and the FIRS instruction. The FIR filter shown in Figure 4–2, with symmetric impulse response about the center tap, is widely used in digital signal processing applications because of its linear phase response. In applications such as speech processing, linear phase response is required to avoid phase distortion, which degrades the quality of the signal waveforms. The output of the filter for length N is given by:

\[ y(n) = \sum_{k=0}^{N/2-1} h(k) [x(n-k) + x(n-(N-1+k))] \quad n = 0, 1, 2 \]

Figure 4–2. Block Diagram of an Nth-Order Symmetric FIR Filter
Figure 4–3 shows the storage diagram of the input sequence for two circular buffers. To build the buffers, the value of N/2 is loaded into a circular buffer size register. AR4 is set to point to the top of buffer 1 and AR5 points to the bottom of buffer 2. The data at the top of buffer 1 is moved to the bottom of buffer 2 for the delayed operation before storing new sample data in buffer 1. The processor then performs the adds and multiplies \( h(0)x(0) + x(-N+1) \). After each iteration of the filtering routine, AR4 points to the next time slot window for the data move and AR5 points to the next input sample. For the next iteration of the filtering routine, AR4 points to address 1 and AR5 points to address N/2–2.

Example 4–2 shows how to implement a symmetric FIR filter on the '54x. It uses the symmetrical finite impulse response (FIRS) instruction and the repeat next instruction and clear accumulator (RPTZ) instruction together. FIRS can add two data values (input sequences stored in data memory) in parallel with multiplication of the previous addition result using an impulse response stored in program memory. FIRS becomes a single-cycle instruction when used with the single-repeat instruction. To perform the delayed operation in this storage scheme, two circular buffers are used for the input sequence.
Example 4–2. Symmetric FIR Implementation Using FIRS Instruction

; TEXAS INSTRUMENTS INCORPORATED

.include  "main.inc"

FIR_COFF .sect  "sym_fir" ; filter coefficients
.word   6Fh
.word   0F3h
.word   269h
.word   50Dh
.word   8A9h
.word   0C99h
.word   0FF8h
.word   11EBh

d_datax_buffer .usect  "cir_bfr",20

d_datay_buffer .usect  "cir_bfr1",20

def  sym_fir_init ; initialize symmetric FIR
.def   sym_fir_task

;–––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––

; Functional Description
; This routine initializes circular buffers both for data and coeffs.
;–––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––

.asg AR0,SYMFIR_INDEX_P
.asg AR4,SYMFIR_DATX_P
.asg AR5,SYMFIR_DATY_P
.sect  "sym_fir"

sym_fir_init: STM #d_datax_buffer,SYMFIR_DATX_P ; load cir_bfr address
; for the 8 most
d_recent samples STM #d_datay_buffer+K_FIR_BFFR/2–1, SYMFIR_DATY_P
; load cir_bfr1 address
; for the 8 old samples
STM #K_neg1,SYMFIR_INDEX_P
; index offset –
; whenever the pointer
; hits the top of the bffr,
; it automatically hits
; bottom address of
; buffer and decrements
; the counter

RPTZ A,#K_FIR_BFFR
STL A,* SYMFIR_DATX_P+
STM #d_datax_buffer, SYMFIR_DATX_P
RPTZ A,#K_FIR_BFFR
STL A,* SYMFIR_DATY_P–
RETD
STM #d_datay_buffer+K_FIR_BFFR/2–1, SYMFIR_DATY_P
Example 4–2. Symmetric FIR Implementation Using FIRS Instruction (Continued)

;------------------------------------------------------
; Functional Description
;This program uses the FIRS instruction to implement symmetric FIR filter
;Circular addressing is used for data buffers. The input scheme for the data;
samples is divided into two circular buffers. The first buffer contains
;samples from X(–N/2) to X(–1) and the second buffer contains samples from
;X(–N) to X(–N/2–1).
;------------------------------------------------------
.asg AR6,INBUF_P
.asg AR7,OUTBUF_P
.asg AR4,SYMFIR_DATX_P
.asg AR5,SYMFIR_DATY_P
.sect “sym_fir”
sym_fir_task:
 STM #K_FRAME_SIZE–1,BRC
 RPTBD sym_fir_filter_loop–1
 STM #K_FIR_BFR/2,BK
 LD *INBUF_P+, B

symmetric_fir:
 MVDD *SYMFIR_DATX_P,*SYMFIR_DATY_P+0% ; move X(–N/2) to X(–N)
 STL B,*SYMFIR_DATX_P ; replace oldest sample with newest
 ; sample
 ADD *SYMFIR_DATX_P+0%,*SYMFIR_DATY_P+0%,A ; add X(0)+X(–N/2–1)
 RPTZ B,#(K_FIR_BFR/2–1)
 FIRS *SYMFIR_DATX_P+0%,*SYMFIR_DATY_P+0%,FIR_COFF
 MAR **SYMFIR_DATX_P(2)% ; to load the next newest sample
 MAR *SYMFIR_DATY_P+% ; position for the X(–N/2) sample
 STH B, *OUTBUF_P+

sym_fir_filter_loop
 RET
 .end
4.2 Infinite Impulse Response (IIR) Filters

IIR filters are widely used in digital signal processing applications. The transfer function of an IIR filter is given by:

\[ H(z) = \frac{b_0 + b_1 z^{-1} + \ldots + b_M z^{-M}}{1 + a_1 z^{-1} + \ldots + a_N z^{-N}} = \frac{Y(z)}{X(z)} \]

The transfer function has both poles and zeros. Its output depends on both input and past output. IIR filters need less computation than FIR filters. However, IIR filters have stability problems. The coefficients are very sensitive to coefficient quantization. Figure 4–4 shows a typical diagram of an IIR filter.

Figure 4–4. Nth-Order Direct-Form Type II IIR Filter

Most often, IIR filters are implemented as a cascade of second-order sections, called biquads. The block diagram is shown in Figure 4–5.

Figure 4–5. Biquad IIR Filter
Example 4–3. Two-Biquad Implementation of an IIR Filter

; TEXAS INSTRUMENTS INCORPORATED

.include "main.inc"

 Sect "iir_coff"
iir_table_start
*
* second-order section # 01
*
.word  -26778 ;A2
.word  29529 ;A1/2
.word   19381 ;B2
.word  -23184 ;B1
.word   19381 ;B0
*
* second-order section # 02
*
.word  -30497 ;A2
.word   31131 ;A1/2
.word   11363 ;B2
.word  -20735 ;B1
.word   11363 ;B0

iir_table_end

iir_coff_table .usect "coff_iir",16
IIR_DP .usect "iir_vars",0
d_iir_d .usect "iir_vars",3*2
d_iir_y .usect "iir_vars",1

.def iir_init
.def iir_task

;––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––
; Functional Description
; This routine initializes buffers both for data and coeffs.
;–––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––

.asg AR5,IIR_DATA_P ; data samples pointer
.asg AR4,IIR_COFF_P ; IIR filter coeffs pointer

sect "iir"
iir_init:

STM #iir_coff_table,IIR_COFF_P  ; move IIR coeffs from program
RPT #K_IIR_SIZE–1  ; move IIR coeffs from program
MVPD #iir_table_start,*IIR_COFF_P+  ; to data
LD #IIR_DP,DP
STM #d_iir_d,IIR_DATA_P  ; AR5:d(n),d(n-1),d(n-2)
RPTZ A,#5  ; initial d(n),d(n-1),d(n-2)=0
STL A,*IIR_DATA_P+  
RET
Example 4–3. Two-Biquad Implementation of an IIR Filter (Continued)

; Functional Description
;
; This subroutine performs IIR filtering using biquad sections
; IIR Low pass filter design
; Filter type : Elliptic Filter
; Filter order : 4 order (cascade: 2nd order + 2nd order)
; cut freq. of pass band : 200 Hz
; cut freq. of stop band : 500 Hz
;
; ... ----+-----+------ x ----+----- ... --
; | A1 | B1 |
; +<-- x d(n-1) --> x +
; | A2 | B2 |
; +<-- x d(n-2) --> x +
;
; second order IIR
;
; -----------------------------
.asg AR5,IIR_DATA_P ; data samples pointer
.asg AR4,IIR_COFF_P ; IIR filter coffs pointer
.asg AR6,INBUF_P
.asg AR7,OUTBUF_P
.asg AR1,IIR_INDEX_P
.sect "iir"

iir_task:
STM #K_FRAME_SIZE–1,BRC ; Perform filtering for 256 samples
RPTB iir_filter_loop–1
LD *INBUF_P+,8,A ; load the input value

iir_filter:
STM #d_iir_d+5,IIR_DATA_P ;AR5:d(n),d(n-1),d(n-2)
MVPD #iir_table_start,*IIR_COFF_P+ ; to data
STM #iir_coff_table,IIR_COFF_P ;AR4:coeff of IIR filter A2,A1,B2,B1,B0
STM #K_BIQUAD–1,IIR_INDEX_P

feedback_path:
MAC *IIR_COFF_P+,*IIR_DATA_P–,A ;input+d(n-2)*A2
MAC *IIR_COFF_P,*IIR_DATA_P,A ;input+d(n-2)*A2+d(n-1)*A1/2
MAC *IIR_COFF_P+,*IIR_DATA_P–,A ; A = A+d(n-1)*A1/2
STH A,*IIR_DATA_P+ ;d(n) = input+d(n-2)*A2+d(n-1)*A1
MAR *IIR_DATA_P+

* Forward path
MPY *IIR_COFF_P+,*IIR_DATA_P–,A ;d(n-2)*B2
MAC *IIR_COFF_P+,*IIR_DATA_P,;d(n-2)*B2+d(n-1)*B1
DELAY *IIR_DATA_P– ;d(n-2)=d(n-1)

elooop:
BANZD feedback_path, *IIR_INDEX_P–
MAC *IIR_COFF_P+,*IIR_DATA_P,A ;d(n-2)*B2+d(n-1)*B1+d(n)*B0
DELAY *IIR_DATA_P– ;d(n-1)=d(n)
STH A,d_iir_y ;output=d(n-2)*B2+d(n-1)*B1+d(n)*B0
LD d_iir_y,2,A ; scale the output
STL A,*OUTBUF_P+ ; replace the oldest bffr value

iir_filter_loop
RET

.end
4.3 Adaptive Filtering

Some applications for adaptive FIR and IIR filtering include echo and acoustic noise cancellation. In these applications, an adaptive filter tracks changing conditions in the environment. Although in theory, both FIR and IIR structures can be used as adaptive filters, stability problems and the local optimum points of IIR filters makes them less attractive for this use. FIR filters are used for all practical applications. The LMS, ST|MPY, and RPTBD instructions on the '54x can reduce the execution time of code for adaptive filtering. The block diagram of an adaptive FIR filter is shown in Figure 4–6. The Adaptive filtering routine is shown in Example 4–4, page 4-14.

Figure 4–6. Adaptive FIR Filter Implemented Using the Least-Mean-Squares (LMS) Algorithm

\[
\begin{align*}
\text{On the '54x, one coefficient can be adapted by using the least-mean-squares (LMS) algorithm, which is given by} \\
b_k(i+1) &= b_k(i) + 2\beta e(i)x(i-k),
\end{align*}
\]

where:

\[
e(i) = d(i) - y(i)
\]

The output of the adaptive filter is given by

\[
y(i) = \sum_{k=0}^{N-1} b_k x(i-k)
\]
The LMS instruction can perform a MAC instruction and an addition with rounding in parallel. The LMS algorithm calculates the filter output and updates each coefficient in the filter in parallel by using the LMS instruction, along with the ST||MPY and RPTBD instructions. For each coefficient in the filter at a given instant, $2\beta e(i)$ is a constant. This factor can be computed once and stored in the temporary register, T, to use in each of the updates. The ST||MPY instruction multiplies a data sample by this factor, then the LMS instruction updates a coefficient in the filter and accumulates the filtered output. Since the factor is stored in T, the adaptive filtering in a time-slot window is performed in N cycles.

An adaptive filter can be used in modeling to imitate the behavior of a physical dynamic system. Figure 4–7 shows a block diagram of system identification, where the adaptive filter adjusts itself to cause its output to match that of the unknown system. $H(z)$ is the impulse response of an unknown system; for example, the echo response in the case of an acoustic echo cancellation system. The signal $x(n)$ trains the system. The size of the adaptive filter is chosen to be N, where N is the number of taps (coefficients) of the known system, $W(z)$.

Two circular buffers store the input sequence. AR3 points to the first buffer, AR2 points to the coefficients of $H(z)$, AR4 points to the coefficients of $W(z)$, and AR5 points to the second buffer. The newest sample is stored in a memory location that is input to the adaptive filter. The input sample is subtracted from the output of the adaptive filter to obtain the error data for the LMS algorithm. In this example, the adaptive filter output is computed for the newest sample and the filter coefficients are updated using the previous sample. Thus, there is an inherent delay between the update of the coefficient and the output of the adaptive filter.

Figure 4–7. System Identification Using Adaptive Filter
Example 4–4. System Identification Using Adaptive Filtering Techniques

; Texas Instruments Incorporated

.include "main.inc"

.include "impulse.h"

ADAPT_DP .usect "adpt_var",0
d_primary .usect "adpt_var",1
d_output .usect "adpt_var",1
d_error .usect "adpt_var",1
d_mu .usect "adpt_var",1
d_mu_e .usect "adpt_var",1
d_new_x .usect "adpt_var",1
d_adapt_count .usect "adpt_var",1

hcoff .usect "bufferh", H_FILT_SIZE ; H(z) coeffs
wcoff .usect "bufferw", ADPT_FILT_SIZE  W(z) coeffs

xh .usect "bufferx", H_FILT_SIZE ; input data to H(z)
xw .usect "bufferw", ADPT_FILT_SIZE  ; input data-adaptive filter

.asg AR0,INDEX_P
.asg AR1,INIT_P ; initialize buffer pointer
.asg AR3,XH_DATA_P ; data coeff buffer pointer
.asg AR5,XW_DATA_P ; data coeff buffer pointer

.adapt_init:adapt_task

; initialize input data location, input to hybrid, with zero.
STM #xh,INIT_P
RPTZ A,#H_FILT_SIZE–1
STL A, *INIT_P+

; initialize input data location, input to adaptive filter, with zero.
STM #xw,INIT_P
RPTZ A,#ADPT_FILT_SIZE–1
STL A, *INIT_P+

; initialize adaptive coefficient with zero.
STM #wcoff,INIT_P
RPTZ A,#ADPT_FILT_SIZE–1
STL A, *INIT_P+

; initialize temporary storage locations with zero
STM #d_primary,INIT_P
RPTZ A,#6
STL A, *INIT_P+

; copy system coefficient into RAM location, Reverse order STM #hcoff,INIT_P
RPT #H_FILT_SIZE–1
MVPD #scoff,*INIT_P+
Example 4–4. System Identification Using Adaptive Filtering Techniques (Continued)

; LD #ADAPT_DP,DP ; set DP now and not worry about it
ST #K_mu,d_mu
STM #1,INDEX_P ; increment value to be used by
; dual address
; associate auxiliary registers for circular computation
STM #xh+H_FILT_SIZE–1,XH_DATA_P ; last input of hybrid buffer
RETD
STM #xw+ADPT_FILT_SIZE–1,XW_DATA_P ; last element of input buffer

; Functional Description

; This subroutine performs the adaptive filtering. The newest sample is stored in a separate location since filtering and adaptation are performed at the same time. Otherwise the oldest sample is over written before updating the w(N–1) coefficient.
;
; d_primary = xh *hcoff
; d_output = xw *wcoff
; LMS algorithm:
; w(i+1) = w(i)+d*mu_error*xw(n–i) for i = 0,1,...127 and n = 0,1,...

.asg AR2,H_COFF_P ; H(Z) coeff buffer pointer
.asg AR3,XH_DATA_P ; data coeff buffer pointer
.asg AR6,INBUF_P ; input buffer address pointer
.asg AR7,OUTBUF_P ; output buffer address pointer
.asg AR4,W_COFF_P ; W(z) coeff buffer pointer
.asg AR5,XW_DATA_P ; data coeff buffer pointer
.sect "filter"
adapt_task:
STM #H_FILT_SIZE,BK ; first circular buffer size
STM #hcoff,H_COFF_P ; H_COFF_P --> last of sys coeff
ADDM #1,d_adapt_count
LD *INBUF_P+, A ; load the input sample
STM #wcoff,W_COFF_P ; reset coeff buffer
STL A,d_new_x ; read in new data
LD d_new_x,A ;
STL A,*XH_DATA_P+0% ; store in the buffer
RPTZ A,#H_FILT_SIZE–1 ; Repeat 128 times
MAC *H_COFF_P+0%,*XH_DATA_P+0%,A ; mult & acc:a = a + (h * x)
STH A,d_primary ; primary signal
; start simultaneous filtering and updating the adaptive filter here.
LD d_mu_e,T ; T = step_size*error
SUB B,B ; zero acc B
STM #(ADPT_FILT_SIZE–2),BRC ; set block repeat counter
RPTBD lms_end-1
MPY *XW_DATA_P+0%, A ; error * oldest sample
LMS *W_COFF_P, *XW_DATA_P ; B = filtered output (y)
; Update filter coeff
ST A, *W_COFF_P+ ; save updated filter coeff
|| MPY *XW_DATA_P+0%,A ; error *x[n–(N–1)]
Example 4–4. System Identification Using Adaptive Filtering Techniques (Continued)

```
LMS *W_COFF_P, *XW_DATA_P ; B = accum filtered output y
; Update filter coeff
lms_end
STH A, *W_COFF_P ; final coeff
MPY *XW_DATA_P, A ; x(0)*h(0)
MVKD #d_new_x, *XW_DATA_P ; store the newest sample
LMS *W_COFF_P, *XW_DATA_P+0% ; store the filtered output
STH B, d_output ; store the filtered output
LD d_primary, A
SUB d_output, A
STL A, d_error ; store the residual error signal
LD d_mu, T
MPY d_error, A ; A=u*e
STH A, d_mu_e ; save the error *step_size
LD d_error, A ; residual error signal
STL A, *OUTBUF_P+ ; check if a frame of samples
BC adapt_task, AGT
RETD
ST #K_0, d_adapt_count ; restore the count
.end
```

* This is an input file used by the adaptive filter program.
* The transfer function is the system to be identified by the adaptive filter

```
.word 0FFFDh
.word 24h
.word 6h
.word 0FFFDh
.word 3h
.word 3h
.word 0FFE9h
.word 7h
.word 12h
.word 1Ch
.word 0FFF3h
.word 0FFE8h .word 0Ch
.word 3h
.word 1Eh
.word 1Ah
.word 22h
.word 0FFF5h
.word 0FFE5h
.word 0FFF1h
.word 0FFC5h
.word 0Ch
.word 0FFE8h
.word 37h
.word 0FFE4h
.word 0FFCAh
.word 1Ch
.word 0FFF7h
```

4-16
Example 4–4.  System Identification Using Adaptive Filtering Techniques (Continued)

.word 2Eh
.word 28h
.word OFFC6h
.word 53h
.word OFFB0h
.word 55h
.word OFF36h
.word 5h
.word OFFCFh
.word OFF99h
.word 64h
.word 41h
.word OFFF1h
.word OFFDFh
.word 0D1h
.word 6Ch
.word 57h
.word 36h
.word 0A0h
.word 0FEE3h
.word 6h
.word 0FEC5h
.word 0ABh
.word 185h
.word OFF8f6h
.word 93h
.word 1Fh
.word 10Eh
.word 59h
.word 0FEF0h
.word 96h
.word OFFBFh
.word OFF47h
.word OFF76h
.word OFF0Bh
.word OFFAFh
.word 14Bh
.word OFF3Bh
.word 132h
.word 289h
.word 80h
.word 0FE1Dh
.word 0FE1Bh
.word 0D4h
.word OFF69h
.word 14Fh
.word 2AAh
.word 0FD43h
.word 0F98Fh
.word 451h
.word 13Ch
.word 0FEF7h
.word 0FE36h
Example 4–4. System Identification Using Adaptive Filtering Techniques (Continued)

```assembly
.word 80h
.word 0FFBBh
.word 0FC8Eh
.word 10Eh
.word 37Dh
.word 6FAh
.word 1h
.word 0FD89h
.word 198h
.word 0FE4Ch
.word 0FE78h
.word 0F215h
.word 479h
.word 749h
.word 289h
.word 0F667h
.word 304h
.word 5F8h
.word 34Fh
.word 47Bh
.word 0FF7Fh
.word 85Bh
.word 0F837h
.word 0F77Eh
.word 0FF80h
.word 0B9Bh
.word 0F03Ah
.word 0EE66h
.word 0F2E8h
.word 0FAD0h
.word 8C3h
.word 0F5D6h
.word 14DCh
.word 0F3A7h
.word 0E542h
.word 10F2h
.word 566h
.word 26AAh
.word 15Ah
.word 2853h
.word 0EE95h
.word 93Dh
.word 20Dh
.word 1230h
.word 238Ah
```
4.4 Fast Fourier Transforms (FFTs)

FFTs are an efficient class of algorithms for the digital computation of the N-point discrete Fourier transform (DFT). In general, their input sequences are assumed to be complex. When input is purely real, their symmetric properties compute the DFT very efficiently.

One such optimized real FFT algorithm is the packing algorithm. The original 2N-point real input sequence is packed into an N-point complex sequence. Next, an N-point FFT is performed on the complex sequence. Finally the resulting N-point complex output is unpacked into the 2N-point complex sequence, which corresponds to the DFT of the original 2N-point real input.

Using this strategy, the FFT size can be reduced by half, at the FFT cost function of $O(N)$ operations to pack the input and unpack the output. Thus, the real FFT algorithm computes the DFT of a real input sequence almost twice as fast as the general FFT algorithm. The following subsections show how to perform a 16-point real FFT ($2N = 16$).

4.4.1 Memory Allocation for Real FFT Example

The memory organization for the real FFT example in Chapter 10, Application Code Examples, uses the memory configuration shown in Figure 4–8 on page 4-20.

The following tables give the organization of values in data memory from the beginning of the real FFT algorithm to its end. Initially, the original 2N-point real input sequence, $a(n)$, is stored in the lower half of the 4N-word data processing buffer, as shown in Figure 4–9 on page 4-21.
Figure 4–8. Memory Allocation for Real FFT Example

<table>
<thead>
<tr>
<th>Program Memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address</td>
</tr>
<tr>
<td>0080h</td>
</tr>
<tr>
<td>015Fh</td>
</tr>
<tr>
<td>FF80h</td>
</tr>
<tr>
<td>FFFFh</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data Memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address</td>
</tr>
<tr>
<td>0000h</td>
</tr>
<tr>
<td>005Fh</td>
</tr>
<tr>
<td>0060h</td>
</tr>
<tr>
<td>0061h</td>
</tr>
<tr>
<td>0062h</td>
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<tr>
<td>0070h</td>
</tr>
<tr>
<td>007Fh</td>
</tr>
<tr>
<td>0400h</td>
</tr>
<tr>
<td>05FFh</td>
</tr>
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<td>0800h</td>
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<td>13FFh</td>
</tr>
<tr>
<td>1400h</td>
</tr>
<tr>
<td>17FFh</td>
</tr>
</tbody>
</table>
**Figure 4–9. Data Processing Buffer**

<table>
<thead>
<tr>
<th>Data Memory</th>
<th></th>
</tr>
</thead>
<tbody>
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<td></td>
</tr>
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<td>0C03h</td>
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<td>0C04h</td>
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<td>0C05h</td>
<td></td>
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<td>0C06h</td>
<td></td>
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<tr>
<td>0C07h</td>
<td></td>
</tr>
<tr>
<td>0C08h</td>
<td></td>
</tr>
<tr>
<td>0C09h</td>
<td></td>
</tr>
<tr>
<td>0C0Ah</td>
<td></td>
</tr>
<tr>
<td>0C0Bh</td>
<td></td>
</tr>
<tr>
<td>0C0Ch</td>
<td></td>
</tr>
<tr>
<td>0C0Dh</td>
<td></td>
</tr>
<tr>
<td>0C0Eh</td>
<td></td>
</tr>
<tr>
<td>0C0Fh</td>
<td></td>
</tr>
<tr>
<td>0C10h</td>
<td>a(0)</td>
</tr>
<tr>
<td>0C11h</td>
<td>a(1)</td>
</tr>
<tr>
<td>0C12h</td>
<td>a(2)</td>
</tr>
<tr>
<td>0C13h</td>
<td>a(3)</td>
</tr>
<tr>
<td>0C14h</td>
<td>a(4)</td>
</tr>
<tr>
<td>0C15h</td>
<td>a(5)</td>
</tr>
<tr>
<td>0C16h</td>
<td>a(6)</td>
</tr>
<tr>
<td>0C17h</td>
<td>a(7)</td>
</tr>
<tr>
<td>0C18h</td>
<td>a(8)</td>
</tr>
<tr>
<td>0C19h</td>
<td>a(9)</td>
</tr>
<tr>
<td>0C1Ah</td>
<td>a(10)</td>
</tr>
<tr>
<td>0C1Bh</td>
<td>a(11)</td>
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<tr>
<td>0C1Ch</td>
<td>a(12)</td>
</tr>
<tr>
<td>0C1Dh</td>
<td>a(13)</td>
</tr>
<tr>
<td>0C1Eh</td>
<td>a(14)</td>
</tr>
<tr>
<td>0C1Fh</td>
<td>a(15)</td>
</tr>
</tbody>
</table>
4.4.2 Real FFT Example

The '54x real FFT algorithm is a radix-2, in-place DFT algorithm. It is shown in the following subsections in four phases:

1) Packing and bit-reversal of input
2) N-point complex FFT
3) Separation of odd and even parts
4) Generation of final output

Initially, any real input sequences of 16 to 1024 points can be used by simply modifying the constants K_FFT_SIZE and K_LOGN appropriately, defined in file main.inc. (The real input size is described as 2N and the FFT size in phase two as N.) For a 256-point real input, for example, K_FFT_SIZE must be set to 128, not 256, and K_LOGN must be 7, not 8. Input data is assumed to be in Q15 format.

4.4.2.1 Phase 1: Packing and Bit-Reversal of Input

In phase 1, the input is bit-reversed so that the output at the end of the entire algorithm is in natural order. First, the original 2N-point real input sequence is copied into contiguous sections of memory labeled real_fft_input and interpreted as an N-point complex sequence, d[n]. The even-indexed real inputs form the real part of d[n] and the odd-indexed real inputs form the imaginary part. This process is called packing. (n is a variable indicating time and can vary from 0 to infinity, while N is a constant). Next, this complex sequence is bit-reversed and stored into the data processing buffer, labeled fft_data.

1) Arrange the real input sequence, a(n) for n = 0, 1, 2, ... n – 1, as shown in Figure 4–9. Divide a(n) into two sequences as shown in Figure 4–10. The first is the original input sequence from 0C10h to 0C1Fh. The other is a packed sequence:
   for n = 0, 1, 2, ... , N – 1

2) Form the complex FFT input, d(n), by using r(n) for the real part and i(n) for the imaginary part:
   \[ d(n) = r(n) + j i(n) \]

3) Store d(n) in the upper half of the data processing buffer in bit-reversed order as shown in Figure 4–10 on page 4-23.
**Figure 4–10. Phase 1 Data Memory**

<table>
<thead>
<tr>
<th>Address</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0C00h</td>
<td>r(0) = a(0)</td>
<td></td>
</tr>
<tr>
<td>0C01h</td>
<td>i(0) = a(1)</td>
<td></td>
</tr>
<tr>
<td>0C02h</td>
<td>r(4) = a(8)</td>
<td></td>
</tr>
<tr>
<td>0C03h</td>
<td>i(4) = a(9)</td>
<td></td>
</tr>
<tr>
<td>0C04h</td>
<td>r(2) = a(4)</td>
<td></td>
</tr>
<tr>
<td>0C05h</td>
<td>i(2) = a(5)</td>
<td></td>
</tr>
<tr>
<td>0C06h</td>
<td>r(6) = a(12)</td>
<td></td>
</tr>
<tr>
<td>0C07h</td>
<td>i(6) = a(13)</td>
<td></td>
</tr>
<tr>
<td>0C08h</td>
<td>r(1) = a(2)</td>
<td></td>
</tr>
<tr>
<td>0C09h</td>
<td>i(1) = a(3)</td>
<td></td>
</tr>
<tr>
<td>0C0Ah</td>
<td>r(5) = a(10)</td>
<td></td>
</tr>
<tr>
<td>0C0Bh</td>
<td>i(5) = a(11)</td>
<td></td>
</tr>
<tr>
<td>0C0Ch</td>
<td>r(3) = a(6)</td>
<td></td>
</tr>
<tr>
<td>0C0Dh</td>
<td>i(3) = a(7)</td>
<td></td>
</tr>
<tr>
<td>0C0Eh</td>
<td>r(7) = a(14)</td>
<td></td>
</tr>
<tr>
<td>0C0Fh</td>
<td>i(7) = a(15)</td>
<td></td>
</tr>
<tr>
<td>0C10h</td>
<td>a(0)</td>
<td></td>
</tr>
<tr>
<td>0C11h</td>
<td>a(1)</td>
<td></td>
</tr>
<tr>
<td>0C12h</td>
<td>a(2)</td>
<td></td>
</tr>
<tr>
<td>0C13h</td>
<td>a(3)</td>
<td></td>
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<tr>
<td>0C14h</td>
<td>a(4)</td>
<td></td>
</tr>
<tr>
<td>0C15h</td>
<td>a(5)</td>
<td></td>
</tr>
<tr>
<td>0C16h</td>
<td>a(6)</td>
<td></td>
</tr>
<tr>
<td>0C17h</td>
<td>a(7)</td>
<td></td>
</tr>
<tr>
<td>0C18h</td>
<td>a(8)</td>
<td></td>
</tr>
<tr>
<td>0C19h</td>
<td>a(9)</td>
<td></td>
</tr>
<tr>
<td>0C1Ah</td>
<td>a(10)</td>
<td></td>
</tr>
<tr>
<td>0C1Bh</td>
<td>a(11)</td>
<td></td>
</tr>
<tr>
<td>0C1Ch</td>
<td>a(12)</td>
<td></td>
</tr>
<tr>
<td>0C1Dh</td>
<td>a(13)</td>
<td></td>
</tr>
<tr>
<td>0C1Eh</td>
<td>a(14)</td>
<td></td>
</tr>
<tr>
<td>0C1Fh</td>
<td>a(15)</td>
<td></td>
</tr>
</tbody>
</table>
4.4.2.2 Phase 2: N-Point Complex FFT

In phase 2, an N-point complex FFT is performed in place in the data-processing buffer. The twiddle factors are in Q15 format and are stored in two separate tables, pointed to by sine and cosine. Each table contains 512 values, corresponding to angles ranging from 0 to almost 180 degrees. The indexing scheme used in this algorithm permits the same twiddle tables for inputs of different sizes. Since circular addressing indexes the tables, the starting address of each table must line up to an address with 0s in the eight LSBs.

1) Perform an N-point complex FFT on \( d(n) \). The resulting sequence is

\[
D[k] = F\{d(n)\} = R[k] + jI[k]
\]

where \( R[k] \) and \( I[k] \) are the real and imaginary parts of \( D[k] \), respectively.

2) Since the FFT computation is done in place, the resulting sequence, \( D[k] \), occupies the upper half of the data-processing buffer, as shown. The lower half of the data processing buffer still contains the original real input sequence, \( a(n) \). This is overwritten in phase 3.

3) All the information from the original 2N-point real sequence, \( a(n) \), is contained in this N-point complex sequence, \( D[k] \). The remainder of the algorithm unpacks \( D[k] \) into the final 2N-point complex sequence, \( A[k] = F\{a(n)\} \).
Figure 4–11. Phase 2 Data Memory

<table>
<thead>
<tr>
<th>Address</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0C00h</td>
<td>R[0]</td>
</tr>
<tr>
<td>0C01h</td>
<td>I[0]</td>
</tr>
<tr>
<td>0C02h</td>
<td>R[1]</td>
</tr>
<tr>
<td>0C03h</td>
<td>I[1]</td>
</tr>
<tr>
<td>0C04h</td>
<td>R[2]</td>
</tr>
<tr>
<td>0C05h</td>
<td>I[2]</td>
</tr>
<tr>
<td>0C06h</td>
<td>R[3]</td>
</tr>
<tr>
<td>0C07h</td>
<td>I[3]</td>
</tr>
<tr>
<td>0C08h</td>
<td>R[4]</td>
</tr>
<tr>
<td>0C09h</td>
<td>I[4]</td>
</tr>
<tr>
<td>0C0Ah</td>
<td>R[5]</td>
</tr>
<tr>
<td>0C0Bh</td>
<td>I[5]</td>
</tr>
<tr>
<td>0C0Ch</td>
<td>R[6]</td>
</tr>
<tr>
<td>0C0Dh</td>
<td>I[6]</td>
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<tr>
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<td>R[7]</td>
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<td>a(14)</td>
</tr>
<tr>
<td>0C1 Fh</td>
<td>a(15)</td>
</tr>
</tbody>
</table>
4.4.2.3 Phase 3: Separation of Odd and Even Parts

Phase 3 separates the FFT output to compute four independent sequences: RP, RM, IP, and IM, which are the even real, odd real, even imaginary, and the odd imaginary parts, respectively.

1) D[k] is separated into its real even part, RP[k], real odd part, RM[k], imaginary even part, IP[k], and imaginary odd part, IM[k] according to the following equations:

\[ RP[k] = RP[N-k] = 0.5 \times (R[k] + R[N-k]) \]
\[ RM[k] = -RM[N-k] = 0.5 \times (R[k] - R[N-k]) \]
\[ IP[k] = IP[N-k] = 0.5 \times (I[k] + I[N-k]) \]
\[ IM[k] = -IM[N-k] = 0.5 \times (I[k] - I[N-k]) \]

\[ RP[0] = R[0] \]
\[ IP[0] = I[0] \]
\[ RM[0] = IM[0] = RM[N/2] = IM[N/2] = 0 \]
\[ RP[N/2] = R[N/2] \]
\[ IP[N/2] = I[N/2] \]

2) The table below shows the organization of the values at the end of phase three. The sequences RP[k] and IP[k] are stored in the upper half of the data processing buffer in ascending order; the sequences RM[k] and IM[k] are stored in the lower half in descending order.
Figure 4–12. Phase 3 Data Memory

<table>
<thead>
<tr>
<th>Address</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0C00h</td>
<td>RP[0] = R[0]</td>
</tr>
<tr>
<td>0C01h</td>
<td>IP[0] = I[0]</td>
</tr>
<tr>
<td>0C02h</td>
<td>RP[1]</td>
</tr>
<tr>
<td>0C03h</td>
<td>IP[1]</td>
</tr>
<tr>
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<td>RP[2]</td>
</tr>
<tr>
<td>0C05h</td>
<td>IP[2]</td>
</tr>
<tr>
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<tr>
<td>0C07h</td>
<td>IP[3]</td>
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<tr>
<td>0C0Ah</td>
<td>RP[5]</td>
</tr>
<tr>
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<td>IP[5]</td>
</tr>
<tr>
<td>0C0Ch</td>
<td>RP[6]</td>
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<tr>
<td>0C0Dh</td>
<td>IP[6]</td>
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<tr>
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<td>0C0Fh</td>
<td>IP[7]</td>
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<td>a(0)</td>
</tr>
<tr>
<td>0C11h</td>
<td>a(1)</td>
</tr>
<tr>
<td>0C12h</td>
<td>IM[7]</td>
</tr>
<tr>
<td>0C13h</td>
<td>RM[7]</td>
</tr>
<tr>
<td>0C14h</td>
<td>IM[6]</td>
</tr>
<tr>
<td>0C15h</td>
<td>RM[6]</td>
</tr>
<tr>
<td>0C16h</td>
<td>IM[5]</td>
</tr>
<tr>
<td>0C17h</td>
<td>RM[5]</td>
</tr>
<tr>
<td>0C18h</td>
<td>IM[4] = 0</td>
</tr>
<tr>
<td>0C19h</td>
<td>RM[4] = 0</td>
</tr>
<tr>
<td>0C1Ah</td>
<td>IM[3]</td>
</tr>
<tr>
<td>0C1Bh</td>
<td>RM[3]</td>
</tr>
<tr>
<td>0C1Ch</td>
<td>IM[2]</td>
</tr>
<tr>
<td>0C1Dh</td>
<td>RM[2]</td>
</tr>
<tr>
<td>0C1Eh</td>
<td>IM[1]</td>
</tr>
<tr>
<td>0C1Fh</td>
<td>RM[1]</td>
</tr>
</tbody>
</table>
4.4.2.4 Phase 4: Generation of Final Output

Phase 4 performs one more set of butterflies to generate the 2N-point complex output, which corresponds to the DFT of the original 2N-point real input sequence. The output resides in the data processing buffer.

1) The four sequences, RP[k], RM[k], IP[k], and IM[k], are used to compute the real FFT of a(n) according to the following equations.

\[
AR[k] = AR[2N - k] = RP[k] + \cos\left(\frac{k\pi}{N}\right) \cdot IP[k] - \sin\left(\frac{k\pi}{N}\right) \cdot RM[k]
\]
\[
AI[k] = -AI[2N - k] = IM[k] - \cos\left(\frac{k\pi}{N}\right) \cdot RM[k] - \sin\left(\frac{k\pi}{N}\right) \cdot IP[k]
\]
\[
AR[0] = RP[0] + IP[0]
\]
\[
AI[0] = IM[0] - RM[0]
\]
\[
AR[N] = RP[0] - IP[0]
\]
\[
AI[N] = 0
\]

where:

\[
\]

2) The real FFT outputs fill up the entire 4N-word data processing buffer. These outputs are real/imaginary, interleaved, and in natural order, as shown in Figure 4–13 on page 4-29. The values RM[0] and IM[0] are not stored because they are not used to compute the final outputs in phase 4.
Figure 4–13. Phase 4 Data Memory

<table>
<thead>
<tr>
<th>Address</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0C00h</td>
<td>AR[0]</td>
</tr>
<tr>
<td>0C01h</td>
<td>AR[0]</td>
</tr>
<tr>
<td>0C02h</td>
<td>AR[1]</td>
</tr>
<tr>
<td>0C03h</td>
<td>AR[1]</td>
</tr>
<tr>
<td>0C04h</td>
<td>AR[2]</td>
</tr>
<tr>
<td>0C05h</td>
<td>AR[2]</td>
</tr>
<tr>
<td>0C06h</td>
<td>AR[3]</td>
</tr>
<tr>
<td>0C07h</td>
<td>AR[3]</td>
</tr>
<tr>
<td>0C08h</td>
<td>AR[4]</td>
</tr>
<tr>
<td>0C09h</td>
<td>AR[4]</td>
</tr>
<tr>
<td>0C0Ah</td>
<td>AR[5]</td>
</tr>
<tr>
<td>0C0Bh</td>
<td>AR[5]</td>
</tr>
<tr>
<td>0C0Ch</td>
<td>AR[6]</td>
</tr>
<tr>
<td>0C0Dh</td>
<td>AR[6]</td>
</tr>
<tr>
<td>0C0 Eh</td>
<td>AR[7]</td>
</tr>
<tr>
<td>0C0Fh</td>
<td>AR[7]</td>
</tr>
<tr>
<td>0C10h</td>
<td>AR[8]</td>
</tr>
<tr>
<td>0C11h</td>
<td>AR[8]</td>
</tr>
<tr>
<td>0C12h</td>
<td>AR[9]</td>
</tr>
<tr>
<td>0C13h</td>
<td>AR[9]</td>
</tr>
<tr>
<td>0C14h</td>
<td>AR[10]</td>
</tr>
<tr>
<td>0C15h</td>
<td>AR[10]</td>
</tr>
<tr>
<td>0C16h</td>
<td>AR[11]</td>
</tr>
<tr>
<td>0C17h</td>
<td>AR[11]</td>
</tr>
<tr>
<td>0C18h</td>
<td>AR[12]</td>
</tr>
<tr>
<td>0C19h</td>
<td>AR[12]</td>
</tr>
<tr>
<td>0C1Ah</td>
<td>AR[13]</td>
</tr>
<tr>
<td>0C1Bh</td>
<td>AR[13]</td>
</tr>
<tr>
<td>0C1Ch</td>
<td>AR[14]</td>
</tr>
<tr>
<td>0C1Dh</td>
<td>AR[14]</td>
</tr>
<tr>
<td>0C1 Eh</td>
<td>AR[15]</td>
</tr>
<tr>
<td>0C1Fh</td>
<td>AR[15]</td>
</tr>
</tbody>
</table>
Resource Management

This chapter introduces features of the '54x that improve system performance. These features allow you to conserve power and manage memory. You can improve the performance of any application through efficient memory management. Some issues include:

- On-chip memory versus off-chip memory
- Random access variables that use direct memory addressing versus aggregate variables that include structures/arrays
- The use of pointers for accessing the arrays and pointers
- Alignment of long words to even addresses
- The K-boundary requirement for circular buffers
- Allocation of stack

This chapter also discusses unique features of the '548 and 'LC548 that help when an application needs a large amount of memory.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1 Memory Allocation</td>
<td>5-2</td>
</tr>
<tr>
<td>5.2 Overlay Management</td>
<td>5-5</td>
</tr>
<tr>
<td>5.3 Memory-to-Memory Moves</td>
<td>5-6</td>
</tr>
<tr>
<td>5.4 Power Management</td>
<td>5-8</td>
</tr>
</tbody>
</table>
5.1 Memory Allocation

The '54x can access a large amount of program and data memory (64K words each), but can handle only a limited amount of on-chip memory. On-chip memory accesses reduce the cycle time, since there are eight different internal buses on the '54x but there is only one external bus for off-chip accesses. This means that off-chip operation requires more cycles to perform an operation than on-chip operation.

The DSP uses wait-state generators to interface to slower memories. The system, then, cannot run at full speed. If on-chip memory consists of dual access RAM (DARAM), accessing two operands from the same block does not incur a penalty. Using single access RAM (SARAM), however, incurs a cycle penalty. You can use on-chip ROM for tables to make efficient use of memory.

Random-access variables use direct addressing mode. This allocates all the random variables on a single data page, using one data page initialization for the application. Data-page relative memory addressing makes efficient use of memory resources. Each data variable has an associated lifetime. When that lifecycle is over, the data variable ceases to exist. Thus, if two data variables have non-overlapping lifetimes, both can occupy the same physical memory. All random variables, then, can form unions in the linker command file.

The actual lifetime of a variable determines whether it is retained across the application or only in the function. By careful organization of the code memory, resources can be used optimally. Aggregate variables, such as arrays and structures, are accessed via pointers located within that program's data page. Aggregate variables reside elsewhere in memory. Depending upon the lifetime of the arrays or structures, these can also form unions accordingly.

Memory management is required for interrupt-driven tasks. Often, programmers assume that all CPU resources are available when required. This may not be the case if tasks are interrupted periodically. These interrupts do not require many CPU resources, but they force the system to respond within a certain time. To ensure that interrupts occur within the specified time and the interrupted code resumes as soon as possible, you must use low overhead interrupts. If the application requires frequent interrupts, you can use some of the CPU resources for these interrupts. For example, when all CPU resources are used, simply saving and restoring the CPU's contents increases the overhead for an interrupt service routine (ISR).

A dedicated auxiliary register is useful for servicing interrupts. Allowing interrupts at certain places in the code permits the various tasks of an application to reuse memory. If the code is fully interruptible (that is, interrupts can occur anywhere and interrupt response time is assured within a certain period),
memory blocks must be kept separate from each other. On the other hand, if a context switch occurs at the completion of a function rather than in the middle of execution, the variables can be overlapped for efficiency. This allows variables to use the same memory addresses at different times.

Long words must be aligned at even boundaries for double-precision operations; that is, the most significant word at an even address and the least significant word at an odd address. Circular buffers start at a K boundary, where K is the smallest integer that satisfies $2^K > R$ and R is the size of the circular buffer. If an application uses circular buffers of different sizes, you must use the align directive to align the buffers to correct sizes. You can do this by allocating the largest buffer size as the first alignment, the next highest as the second alignment, and so forth. Example 5–1 shows the memory management alignment feature where the largest circular buffer is 1024 words, and therefore, is assigned first. A 256-word buffer is assigned next. Unused memory can be used for other functions without conflict.

Example 5–1. Memory Management

```plaintext
DRAM    : origin = 0x0100, length = 0x1300
inpt_buf : {} > DRAM,align(1024) PAGE 1
outdata : {} > DRAM,align(1024) PAGE 1
UNION   : > DRAM align(1024) PAGE 1
{        
  fft_bffr
  adpt_sct:
  {       
    *(bufferw)
    .+=80h;
    *(bufferp)
  }
}
UNION   : > DRAM align(256) PAGE 1
{        
  fir_bfr
  cir_bfr
  coff_iir
  bufferh
  twid_sin
}
UNION   : > DRAM align(256) PAGE 1
{        
  fir_coff
  cir_bfr1
  bufferx
  twid_cos
}
```
Stack allocation can also benefit from efficient memory management. The stack grows from high to low memory addresses. The stack pointer (SP) decrements the stack by 1 before pushing its contents, which must be preserved, onto the stack and post increments after a pop. The bottom location is added to the stack, giving the actual stack size. The last element is always empty. Whether the stack is on chip or off chip affects the cycle count for accessing data.

Example 5–2 shows stack initialization when the application is written in assembly. The variable SYSTEM_STACK holds the size of the stack. It is loaded into the SP, which points to the end of the stack. The predecrement during the push operation and the postincrement during the pop cannot overflow the stack. Example 5–3 shows stack initialization when the application is written in C.

**Example 5–2. Stack Initialization for Assembly Applications**

```assembly
K_STACK_SIZE .set 100
STACK .usect "stack", K_STACK_SIZE
SYSTEM_STACK .set STACK+K_STACK_SIZE
  .ref SYSTEM_STACK
  STM #SYSTEM_STACK, SP ; initialization of SP–this is done
    ; vectors.asm
  stack : {} DRAM PAGE 1 ; initialization of stack
    ; in linker command file
```

The compiler uses a stack to allocate local variables, pass arguments, and save the processor status. The stack size is set by the linker and the default size is 1 K words. In Example 5–3, the .stack section creates a stack size of 1 K words. A section of 100 words is created, referenced as top_stck and btm_stck, for the CPU requirements. The rest of the stack (1024 – 100) words can be used for passing arguments and local variables. Only the btm_stck is referenced in the code; hence, several sections can be created within the 1 K words of the stack.

**Example 5–3. Stack Initialization for C Applications**

```c
    .ref btm_stck ; bottom of stack label
    STM #btm_stck, SP ; initialization of SP–this is done
      ; vectors.asm
    .stack :
      {
        top_stck =.; /* top of stack */
        .+=100; /* size of the stack */
        btm_stck =.; /* this is done in linker command file */
      }
```

---

Memory Allocation

---

PRELIMINARY
5.2 Overlay Management

Some systems use a memory configuration in which all or part of the memory space is overlaid. This allows the system to map different banks of physical memory into and out of a single address range. Multiple banks of physical memory can overlay each other at one address range. This is achieved by setting the OVLY bit in the PMST register. This is particularly useful in loading the coefficients of a filter, since program and data use the same physical memory.

If an application needs more than 64K words of either data or program memory, two options are available. The first extends the 16-bit address line to a 16 + n-address line for the extended memory space. The '548 provides 16 + 7 address lines to access 8M words of program space. The other option uses an external device that provides upper addresses beyond the 16-bit memory range. The DSP writes a value to a register located in its I/O space, whose data lines are the higher address bits. It implements bank switching to cross the 64K boundary. Since the bank switch requires action from the DSP, frequent switching between the banks is not very efficient. It is more efficient to partition tasks within a bank and switch banks only when starting new tasks.

The 'LC548 is designed to support a much larger program space of 8M words. Its memory-mapped register controls paging, and its extra instructions address extended program space. The OVLY bit configures the 8M words for on- or off-chip memory. If OVLY = 1, the lower half (128 pages) is a shared, on-chip, 32K-word block and the remaining 4M words are off-chip. If OVLY = 0, the entire 8M words of memory are off chip.
5.3 Memory-to-Memory Moves

There are various reasons for performing memory-to-memory moves. These reasons include making copies of buffers to preserve the original, moving contents from ROM to RAM, and moving copies of code from their load location to their execution location. Example 5–4 implements memory-to-memory moves on the '54x using single-instruction repeat loops.

Example 5–4. Memory-to-Memory Block Moves Using the RPT Instruction

```assembly
; ; mmregs
.text
 ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
 ; This routine uses the MVDD instruction to move information in data memory to other data memory locations.
 ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
 MOVE_DD:
    STM #4000h,AR2 ;Load pointer to source in data memory.
    STM #100h,AR3 ;Load pointer to destination in data memory.
    RPT #(1024–1) ;Move 1024 value.
    MVDD *AR2+,*AR3+
    RET
 ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
 ; This routine uses the MVDP instruction to move external data memory to internal program memory.
 ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
 MOVE_DP:
    STM #0E000h,AR1 ;Load pointer to source in data memory.
    RPT #(8192–1) ;Move 8K to program memory space.
    MVDP *AR1+,#800h
    RET
```

Example 5–4. Memory-to-Memory Block Moves Using the RPT Instruction (Continued)

; This routine uses the MVPD instruction to move external program memory to internal data memory.
MOVE_PD:  
    STM #0100h,AR1 ;Load pointer to destination in data memory.
    RPT #(128–1) ;Move 128 words from external MVPD #3800h,*AR1+ ;program to internal data memory.
    RET

; This routine uses the READA instruction to move external program memory to internal data memory. This differs from the MVPD instruction in that the accumulator contains the address in program memory from which to transfer. This allows for a calculated, rather than pre-determined, location in program memory to be specified.
READ_A:  
    STM #0100h,AR1 ;Load pointer to destination in data memory.
    RPT #(128–1) ;Move 128 words from external READA *AR1+ ;program to internal data memory.
    RET

; This routine uses the WRITEA instruction to move data memory to program memory. The calling routine must contain the destination program memory address in the accumulator.
WRITE_A:  
    STM #380h,AR1 ;Load pointer to source in data memory.
    RPT #(128–1) ;Move 128 words from data WRITA *AR1+ ;memory to program memory.
    RET
5.4 Power Management

The '54x family of DSPs exhibits very low power dissipation and flexible power management. This is important in developing applications for portable systems, particularly wireless systems. Three aspects of power management are discussed here: on- versus off-chip memory, the use of HOLD, and the use of IDLE modes.

To fetch and execute instructions from on-chip memory requires less power than accessing them from off-chip memory. The difference between these two accesses becomes noteworthy if a large piece of code resides off chip and is used more frequently than the on-chip code. The code can be partitioned so that the code that consumes the most power and is used most frequently is placed on-chip. (Masked ROM devices are another alternative for very high-performance applications.)

If the program is executed from internal memory and no external access occurs, switching of address outputs can be disabled with the AVIS bit in the PMST register. This feature saves a significant amount of power. However, once the AVIS bit is set, the address bus is still driven in its previous state. The external bus function in the bank-switching control register (BSCR) contributes to the state of the address, control, and data lines. If it is disabled, the address and data buses, along with the control lines, become inactive after the current bus cycle.

The HOLD signal and the HM bit initiate a power-down mode by either shutting off CPU execution or continuing internal CPU execution if external access is not necessary. This makes external memory available for other processors. The timers and serial ports are not used, and the device can be interrupted and serviced.

Using the IDLE1, IDLE2, and IDLE3 modes dissipates less power than normal operation. The system clock is not halted in IDLE1, but CPU activities are stopped. Peripherals and timers can bring the device out of power-down mode. The system can use the timer interrupt as a wake-up if the device needs to be in power-down mode periodically. The IDLE2 instruction halts both CPU and peripherals. Unlike the IDLE1 mode, an external interrupt wakes up the processor in IDLE2. The IDLE2 mode saves a significant amount of power, compared to IDLE1. The IDLE3 mode shuts off the internal clock, also saving power.
Arithmetic and Logical Operations

This chapter shows how the '54x supports typical arithmetic and logical operations, including multiplication, addition, division, square roots, and extended-precision operations.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1 Division and Modulus Algorithm</td>
<td>6-2</td>
</tr>
<tr>
<td>6.2 Sines and Cosines</td>
<td>6-9</td>
</tr>
<tr>
<td>6.3 Square Roots</td>
<td>6-14</td>
</tr>
<tr>
<td>6.4 Extended-Precision Arithmetic</td>
<td>6-17</td>
</tr>
<tr>
<td>6.5 Floating-Point Arithmetic</td>
<td>6-24</td>
</tr>
<tr>
<td>6.6 Logical Operations</td>
<td>6-43</td>
</tr>
</tbody>
</table>
6.1 Division and Modulus Algorithm

The '54x implements division operations by using repeated conditional subtraction. Example 6–1 uses four types of integer division and modulus:

Type I: 32-bit by 16-bit unsigned integer division and modulus
Type II: 32-bit by 16-bit signed integer division and modulus
Type III: 16-bit by 16-bit unsigned integer division and modulus
Type IV: 16-bit by 16-bit signed integer division and modulus

SUBC performs binary division like long division. For 16-bit by 16-bit integer division, the dividend is stored in low part accumulator A. The program repeats the SUBC command 16 times to produce a 16-bit quotient in low part accumulator A and a 16-bit remainder in high part accumulator B. For each SUBC subtraction that results in a negative answer, you must left-shift the accumulator by 1 bit. This corresponds to putting a 0 in the quotient when the divisor does not go into the dividend. For each subtraction that produces a positive answer, you must left shift the difference in the ALU output by 1 bit, add 1, and store the result in accumulator A. This corresponds to putting a 1 in the quotient when the divisor goes into the dividend.

Similarly, 32-bit by 16-bit integer division is implemented using two stages of 16-bit by 16-bit integer division. The first stage takes the upper 16 bits of the 32-bit dividend and the 16-bit divisor as inputs. The resulting quotient becomes the higher 16 bits of the final quotient. The remainder is left shifted by 16 bits and adds the lower 16 bits of the original dividend. This sum and the 16-bit divisor become inputs to the second stage. The lower 16 bits of the resulting quotient is the final quotient and the resulting remainder is the final remainder.

Both the dividend and divisor must be positive when using SUBC. The division algorithm computes the quotient as follows:

1) The algorithm determines the sign of the quotient and stores this in accumulator B.

2) The program determines the quotient of the absolute value of the numerator and the denominator, using repeated SUBC commands.

3) The program takes the negative of the result of step 2, if appropriate, according to the value in accumulator B.
For unsigned division and modulus (types I and III), you must disable the sign extension mode (SXM = 0). For signed division and modulus (types II and IV), turn on sign extension mode (SXM = 1). The absolute value of the numerator must be greater than the absolute value of the denominator.

Example 6–1. Unsigned/Signed Integer Division Examples

```assembly
;; File Name: DIV_ASM.ASM
;; Title: Divide & Modulus - Assembly Math Utilities.
;; Original draft: Alex Tessaralo
;; Modified for ’54x: Simon Lau & Philip Jones
;; Texas Instruments Inc.
;; Target: C54X
;; Contents: DivModUI32 ; 32-bit By 16-bit Unsigned Integer Divide
;; ; And Modulus.
;; DivModUI16 ; 16-bit By 16-bit Unsigned Integer Divide
;; ; And Modulus.
;; DivModI32 ; 32-bit By 16-bit Signed Integer Divide
;; ; And Modulus.
;; DivModI16 ; 16-bit By 16-bit Signed Integer Divide
;; ; And Modulus.
;; History: mm/dd/yy | Who | Description Of Changes.
;; 08/01/96 | Simon L. | Original draft.
;; Usage ASM:
;; .bss d_NumH,1 ; 00000000h to FFFFFFFFh
;; .bss d_NumL,1
;; .bss d_Den,1 ; 0000h to FFFFh
;; .bss d_QuotH,1 ; 00000000h to FFFFFFFFh
;; .bss d_QuotL,1
;; .bss d_Rem,1 ; 0000h to FFFFh
;; CALL DivModUI32
;; Input: d_NumH
;; d_NumL
;; d_Den
```
Example 6–1. Unsigned/Signed Integer Division Examples (Continued)

;; Modifies: SXM
;; accumulator A
;; Output: d_QuotH
d_QuotL
d_Rem

-----------------------------

;; Algorithm: Quot = Num/Den
;; Rem = Num%Den
;; NumH = n3|n2       QuotH = q3|q2
;; NumL = n1|n0       QuotL = q1|q0
;; Den = d1|d0       Rem = r1|r0

;; Phase1: t1|t0|q3|q2 = A (after repeating SUBC 16 times)
;; d1|d0 ) 00|00|n3|n2 = A (before)

;; Phase2: r1|r0|q1|q0 = A (after repeating SUBC 16 times)
;; d1|d0 ) t1|t0|n1|n0 = A (before)

;; NOTES: Sign extension mode must be turned off.

.def DivModUI32
.ref d_NumH
.ref d_NumL
.ref d_Den
.ref d_QuotH
.ref d_QuotL
.ref d_Rem
.text DivModUI32:
RSBX SXM ; sign extension mode off
LD d_NumH,A
RPT #(16–1)
SUBC d_Den,A
STLA, d_QuotH
XOR d_QuotH,A ; clear AL
OR d_NumL,A ; AL = NumL
RPT #(16–1)
SUBC d_Den,A
STLA, d_QuotL
STHA, d_Rem
RET

;; Module Name: DivModUI16
;
;; Description: 16 Bit By 16 Bit Unsigned Integer Divide And Modulus
;; Usage ASM:
Example 6–1. Unsigned/Signed Integer Division Examples (Continued)

;; .bss  d_Num,1 ; 0000h to FFFFh
;; .bss  d_Den,1 ; 0000h to FFFFh
;; .bss  d_Quot,1 ; 0000h to FFFFh
;; .bss  d_Rem,1 ; 0000h to FFFFh
;;
;; CALL  DivModUI16

;; Input: d_Num
;; d_Den

;; Modifies: SXM
;; accumulator A

;; Output: d_Quot
;; d_Rem

;;––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––
;; Algorithm: Quot = Num/Den
;; Rem = Num%Den
;;
;; Num = n1|n0   Quot = q1|q0
;; Den = d1|d0   Rem = r1|r0
;;
;; r1|r0|q1|q0 = A  (after repeating SUBC 16 times)
;; d1|d0 ) 00|00|n1|n0 = A  (before)

;; NOTES: Sign extension mode must be turned off.

.def  DivModUI16
.ref  d_Num
.ref  d_Den
.ref  d_Quot
.ref  d_Rem
.text

DivModUI16:
    RSBX SXM ; sign extension mode off
    LD  @d_Num,A
    RPT  #(16–1)
    SUBC  @d_Den,A
    STH  A,8@d_Rem

RET

;; Module Name: DivModI32
;; Description: 32 Bit By 16 Bit Signed Integer Divide And Modulus.
;; Usage ASM:
;; .bss  d_NumH,1 ; 80000001h to 7FFFFFFFh
;; .bss  d_NumL,1
;; .bss  d_Den,1 ; 8000h to 7FFFh
;; .bss  d_QuotH,1 ; 80000001h to 7FFFFFFFh
**Example 6–1. Unsigned/Signed Integer Division Examples (Continued)**

```assembly
;; .bss  d_QuotL,1
;; .bss  d_Rem,1 ; 8000h to 7FFFh
;; CALL DivModI32
;;––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––;;
;; Input:  d_NumH
;;       d_NumL
;;       d_Den
;;––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––;;
;; Modifies:  SXM
;;       T
;;       accumulator A
;;       accumulator B
;;––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––;
;; Output:  d_QuotH
;;       d_QuotL
;;       d_Rem
;;––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––;;
;; Algorithm: Quot = Num/Den
;;       Rem = Num%Den
;;;; Signed division is similar to unsigned division except that
;;;; the sign of Num and Den must be taken into account.
;;;; First the sign is determined by multiplying Num by Den.
;;;; Then division is performed on the absolute values.
;;;; NumH = n3|n2      QuotH = q3|q2
;;;; NumL = n1|n0      QuotL = q1|q0
;;;; Den = d1|d0      Rem = r1|r0
;;;; Phase1: t1|t0|q3|q2 = A  (after repeating SUBC 16 times)
;;;; d1|d0 ) 00|00|n3|n2 = A  (before)
;;;; Phase2: r1|r0|q1|q0 = A  (after repeating SUBC 16 times)
;;;; d1|d0 ) t1|t0|n1|n0 = A  (before)
;;;; NOTES: Sign extension must be turned on.
;;;;===========================================================================
.def DivModI32
 .ref  d_NumH
 .ref  d_NumL
 .ref  d_Den
 .ref  d_QuotH
 .ref  d_QuotL
 .ref  d_Rem
.text
DivModI32:
SSBX  SXM ; sign extention mode on
LD d_Den,16,A
MPYA d_NumH ; B has sign of quotient
ABS   A
```

**PRELIMINARY**
Example 6–1. Unsigned/Signed Integer Division Examples (Continued)

```
STH A, d_Rem ; d_Rem = abs(Den) temporarily
LD d_NumH, 16, A
ADDS d_NumL, A
ABS A
STH A, d_QuotH ; d_QuotH = abs(NumH) temporarily
STL d_QuotL, A
LD d_QuotH, A
RPT # (16–1)
SUBC d_Rem, A
STL A, d_QuotH ; AH = abs(QuotH)
XOR d_QuotH, A ; clear AL
OR d_QuotL, A ; AL = abs(NumL)
RPT # (16–1)
SUBC d_Rem, A
STL A, d_QuotL ; AL = abs(QuotL)
STH A, d_Rem ; AH = Rem
BCD DivModI32Skip, BGEQ ; if B neg, then Quot =
LD d_QuotH, 16, A
ADDS d_QuotL, A
NEG A
STH A, d_QuotH
STL A, d_QuotL
DivModI32Skip:
RET
```

```
;; Module Name: DivModI16
;; ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; Description: 16 Bit By 16 Bit Signed Integer Divide And Modulus.
;; ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; Usage ASM:
;; ;.bss d_Num, 1 ; 8000h to 7FFFh (Q0.15 format)
;; ;.bss d_Den, 1 ; 8000h to 7FFFh (Q0.15 format)
;; ;.bss d_Quot, 1 ; 8000h to 7FFFh (Q0.15 format)
;; ;.bss d_Rem, 1 ; 8000h to 7FFFh (Q0.15 format)
;; ;CALL DivModI16
;; ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; Input: d_Num
;; ; d_Den
;; ;
;; Modifies: AR2
;; ; T
;; ; accumulator A
;; ; accumulator B
;; ; SXM
;; ;
;; Output: d_Quot
;; ; d_Rem
;; ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; Algorithm: Quot = Num/Den
;; Rem = Num%Den
```
Example 6–1. Unsigned/Signed Integer Division Examples (Continued)

;; Signed division is similar to unsigned division except that
;; the sign of Num and Den must be taken into account.
;; First the sign is determined by multiplying Num by Den.
;; Then division is performed on the absolute values.
;;
;; Num = n1|n0        Quot = q1|q0
;; Den = d1|d0        Rem = r1|r0
;;
;; r1|r0|q1|q0 = A     (after repeating SUBC 16 times)
;; d1|d0 ) 00|00|n1|n0 = A     (before)
;;
;; NOTES: Sign extension mode must be turned on.
;;
;;===========================================================================
.def DivModI16
.ref d_Num
.ref d_Den
.ref d_Quot
.ref d_Rem
.text
DivModI16:
  SSBX SXM ; sign extension mode on
  STM #d_Quot,AR2
  LD d_Den,16,A
  MPYA d_Num ; B has sign of quotient
  ABS A
  STH A,d_Rem ; d_Rem = abs(Den) temporarily
  LD d_Num,A
  ABS A ; AL = abs(Num)
  RPT #(16–1) SUBC d_Rem,A
  STL A,d_Quot ; AL = abs(Quot)
  STH A,d_Rem ; AH = Rem
  LD #0,A
  SUB d_Quot,16,A ; AH = -abs(Quot)
  SACCD A,*AR2,BLT ; If B neg, Quot = -abs(Quot)
  RET

;;===========================================================================
;;End Of File.
;;===========================================================================
6.2 Sines and Cosines

Sine-wave generators are used in signal processing systems, such as communications, instrumentation, and control. In general, there are two methods to generate sine and cosine waves. The first is the table look-up method, which is used for applications not requiring extreme accuracy. This method uses large tables for precision and accuracy and requires more memory. The second method is the Taylor series expansion, which is more efficient. This method determines the sine and cosine of an angle more accurately and uses less memory than table look-up, and it is discussed here.

The first four terms of the expansion compute the angle. The Taylor series expansions for the sine and cosine of an angle are:

\[
\sin(\theta) = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \frac{x^9}{9!}
\]
\[
= x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} \left(1 - \frac{x^2}{8.9}\right)
\]
\[
= x - \frac{x^3}{3!} + \frac{x^5}{5!} \left(1 - \frac{x^2}{6.7} \left(1 - \frac{x^2}{8.9}\right)\right)
\]
\[
= x \left(1 - \frac{x^2}{2.3} \left(1 - \frac{x^2}{4.5} \left(1 - \frac{x^2}{6.7} \left(1 - \frac{x^2}{8.9}\right)\right)\right)\right)
\]

\[
\cos(\theta) = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \frac{x^8}{8!}
\]
\[
= 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} \left(1 - \frac{x^2}{7.8}\right)
\]
\[
= 1 - \frac{x^2}{2!} + \frac{x^4}{4!} \left(1 - \frac{x^2}{5.6} \left(1 - \frac{x^2}{7.8}\right)\right)
\]
\[
= 1 - \frac{x^2}{2} \left(1 - \frac{x^2}{3.4} \left(1 - \frac{x^2}{5.6} \left(1 - \frac{x^2}{7.8}\right)\right)\right)
\]

The following recursive formulas generate the sine and cosine waves:

\[
\sin(n\theta) = 2 \cos(\theta)\sin((n-1)\theta) - \sin((n-2)\theta)
\]
\[
\cos(n\theta) = 2 \cos(\theta)\cos((n-1)\theta) - \cos((n-2)\theta)
\]

These equations use two steps to generate a sine or cosine wave. The first evaluates \(\cos(\theta)\) and the second generates the signal itself, using one multiply and one subtract for a repeat counter, \(n\).
Example 6–2 and Example 6–3 assumes that the delayed \( \cos((n-1)) \) and \( \cos((n-2)) \) are precalculated and are stored in memory. The Taylor series expansion to evaluate the delayed \( \cos((n-1)) \), \( \cos((n-2))/\sin((n-1)) \), and \( \sin((n-2)) \) values for a given \( \theta \) can also be used.

**Example 6–2. Generation of a Sine Wave**

; Functional Description
; This function evaluates the sine of an angle using the Taylor series expansion.
; \( \sin(\theta) = x(1-x^2/2/3(1-x^2/4/5(1-x^2/6/7(1-x^2/8/9)))) \)

```
.dmmregs
.def d_x, d_squar_x, d_coff, d_sinx, C_1
.d_coff .sect "coeff"
.word 01c7h
.word 030bh
.word 0666h
.word 1556h
d_x .usect "sin_vars", 1
d_squar_x .usect "sin_vars", 1
d_temp .usect "sin_vars", 1
d_sinx .usect "sin_vars", 1
C_1 .usect "sin_vars", 1
.text
sin_start:
STM #d_coff, AR3 ; c1=1/72, c2=1/42, c3=1/20, c4=1/6
STM #d_x, AR2 ; input value
STM #C_1, AR4 ; A1, A2, A3, A4
sin_angle:
LD #d_x, DP
ST #6487h, d_x ; pi/4
ST #7fffh, C_1
SQR *AR2+, A ; let x^2 = P
ST A, *AR2 ; AR2 – > x^2
|| LD *AR4, B
MASR *AR2+, *AR3+, B, A ; (1-x^2)/72
MPYA A ; 1-x^2(1-x^2)/72
; T = x^2
STH A, *AR2
MASR *AR2=, *AR3+, B, A ; A = 1-x^2/42(1-x^2/72)
; T =x^2(1-x^2/72)
MPYA *AR2+ ; B = A(32-16)x^2
ST B, *AR2 ;
|| LD *AR4, B
MASR *AR2=, *AR3+, B, A ; A = 1-x^2/20(1-x^2/42(1-x^2/72)
MPYA *AR2+ ; B = A(32-16)x^2
ST B, *AR2
|| LD *AR4, B
MASR *AR2=, *AR3+, B, A ; AR2 – > d_squar_x
MPYA d_x
STH B, d_sinx ; sin(\theta)
RET
.end
```
Example 6–2. Generation of a Sine Wave (Continued)

; Functional Description
; This function generates the sine of angle. Using the recursive given above, the
; cosine of the angle is found and the recursive formula is used to generate the
; sine wave. The sin(n–1) and sin(n–2) can be calculated using the Taylor
; series expansion or can be pre-calculated.

    .mmregs
       .ref   cos_prog,cos_start
    d_sin_delay1 .usect "cos_vars",1
    d_sin_delay2 .usect "cos_vars",1
    K_sin_delay_1 .set 0A57Eh ; sin(-pi/4)
    K_sin_delay_2 .set 8000h ; sin(-2*pi/4);
    K_2 .set 2h ; circular buffer size
    K_256 .set 256 ; counter
    K_THETA .set 6487h ; pi/4
    .text

    start:
       LD    #d_sin_delay1,DP
       CALL  cos_start
       STM   #d_sin_delay1,AR3 ; intialize the buffer
       RPTZ  A,#3h
       STL   A,*AR3+
       STM   #1,AR0
       STM   #K_2,BK
       STM   #K_256-1,BRC
       STM   #d_sin_delay1,AR3
       ST    #K_sin_delay_1,*AR3+% ; load calculated initial values of sin((n–1) )
       ST    #K_sin_delay_2,*AR3+% ; load calculated initial values of sin((n–2) )
       ; this generates the sine_wave

    sin_generate:
       RPTB  end_of_sine
       MPY   *AR2,*AR3+0%,A ; cos(theta)*sin((n–1)theta)
       SUB   *AR3,15,A ; 1/2*sin((n–2)theta)
       SFTA  A,1,A ; sin(n*theta)
       STH   A,*AR3 ; store
       end_of_sine
       NOP
       NOP
       B    sin_generate
    .end
Example 6–3. Generation of a Cosine Wave

; Functional Description
; this computes the cosine of an angle using the Taylor Series Expansion

.def d_x, d_squrr_x, d_coff, d_cosx, C_7FFF
.def cos_prog, cos_start

STH A,*AR3 ; store
.word 024ah ; 1/7.8
.word 0444h ; 1/5.6
.word 0aa9h ; 1/3.4
d_x .usect "cos_vars",1
d_squrr_x .usect "cos_vars",1
d_cosx .usect "cos_vars",1
C_7FFF .usect "cos_vars",1
K_THETA .set 6487h ; pi/4
K_7FFF .set 7FFFh

.cos_start:
STM #d_coff, AR3 ; c1=1/56, c2=1/30, c3=1/12
STM #d_x, AR2 ; input theta
STM #C_7FFF, AR4 ; A1, A2, A3, A4

.cos_prog:
LD #d_x, DP
ST #K_THETA, d_x ; input theta
ST #K_7FFF, C_7FFF
SQR *AR2+, A ; let x^2 = P
ST A, *AR2 ; AR2 — > x^2
|| LD *AR4, B ;
MASR *AR2+, *AR3+, B, A ; (1–x^2)/72
MPYA A ; 1–x^2(1–x^2)/72
STH A,*AR2
MASR *AR2–, *AR3+, B, A ; A = 1–x^2/42(1–x^2/72)
MPYA A ; 1–x^2(1–x^2/72)/2 ; T = x^2
STH A, *AR2
MASR *AR2–, *AR3+, B, A ; A = 1–x^2/20(1–x^2/42(1–x^2/72))
SFTA A, -1, A ; -1/2
NEG A
MPYA *AR2+ ; B = A(32–16)*x^2
RET
ADD *AR4, 16, B
ST B, *AR2 ; cos(theta)
.end

.mmregs
.ref cos_prog, cos_start

d_cos_delay1 .usect "cos_vars",1
d_cos_delay2 .usect "cos_vars",1
d_theta .usect "cos_vars",1
Example 6–3. Generation of a Cosine Wave (Continued)

K_cos_delay_1 .set 06ed9h ; cos(-pi/6)
K_cos_delay_2 .set 4000h ; cos(-2*pi/6);
K_2 .set 2h ; circular buffer size
K_256 .set 256 ; counter
K_theta .set 4303h ; sin(pi/2–pi/6)= cos(pi/6)

.start:
LD #d_cos_delay1,DP
CALL cos_start
CALL cos_prog ; calculate cos(theta)
STM #d_cos_delay1,AR3
RPTZ A,#3h
STL A,*AR3+
STM #d_cos_delay1,AR3
ST #K_cos_delay_1,*AR3+
ST #K_cos_delay_2,*AR3
STM #d_cos_delay1,AR3 ; output values
ST #K_theta,d_theta
STM #1,AR0
STM #K_2,BK
STM #K_256-1,BRC

.cos_generate:
RPTB end_of_cose
MPY *AR2,*AR3+0%,A ; cos(theta)*cos((n-1)theta)
SUB *AR3,15,A ; 1/2*cos((n-2)theta)
SFTA A,1,A ; cos(n*theta)
STH A,*AR3 ; store
PORTW *AR3,56h ; write to a port

.end
6.3 Square Roots

Example 6–4 uses a 6-term Taylor series expansion to approximate the square root of a single-precision 32-bit number. A normalized, 32-bit, left-justified number is passed to the square root function. The output is stored in the upper half of the accumulator, and the EXP and NORM instructions normalize the input value. The EXP instruction computes an exponent value in a single cycle and stores the result in T, allowing the NORM instruction to normalize the number in a single cycle. If the exponent is an odd power, the mantissa is (multiplied by 1 divided by the square root of 2) to compensate after finding the square root of the 32-bit number. The exponent value is negated to denormalize the number.

\[ y^{0.5} = (1 + x)^{0.5} \]

where:

\[ x = y - 1 \]

\[ = 1 + \frac{x}{2} - \frac{x^2}{8} + \frac{x^3}{16} - \frac{5x^4}{128} + \frac{7x^5}{256} \]

\[ = 1 + \frac{x}{2} - 0.5 \left( \frac{x}{2} \right)^2 + 0.5 \left( \frac{x}{2} \right)^3 - 0.625 \left( \frac{x}{2} \right)^4 + 0.875 \left( \frac{x}{2} \right)^5 \]

where:

\[ 0.5 \leq x < 1 \]

Example 6–4. Square Root Computation

*****************************************************************************
* Six term Taylor Series is used here to compute the square root of a number
* \( y^{0.5} = (1+ x)^{0.5} \) where \( x = y - 1 \)
* \( = 1 + \frac{x}{2} - 0.5 \left( \frac{x}{2} \right)^2 + 0.5 \left( \frac{x}{2} \right)^3 - 0.625 \left( \frac{x}{2} \right)^4 + 0.875 \left( \frac{x}{2} \right)^5 \)
* \( 0.5 \leq x < 1 \)
******************************************************************************

.mmregs
.sect "squr_var"
.d_part_prod .word 0
.d_part_shift .word 0
C_8000 .word 0
C_sqrt_one_half .word 0
.d_625 .word 0
.d_875 .word 0
.tmp_rg1 .word 0
K_input .set 800h ; input # = 0.0625
K_8000 .set 8000h ; -1 or round off bit
K_4000 .set 4000h ; 0.5 coeff
Example 6–4. Square Root Computation (Continued)

K_SQRT_HALF .set 5a82h ; 1/sqrt2
K_625 .set -20480 ; coeff 0.625
K_875 .set 28672 ; coeff 0.875
.text

sqroot:
LD #d_part_prod,DP
ST #K_8000,C_8000
ST #K_input,d_part_prod
ST #K_SQRT_HALF,C_sqrt_one_half
ST #K_875,d_875
ST #K_625,d_625
LD d_part_prod,16,A ; load the #
EXP A
nop ; dead cycle
NORM A
ADDs C_8000,A ; round off bit
LDM T,B
SFTA B,–1,B ; check for odd or even power
BCD res_even,NC
NE B ; negate the power
STL B,d_part_shift ; this shift is used to denormalize the #
LD d_part_prod,16,B ; load the normalized input #
CALLD sq_root ; square root program
ABS B
NOP ; cycle for delayed slot
LD B,A ;
BD res_common
SUB B,B ; zero B
MACAR C_sqrt_one_half,B ; square root of 1/2
res_even
LD d_part_prod,16,B
CALLD sq_root
ABS B
NOP ; cycle for the delayed slot
res_common
LD d_part_shift,T ; right shift value
RETD
STH B,d_part_prod
LD d_part_prod,TS,A ; denormalize the #
sq_root:
SFTA B,–1,B ; x/2 = y-1/2
SUB #K_4000,16,B,B
STH B,tmp_rgl ; tmp_rgl = x/2
SUB #K_8000,16,B ; B = 1+x/2
SQRU tmp_rgl,A ; A (x/2)^2, T = x/2
NEG A ; A = –A
ADD A,–1,B ; B = 1+x/2-.5(x/2)^2
Example 6–4. Square Root Computation (Continued)

SQR A,A ; A = (x/2)^4
MACA d_625,B ; 0.625*A+B ; T = 0.625
LD tmp_rgl,T ; T = x/2
MPYA A ; (x/2)^4*x/2
MACA d_875,B ; 0.875*A+B
SQR tmp_rgl,A ; x/2^2; T = x/2
MPYA A ; A = x/2*x/2^2
RETD
ADD A,–1,B
ADDS C_8000,B ; round off bit
.end
6.4 Extended-Precision Arithmetic

Numerical analysis, floating-point computations, and other operations may require arithmetic operations with more than 32 bits of precision. Since the '54x devices are 16/32-bit fixed-point processors, software is required for arithmetic operations with extended precision. These arithmetic functions are performed in parts, similar to the way in which longhand arithmetic is done.

The '54x has several features that help make extended-precision calculations more efficient. One of the features is the carry bit, which is affected by most arithmetic ALU instructions, as well as the rotate and shift operations. The carry bit can also be explicitly modified by loading ST0 and by instructions that set or reset status register bits. For proper operation, the overflow mode bit should be reset (OVM = 0) to prevent the accumulator from being loaded with a saturation value.

The two '54x internal data buses, CB and DB, allow some instructions to handle 32-bit operands in a single cycle. The long-word load and double-precision add/subtract instructions use 32-bit operands and can efficiently implement multi-precision arithmetic operations.

The hardware multiplier can multiply signed/unsigned numbers, as well as multiply two signed numbers and two unsigned numbers. This makes 32-bit multiplication efficient.
6.4.1 Addition and Subtraction

The carry bit, C, is set in ST0 if a carry is generated when an accumulator value is added to:

- The other accumulator
- A data-memory operand
- An immediate operand

A carry can also be generated when two data-memory operands are added or when a data-memory operand is added to an immediate operand. If a carry is not generated, the carry bit is cleared.

The ADD instruction with a 16-bit shift is an exception because it only sets the carry bit. This allows the ALU to generate the appropriate carry when adding to the lower or upper half of the accumulator causes a carry.

Figure 6–1 shows several 32-bit additions and their effect on the carry bit.

Figure 6–1. 32-Bit Addition

<table>
<thead>
<tr>
<th>C MSB</th>
<th>LSB</th>
<th>C MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>1 0 0 0 0 0 0 0 0 0 0 0 0 0</td>
<td>1 F F F F F F F F F F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C MSB</td>
<td>LSB</td>
<td>C MSB</td>
<td>LSB</td>
</tr>
<tr>
<td>X 0 0 7 F F F F F F F F ACC</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 0 0 8 0 0 0 0 0 0 0 0 0 0</td>
<td>1 0 0 7 F F F F F F F F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C MSB</td>
<td>LSB</td>
<td>C MSB</td>
<td>LSB</td>
</tr>
<tr>
<td>X F F 8 0 0 0 0 0 0 0 0 0 0 ACC</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 F F 8 0 0 0 0 0 0 0 0 0 0 1</td>
<td>1 F F 7 F F F F F F F F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C MSB</td>
<td>LSB</td>
<td>C MSB</td>
<td>LSB</td>
</tr>
<tr>
<td>X F F F F F F F F F F</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 0 0 8 0 0 0 0 0 0 0 0 0 0</td>
<td>1 0 0 0 0 0 0 0 0 0 0 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C MSB</td>
<td>LSB</td>
<td>C MSB</td>
<td>LSB</td>
</tr>
<tr>
<td>X F F 8 0 0 0 0 0 0 0 0 0 0 ACC</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 F F 8 0 0 0 1 F F F F</td>
<td>1 F F F F F F F F F F</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ADD Smem,16,src

<table>
<thead>
<tr>
<th>C MSB</th>
<th>LSB</th>
<th>C MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 F F 8 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 F F 8 0 0 1 F F F F</td>
<td>1 F F F F F F F F F F</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Example 6–5 adds two 64-bit numbers to obtain a 64-bit result. The partial sum of the 64-bit addition is efficiently performed by the DLD and DADD instructions, which handle 32-bit operands in a single cycle. For the upper half of a partial sum, the ADDC (ADD with carry) instruction uses the carry bit generated in the lower 32-bit partial sum. Each partial sum is stored in two memory locations by the DST (long-word store) instruction.

Example 6–5. 64-Bit Addition

```
; ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
; 64-bit Addition
; ;
;   X3 X2 X1 X0
; +  Y3 Y2 Y1 Y0
; ;-----------
;   W3 W2 W1 W0
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
ADD64: DLD @X1,A ;A = X1 X0
      DADD @Y1,A ;A = X1 X0 + Y1 Y0
      DST A,@W1
      DLD @X3,A ;A = X3 X2
      ADDC @Y2,A ;A = X3 X2 + 00 Y2 + C
      ADD @Y3,16,A ;A = X3 X2 + Y3 Y2 + C
      DST A,@W3
      RET
```

Similar to addition, the carry bit is reset if a borrow is generated when an accumulator value is subtracted from:

- The other accumulator
- A data-memory operand
- An immediate operand

A borrow can also be generated when two data-memory operands are subtracted or when an immediate operand is subtracted from a data-memory operand. If a borrow is not generated, the carry bit is set.

The SUB instruction with a 16-bit shift is an exception because it only resets the carry bit. This allows the ALU to generate the appropriate carry when subtracting from the lower or the upper half of the accumulator causes a borrow.

Figure 6–2 shows several 32-bit subtractions and their effect on the carry bit.
**Figure 6–2. 32-Bit Subtraction**

<table>
<thead>
<tr>
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<th>LSB</th>
<th>C MSB</th>
<th>LSB</th>
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</thead>
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<td>X F F 0 0 0 0 0 0 0 0 ACC</td>
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<td></td>
</tr>
<tr>
<td>-</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 F F F F F F F F F F</td>
<td>0 0 0 0 0 0 0 0 0 0 1</td>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>C MSB</th>
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<th>C MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
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<td>X 0 0 7 F F F F F F F ACC</td>
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<td></td>
</tr>
<tr>
<td>-</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 0 0 7 F F F F F F F E</td>
<td>C F F 8 0 0 0 0 0 0 0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C MSB</th>
<th>LSB</th>
<th>C MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>X F F 8 0 0 0 0 0 0 0 ACC</td>
<td>X F F 8 0 0 0 0 0 0 0 ACC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 F F 7 F F F F F F E</td>
<td>0 F F 8 0 0 0 0 0 0 1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**SUBB**

<table>
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<th>C MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 0 0 0 0 0 0 0 0 ACC</td>
<td>0 F F F F F F F F F F ACC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>0 SUBB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 F F F F F F F F F F</td>
<td>1 F F F F F F F F F E</td>
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</tr>
</tbody>
</table>

**SUB Smem,16,src**

<table>
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<th>LSB</th>
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<tbody>
<tr>
<td>1 F F 8 0 0 0 F F F F ACC</td>
<td>0 F F 8 0 0 0 F F F F ACC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0 0 0 0 0 1 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 0 0 7 F F F F F F F</td>
<td>0 F F 8 0 0 1 F F F F</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Example 6–6 subtracts two 64-bit numbers on the ’54x. The partial remainder of the 64-bit subtraction is efficiently performed by the DLD (long word load) and the DSUB (double precision subtract) instructions, which handle 32-bit operands in a single cycle. For the upper half of a partial remainder, the SUBB (SUB with borrow) instruction uses the borrow bit generated in the lower 32-bit partial remainder. Each partial remainder is stored in two consecutive memory locations by a DST.

Example 6–6. 64-Bit Subtraction

```
;---------------------------------------------------------------;
; 64 bit Subtraction                                           |
;---------------------------------------------------------------;
;       X3 X2 X1 X0                                           |
;     – Y3 Y2 Y1 Y0                                           |
;     –––––––––––                                             |
;       W3 W2 W1 W0                                           |
;---------------------------------------------------------------;
DLD @X3,A  ;A = X3 X2
SUBB @Y2,A  ;A = X3 X2 – 00 Y2 – (inv C)
DST A,@W1
SUB @Y3,16,A  ;A = X3 X2 – Y3 Y2 – (inv C)
DST A,@W3
RET
```

6.4.2 Multiplication

The MPYU (unsigned multiply) and MACSU (signed/unsigned multiply and accumulate) instructions can also handle extended-precision calculations.

Figure 6–3 shows how two 32-bit numbers obtain a 64-bit product. The MPYU instruction multiplies two unsigned 16-bit numbers and places the 32-bit result in one of the accumulators in a single cycle. The MACSU instruction multiplies a signed 16-bit number by an unsigned 16-bit number and accumulates the result in a single cycle. Efficiency is gained by generating partial products of the 16-bit portions of a 32-bit (or larger) value instead of having to split the value into 15-bit (or smaller) parts.
The program in Example 6–7 shows that a multiply of two 32-bit integer numbers requires one multiply, three multiply/accumulates, and two shifts. The product is a 64-bit integer number. Note in particular, the use of MACSU, MPYU and LD instructions. The LD instruction can perform a right-shift in the accumulator by 16 bits in a single cycle.

Example 6–8 performs fractional multiplication. The operands are in Q31 format, while the product is in Q30 format.
Example 6–7. 32-Bit Integer Multiplication

; This routine multiplies two 32-bit signed integers resulting in a 64-bit product. The operands are fetched from data memory and the result is written back to data memory.
; Data Storage:
; X1,X0 32-bit operand
; Y1,Y0 32-bit operand
; W3,W2,W1,W0 64-bit product
; Entry Conditions:
; SXM = 1, OVM = 0

STM #X0,AR2 ; AR2 = X0 addr
STM #Y0,AR3 ; AR3 = Y0 addr
LD *AR2,T ; T = X0
MPYU *AR3+,A ; A = X0*Y0
STL A,W0 ; save W0
LD A,-16,A ; A = A >> 16
MACSU *AR2+,*AR3–,A ; A = X0*Y0>>16 + X0*Y1
MACSU *AR3+,*AR2,A ; A = X0*Y0>>16 + X0*Y1 + X1*Y0
STL A,W1 ; save W1
LD A,-16,A ; A = A >> 16
MAC *AR2,*AR3,A ; A = (X0*Y1 + X1*Y0)>>16 + X1*Y1
STL A,W2 ; save W2
STH A,W3 ; save W3

Example 6–8. 32-Bit Fractional Multiplication

; This routine multiplies two Q31 signed integers resulting in a Q30 product. The operands are fetched from data memory and the result is written back to data memory.
; Data Storage:
; X1,X0 Q31 operand
; Y1,Y0 Q31 operand
; W1,W0 Q30 product
; Entry Conditions:
; SXM = 1, OVM = 0

STM #X0,AR2 ; AR2 = X0 addr
STM #Y1,AR3 ; AR3 = Y1 addr
LD #0,A ; clear A
MACSU *AR2+,*AR3–,A ; A = X0*Y1
MACSU *AR3+,*AR2,A ; A = X0*Y1 + X1*Y0
LD A,-16,A ; A = A >> 16
MAC *AR2,*AR3,A ; A = A + X1*Y1
STL A,W0 ; save lower product
STH A,W1 ; save upper product
6.5 Floating-Point Arithmetic

In fixed-point arithmetic, the binary point that separates the integer from the fractional part of the number is fixed at a certain location. For example, if a 32-bit number places the binary point after the most significant bit (which is also the sign bit), only fractional numbers (numbers with absolute values less than 1), can be represented. The fixed-point system, although simple to implement in hardware, imposes limitations in the dynamic range of the represented number. You can avoid this difficulty by using floating-point numbers.

A floating-point number consists of a mantissa, m, multiplied by a base, b, raised to an exponent, e, as follows:

\[ m \times b^e \]

To implement floating-point arithmetic on the '54x, operands must be converted to fixed-point numbers and then back to floating-point numbers. Fixed-point values are converted to floating-point values by normalizing the input data.

Floating-point numbers are generally represented by mantissa and exponent values. To multiply two numbers, add their mantissas, multiply the exponents, and normalize the resulting mantissa. For floating-point addition, shift the mantissa so that the exponents of the two operands match. Left-shift the lower-power operand by the difference between the two exponents. Add the exponents and normalize the result.

Figure 6–4 illustrates the IEEE standard format to represent floating-point numbers. This format uses sign-magnitude notation for the mantissa, and the exponent is biased by 127. In a 32-bit word representing a floating-point number, the first bit is the sign bit, represented by s. The next eight bits correspond to the exponent, which is expressed in an offset-by-127 format (the actual exponent is \( e - 127 \)). The following 23 bits represent the absolute value of the mantissa, with the most significant 1 implied. The binary point is placed after this most significant 1. The mantissa, then, has 24 bits.
The values of the numbers represented in the IEEE floating-point format are as follows:

\((-1)^s \times 2^{e-127} \times (01.f)\) If \(0 < e < 255\)

Special Cases:

\((-1)^s \times 0.0\) If \(e = 0\), and \(f = 0\) (zero)

\((-1)^s \times 2^{-126} \times (0.f)\) If \(e = 0\) and \(f \neq 0\) (denormalized)

\((-1)^s \times \text{infinity}\) If \(e = 255\) and \(f = 0\) (infinity)

NaN (not a number) If \(e = 255\) and \(f \neq 0\)

Example 6–9 through Example 6–11 illustrate how the '54x performs floating-point addition, multiplication, and division.

**Example 6–9. Add Two Floating-Point Numbers**

```
;******************************************************************************
; FLOAT_ADD – add two floating point numbers
; Copyright (c) 1993–1994 Texas Instruments Incorporated
; NOTE: The ordering of the locals are placed to take advantage of long word loads and stores which require the hi and low words to be at certain addresses.
; Any future modifications which involve the stack must take this quirk into account
;******************************************************************************
;Operand 1 (OP1) and Operand (OP2) are each packed into sign, exponent, and the words of mantissa. If either exponent is zero special case processing is initiated. In the general case, the exponents are compared and the mantissa of the lower exponent is renormalized according to the number with the larger exponent. The mantissas are also converted to a two’s complement format to perform the actual addition. The result of the addition is then renormalized with the corresponding adjustment in the exponent. The resulting mantissa is converted back to its original sign-magnitude format and the result is repacked into the floating point representation.
;******************************************************************************

; resource utilization: B accumulator, T-register
; status bits affected: TC, C, SXM, OVM,
; entry requirements : CPL bit set
```
Example 6–9. Add Two Floating-Point Numbers (Continued)

; Floating Point Format – Single Precision

; Single precision floating point format is a 32 bit format consisting of a 1 bit sign field, an 8 bit exponent field, and a 23 bit mantissa field. The fields are defined as follows

; Sign <S>: 0 = positive values; 1 = negative value
; Exponent <E7–E0>: offset binary format
; 00 = special cases (i.e. zero)
; 01 = exponent value + 127 = –126
; FE = exponent value + 127 = +127
; FF = special cases (not implemented)
; Mantissa <M22–M0>: fractional magnitude format with implied 1
; Range: –1.9999998 e+127 to –1.0000000 e–126
; +1.0000000 e–126 to +1.9999998 e+127
; (where e represents 2 to the power of)
; –3.4028236 e+38 to –1.1754944 e–38
; +1.1754944 e–38 to +3.4028236 e+38
; (where e represents 10 to the power of)

res_hm .usect "flt_add",1 ; result high mantissa
res_lm .usect "flt_add",1 ; result low mantissa
res_exp .usect "flt_add",1 ; result exponent
res_sign .usect "flt_add",1 ; result sign
op2_hm .usect "flt_add",1 ; OP2 high mantissa
op2_lm .usect "flt_add",1 ; OP2 low mantissa
op2_se .usect "flt_add",1 ; OP2 sign and exponent
op1_se .usect "flt_add",1 ; OP1 sign and exponent
op1_hm .usect "flt_add",1 ; OP1 high mantissa
op1_lm .usect "flt_add",1 ; OP1 low mantissa
op1_msw .usect "flt_add",1 ; OP1 packed high word
op1_lsw .usect "flt_add",1 ; OP1 packed low word
op2_msw .usect "flt_add",1 ; OP2 packed high word
op2_lsw .usect "flt_add",1 ; OP2 packed low word
err_no .usect "flt_add",1 ;

.mmregs

******************************************************************************

* Floating point number 12.0 can be represented as 1100 = 1.100 x 23 => sign =0
* biased exponent = 127+3 = 130
* 130 = 10000010
* Mantissa 10000000000000000000000 = 4140h
******************************************************************************
Example 6–9. Add Two Floating-Point Numbers (Continued)

K_OP1_HIGH .set 4140h ; floating point number 12.0
K_OP1_LOW .set 0000h
K_OP2_HIGH .set 4140h ; floating point number 12.0
K_OP2_LOW .set 0000h

.mreg
.text
start_flt:
RSBX C16
LD #res_hm,DP ; initialize the page pointer
LD #K_OP2_HIGH,A ; load floating #2 – 12
STL A,op2_msw
LD #K_OP2_LOW,A
STL A,op2_lsw
LD #K_OP1_HIGH,A ; load floating #1 – 12
STL A,op1_msw
LD #K_OP1_LOW,A
STL A,op1_lsw

*;*****************************************************************************
*; CONVERSION OF FLOATING POINT FORMAT – UNPACK
*; Test OP1 for special case treatment of zero.
*; Split the MSW of OP1 in the accumulator.
*; Save the exponent on the stack [xxxx xxxx EEEE EEEE].
*; Add the implied one to the mantissa value.
*; Store the mantissa as a signed value
*;*****************************************************************************
DLD op1_msw,A ; load the OP1 high word
SFTA A,8 ; shift right by 8
SFTA A,–8
BC op1_zero,A EQ ; If op1 is 0, jump to special case
LD A,0 ; Copy OP1 to acc B
RSBX SXM ; Reset for right shifts used for masking
SFTL A,1 ; Remove sign bit
STH A,–8,op1_se ; Store exponent to stack
SFTL A,8 ; Remove exponent
SFTL A,–9
ADD #080h,16,A ; Add implied 1 to mantissa
XC 1,BLT ; Negate OP1 mantissa for negative values
NEG A
SSBX SXM ; Make sure OP2 is sign-extended
DST A,op1_hm ; Store mantissa

*;*****************************************************************************
*; CONVERSION OF FLOATING POINT FORMAT – UNPACK
*; Test OP1 for special case treatment of zero.
*; Split the MSW of OP1 in the accumulator.
*; Save the exponent on the stack [xxxx xxxx EEEE EEEE].
*; Add the implied one to the mantissa value.
*; Store the mantissa as a signed value
*;*****************************************************************************

PRELIMINARY
Example 6–9. Add Two Floating-Point Numbers (Continued)

```
DLD op2_msw,A ; Load acc with op2
BC op2_zero,AEQ ; If op2 is 0, jump to special case
LD A,B ; Copy OP2 to acc B
SFTL A,1 ; Remove sign bit
STH A,-8,op2_se ; Store exponent to stack
RSBX SXM ; Reset for right shifts used for masking
SFTL A,8 ; Remove exponent
SFTL A,-9
ADD #080h,16,A ; Add implied 1 to mantissa
XC 1,HLT ; Negate OP2 mantissa for negative values
NEG A
SSBX SXM ; Set sign extension mode
DST A,op2_hm ; Store mantissa

;*****************************************************************************
; EXPONENT COMPARISON
; Compare exponents of OP1 and OP2 by subtracting: exp OP2 - exp OP1
; Branch to one of three blocks of processing
; Case 1: exp OP1 is less than exp OP2
; Case 2: exp OP1 is equal to exp OP2
; Case 3: exp OP1 is greater than exp OP2
;*****************************************************************************
LD op1_se,A ; Load OP1 exponent
LD op2_se,B ; Load OP2 exponent
SUB A,B ; Exp OP2 - exp OP1 --> B
BC op1_gt_op2,BLT ; Process OP1 > OP2
BC op2_gt_op1,BGT ; Process OP2 > OP2

;*****************************************************************************
; exp OP1 = exp OP2
; Mantissas of OP1 and OP2 are normalized identically.
; Add mantissas: mant OP1 + mant OP2
; If result is zero, special case processing must be executed.
; Load exponent for possible adjustment during normalization of result
;*****************************************************************************
a_eq_b
DLD op1_hm,A ; Load OP1 mantissa
DADD op2_hm,A ; Add OP2 mantissa
BC res_zero,AEQ ; If result is zero, process special case
LD op1_se,B ; Load exponent in preparation for normalizing

;*****************************************************************************
; normalize THE RESULT
; Take the absolute value of the result.
; Set up to normalize the result.
; The MSB may be in any of bits 24 through 0.
; Left shift by six bits; bit 24 moves to bit 30, etc.
; Normalize resulting mantissa with exponent adjustment.
;*****************************************************************************
```
Example 6–9. Add Two Floating-Point Numbers (Continued)

```
normalize
    STH A,res_sign ; Save signed mantissa on stack
    ABS A ; Create magnitude value of mantissa
    SFTL A,6 ; Pre-normalize adjustment of mantissa
    EXP A ; Get amount to adjust exp for normalization
    NOP
    NORM A ; Normalize the result
    ST T,res_exp ; Store exp adjustment value
    ADD #1,B ; Increment exp to account for implied carry
    SUB res_exp,B ; Adjust exponent to account for normalization

*;*****************************************************************************
*;       POST–NORMALIZATION ADJUSTMENT AND STORAGE
*; Test result for underflow and overflow.
*; Right shift mantissa by 7 bits.
*; Mask implied 1
*; Store mantissa on stack.
*;*****************************************************************************
*;normalized
    STL B,res_exp ; Save result exponent on stack
    BC underflow,BLEQ ; process underflow if occurs
    SUB #0FFh,B ; adjust to check for overflow
    BC overflow,BGEQ ; process overflow if occurs
    SFTL A,-7 ; Shift right to place mantissa for splitting
    STL A,res_lm ; Store low mantissa
    AND #07F00h,8,A ; Eliminate implied one
    STH A,res_hm ; Save result mantissa on stack**

*;*****************************************************************************
*;*****************************************************************************
*;       CONVERSION OF FLOATING POINT FORMAT – PACK
*; Load sign.
*; Pack exponent.
*; Pack mantissa.
*;*****************************************************************************
*;
    LD res_sign,9,A ; 0000 000S 0000 0000 0000 0000 0000 0000
    AND #100h,16,A
    ADD res_exp,16,A ; 0000 000S EEEE EEEE 0000 0000 0000 0000
    SFTL A,7 ; SEE EEEE EEEE 0000 0000 0000 0000 0000
    DADD res_hm,A ; SEE EEEE EMMM MMMM MMMM MMMM MMMM

*;*****************************************************************************
*;       CONTEXT RESTORE
*; Pop local floating point variables.
*; Restore contents of B accumulator, T Register
*;*****************************************************************************
*;
    return_value
    NOP
    NOP
    RET
```
Example 6–9. Add Two Floating-Point Numbers (Continued)

;*****************************************************************************;
; exp OP1 > exp OP2
; Test if the difference of the exponents is larger than 24 (precision of the mantissa)
; Return OP1 as the result if OP2 is too small.
; Mantissa of OP2 must be right shifted to match normalization of OP1
; Add mantissas: mant OP1 + mant op2
;*****************************************************************************;

op1_gt_op2
ABS B ; If exp OP1 >= exp OP2 + 24 then return OP1
SUB #24,B
BC return_op1,BGEQ
ADD #23,B ; Restore exponent difference value
STL B,res_sign ; Store exponent difference to be used as RPC
DLD op2_hm,A ; Load OP2 mantissa
RPT res_sign ; Normalize OP2 to match OP1
SFTA A,–1
BD normalize ; Delayed branch to normalize result
LD op1_se,B ; Load exponent value to prep for normalization
DADD op1_hm,A ; Add OP1 to OP2

;*****************************************************************************;
; exp OP2 > exp OP1
; Test if the difference of the exponents is larger than 24 (precision of the mantissa).
; Return OP2 as the result if OP1 is too small.
; Mantissa of OP1 must be right shifted to match normalization of OP2.
; Add mantissas: mant OP1 + mant OP2
;*****************************************************************************;

op2_gt_op1
SU B #24,B ; If exp OP2 >= exp OP1 + 24 then return OP2
BC return_op2,BGEQ
ADD #23,B ; Restore exponent difference value
STL B,res_sign ; Store exponent difference to be used as RPC
DLD op1_hm,A ; Load OP1 mantissa
RPT res_sign ; Normalize OP1 to match OP2
SFTA A,–1 ; BD normalize ; Delayed branch to normalize result
LD op2_se,B ; Load exponent value to prep for normalization
DADD op2_hm,A ; Add OP2 to OP1

;*****************************************************************************;
; OP1 << OP2 or OP1 = 0
;*****************************************************************************;

return_op2
op1_zero
BD return_value
DLD op2_msw,A ; Put OP2 as result into A
NOP

;*****************************************************************************;
; OP1 << OP2 or OP1 = 0
;*****************************************************************************;
Example 6–9. Add Two Floating-Point Numbers (Continued)

```assembly
op2_zero
    return_op1
        DLD op1_hm,A ; Load signed high mantissa of OP1
        BC op1_pos,AGT ; If mantissa is negative . . .
        NEG A ; Negate it to make it a positive value
        ADDM #100h,op1_se ; Place the sign value back into op1_se

    op1_pos
        SUB #80h,16,A ; Eliminate implied one from mantissa
        LD op1_se,16,B ; Put OP1 back together in acc A as a result
        BD return_value
        SFTL B,7
        ADD B,A

    ;******************************************************************************
    ;       overflow PROCESSING
    ;       Push errno onto stack.
    ;       Load accumulator with return value.
    ;******************************************************************************
    ;
    overflow
        ST #2,err_no ; Load error no
        LD res_sign,16,A ; Pack sign of result
        AND #8000,16,A ; Mask to get sign
        OR #0FFFFh,A ; Result low mantissa = 0FFFFh
        BD return_value ; Branch delayed
        ADD #07F7Fh,16,A ; Result exponent = 0FEh
                       ; Result high mant = 07Fh

    ;******************************************************************************
    ;       underflow PROCESSING
    ;       Push errno onto stack.
    ;       Load accumulator with return value.
    ;******************************************************************************
    ;
    underflow
        ST #1,err_no ; Load error no
        RET

res_zero
    BD return_value ; Branch delayed
    SUB A,A ; For underflow result = 0
    NOP```

Example 6–10. Multiply Two Floating-Point Numbers

;*****************************************************************************
;  Float_MUL – multiply two floating point numbers
;  Copyright (c) 1993–1994 Texas Instruments Incorporated
;*****************************************************************************

;This routine multiplies two floating point numbers. OP1 and OP2 are each unpacked
;into sign, exponent, and two words of mantissa. If either exponent is zero
;special case processing is initiated. The exponents are summed. If the result is
;less than zero underflow has occurred. If the result is zero, underflow may have
;occurred. If the result is equal to 254 overflow may have occurred. If the result
;is greater than 254 overflow has occurred. Underflow processing returns a value
;of zero. Overflow processing returns the largest magnitude value along with the
;appropriate sign. If no special cases are detected, a 24x24-bit multiply is
;executed. The result of the exclusive OR of the sign bits, the sum of the
;exponents and the 24 bit truncated mantissa are packed and returned

;*****************************************************************************

; Floating Point Format – Single Precision

<table>
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<th>29</th>
<th>28</th>
<th>27</th>
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<tbody>
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<td>M13</td>
<td>M12</td>
<td>M11</td>
<td>M10</td>
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<td>M7</td>
<td>M6</td>
<td>M5</td>
<td>M4</td>
<td>M3</td>
<td>M2</td>
<td>M1</td>
<td>M0</td>
</tr>
</tbody>
</table>

; Single precision floating point format is a 32 bit format consisting of a
;1 bit sign field, an 8 bit exponent field, and a 23 bit mantissa field. The
;fields are defined as follows.

Sign <S> : 0 = positive values; 1 = negative values
Exponent <E7–E0> : offset binary format
  00 = special cases (i.e. zero)
  01 = exponent value + 127 = –126
  FE = exponent value + 127 = +127
  FF = special cases (not implemented)
Mantissa <M22–M0> : fractional magnitude format with implied 1

Range : –1.9999998 e+127 to –1.0000000 e–126
        +1.0000000 e–126 to +1.9999998 e+127
        (where e represents 2 to the power of)
        –3.4028236 e+38 to –1.1754944 e–38
        +1.1754944 e–38 to +3.4028236 e+38
        (where e represents 10 to the power of)

;*****************************************************************************
Example 6–10. Multiply Two Floating-Point Numbers (Continued)

res_hm .usect "flt_add",1 ;result high mantissa
res_lm .usect "flt_add",1 ;result low mantissa
res_exp .usect "flt_add",1 ;result exponent
res_sign .usect "flt_add",1 ; result sign
op2_hm .usect "flt_add",1 ; OP2 high mantissa
op2_lm .usect "flt_add",1 ; OP2 low mantissa
op2_se .usect "flt_add",1 ; OP2 sign and exponent
op1_se .usect "flt_add",1 ; OP1 sign and exponent
op1_hm .usect "flt_add",1 ; OP1 high mantissa
op1_lm .usect "flt_add",1 ; OP1 low mantissa
op1_msw .usect "flt_add",1 ; OP1 packed high word
op1_lsw .usect "flt_add",1 ; OP1 packed low word
op2_msw .usect "flt_add",1 ; OP2 packed high word
op2_lsw .usect "flt_add",1 ; OP2 packed low word
err_no .usect "flt_add",1 ;

*******************************************************************
* Floating point number 12.0 can be represented as 1100 = 1.100 x 2^3 => sign =0
* biased exponent = 127+3 = 130
* 130 = 10000010
* Mantissa 100000000000000000000000
* Thus 12.0 can be represented as 0100000101000000000000000000000000= 4140h
*******************************************************************

K_OP1_HIGH .set 4140h ; floating point number 12.0
K_OP1_LOW .set 0000h
K_OP2_HIGH .set 4140h ; floating point number 12.0
K_OP2_LOW .set 0000h

.start_flt:
RSBX C16 ; Insure long adds for later
LD #res_hm,DP ; initialize the page pointer
LD #K_OP2_HIGH,A ; load floating #2 – 12
STL A,op2_msw
LD #K_OP2_LOW,A
STL A,op2_lsw
LD #K_OP1_HIGH,A ; load floating #1 – 12
STL A,op1_msw
LD #K_OP1_LOW,A
STL A,op1_lsw

;*****************************************************************************
*;       CONVERSION OF FLOATING POINT FORMAT – UNPACK
*;  Test OP1 for special case treatment of zero.
*;  Split the MSW of A in the accumulator.
*;  Save the sign and exponent on the stack [xxxx xxxxS EEEE EEEE].
*;  Add the implied one to the mantissa value
*;  Store entire mantissa with a long word store
*;*****************************************************************************
DLD op1_msw,A ; OP1
SFTA A,8
SFTA A,-8
BC op_zero,AEQ ; if op1 is 0, jump to special case
Example 6–10. Multiply Two Floating-Point Numbers (Continued)

```
STH A,–7,op1_se ; store sign AND exponent to stack
STL A,op1_lm ; store low mantissa
AND #07Fh,16,A ; mask off sign & exp to get high mantissa
ADD #080h,16,A ; ADD implied 1 to mantissa
STH A,op1_hm ; store mantissa to stack

;*****************************************************************************
;       CONVERSION OF FLOATING POINT FORMAT – UNPACK
;  Test OP2 for special case treatment of zero.
;  Split the MSW of A in the accumulator.
;  Save the sign and exponent on the stack [xxxx xxxxS EEEE EEEE].
;  Add the implied one to the mantissa value.
;  Store entire mantissa with a long word store
;*****************************************************************************
DLD op2_msw,A ; load acc a with OP2
BC op_zero,AEQ ; if OP2 is 0, jump to special case
STH A,–7,op2_se ; store sign and exponent to stack
STL A,op2_lm ; store low mantissa
AND #07Fh,16,A ; mask off sign & exp to get high mantissa
ADD #080h,16,A ; add implied 1 to mantissa
STH A,op2_hm ; store mantissa to stack

;*****************************************************************************
;       SIGN EVALUATION
;  Exclusive OR sign bits of OP1 and OP2 to determine sign of result.
;*****************************************************************************
LD op1_se,A ; load sign and exp of op1 to acc
XOR op2_se,A ; xor with op2 to get sign of result
AND #00100h,A ; mask to get sign
STL A,res_sign ; save sign of result to stack

;*****************************************************************************
;       EXPONENT SUMMATION
;  Sum the exponents of OP1 and OP2 to determine the result exponent. Since
;  the exponents are biased (excess 127) the summation must be decremented
;  by the bias value to avoid double biasing the result
;  Branch to one of three blocks of processing
;  Case 1: exp OP1 + exp OP2 results in underflow (exp < 0)
;  Case 2: exp OP1 + exp OP2 results in overflow (exp >= 0FFh)
;  Case 3: exp OP1 + exp OP2 results are in range (exp >= 0 & exp < 0FFh)
;  NOTE: Cases when result exp = 0 may result in underflow unless there
;        is a carry in the result that increments the exponent to 1.
;  Cases when result exp = 0FEh may result in overflow if there
;        is a carry in the result that increments the exponent to 0FFh.
;*****************************************************************************
LD op1_se,A ; Load OP1 sign and exponent
AND #00FFh,A ; Mask OP1 exponent
LD op2_se,B ; Load OP2 sign and exponent
AND #0FFh,B ; Mask OP2 exponent
SUB #07Fh,B ; Subtract offset (avoid double bias)
ADD B,A ; Add OP1 exponent
STL A,res_exp ; Save result exponent on stack
BC underflow,ALT ; branch to underflow handler if exp < 0
SUB #0FFh,A ; test for overflow
BC overflow,AGT ; branch to overflow is exp > 127
```

Example 6–10. Multiply Two Floating-Point Numbers (Continued)

*MULTIPLICATION

*Multiplication is implemented by parts. Mantissa for OP1 is three bytes
*identified as Q, R, and S
*(Q represents OP1 high mantissa and R and S represent the two bytes of OP1 low
*mantissa). Mantissa for
*OP2 is also 3 bytes identified as X, Y, and Z (X represents OP2 high mant and
*y and Z represent the two bytes
*of OP2 low mantissa). Then
*
\[
\begin{array}{c}
0 \quad Q \quad R \quad S \\
0 \quad X \quad Y \quad Z
\end{array}
\]

* \[RS*YZ\] \(<--\text{save only upper 16 bits of result}\)
* \[RS*0X\]
* \[0Q*YZ\]
* \[0Q*0X\] \(<--\text{upper 16 bits are always zero}\)
*
\[
\begin{array}{c}
\text{result} \\
\text{result is always in the internal 32 bits}
\end{array}
\]

*(which ends up in the accumulator) of the possible 64 bit product

;*****************************************************************************
LD op1_lm,T ; load low mant of op1 to T register
MPYU op2_lm,A ; RS * YZ
MPYU op2_hm,B ; RS * 0X
ADD A,–16,B ; B = (RS * YZ) + (RS * 0X)
LD op1_hm,T ; load high mant of op1 to T register
MPYU op2_lm,A ; A = 0Q * YZ
ADD B,A ; A = (RS * YZ) + (RS * 0X) + (0Q * YZ)
MPYU op2_hm,B ; B = 0Q * 0X
STL B,res_hm ; get lower word of 0Q * 0X
ADD res_hm,16,A ; A = final result
;*****************************************************************************
; POST–NORMALIZATION ADJUSTMENT AND STORAGE
; Set up to adjust the normalized result.
; The MSB may be in bit 31. Test this case and increment the exponent
; and right shift mantissa 1 bit so result is in bits 30 through 7
; Right shift mantissa by 7 bits.
; Store low mantissa on stack.
; Mask implied 1 and store high mantissa on stack.
; Test result for underflow and overflow.
;************************************************************************************
ADD #040h,A ; Add rounding bit
SFTA A,8 ; sign extend result to check if MSB is in 31
SFTA A,–8
RSBX SXM ; turn off sign extension for normalization
LD res_exp,B ; load exponent of result
BC normalized,AGEQ ; check if MSB is in 31
SFTL A,–1 ; Shift result so result is in bits 30:7
ADD #1,B ; increment exponent
STL B,res_exp ; save updated exponent normalized
BC underflow,BLEQ ; check for underflow
SUB #0FFh,B ; adjust to check for overflow
BC overflow,BGEQ ; check for overflow
SFTL A,–7 ; shift to get 23 msb bits of mantissa result
STL A,res_lm ; store low mantissa result
Example 6–10. Multiply Two Floating-Point Numbers (Continued)

```
AND #07F00h, 8, A ; remove implied one
STH A, res_hm ; store the mantissa result

CONVERSION OF FLOATING POINT FORMAT – PACK
Load sign.
Pack exponent.
Pack mantissa.

LD res_sign, 16, A ; 0000 000S 0000 0000 0000 0000 0000 0000
ADD res_exp, 16, A ; 0000 000S EEEE EEEE 0000 0000 0000 0000
SFTL A, 7 ; SEEE EEEE E000 0000 0000 0000 0000 0000
DADD res_hm, A ; SEEE EEEE MMMM MMMM MMMM MMMM MMMM

CONTEXT RESTORE

overflow
ST #2, err_no ; Load error no
LD res_sign, 16, B ; Load sign of result
LD #0FFFFh, A ; Result low mantissa = 0FFFFh
OR B, 7, A ; Add sign bit
BD return_value ; Branch delayed
ADD #07F7Fh, 16, A ; Result exponent = 0FEh
                  ; Result high mant = 07Fh

underflow
ST #1, err_no ; Load error no
BD return_value ; Branch delayed
SUB A, A ; For underflow result = 0
NOP
```
Example 6–11. Divide a Floating-Point Number by Another

;*****************************************************************************
; FLOAT_DIV – divide two floating point numbers
; Copyright (c) 1993–1994 Texas Instruments Incorporated
;*****************************************************************************
;Implementation: OP1 and OP2 are each unpacked into sign, exponent, and two words
;of mantissa. If either exponent is zero special case processing is initiated.
;The difference of the exponents are taken. IF the result is less than zero underflow
;has occurred. If the result is zero, underflow may have occurred. If the result
;is equal to 254 overflow may have occurred. If the result is greater than 254
;overflow has occurred.
; Underflow processing returns a value of zero. Overflow processing returns the
;largest magnitude value along with the appropriate sign. If no special cases are
;detected, a 24x24–bit divide is ;executed. The result of the exclusive OR of the
;sign bits, the difference of the exponents and the 24 bit truncated mantissa are
;packed and returned.
;*****************************************************************************
;*****************************************************************************
;       resource utilization:  B accumulator , T register
;       status bits affected: TC, C, SXM, OVM, C16
;       entry requirements : CPL bit set
;*****************************************************************************

; Floating Point Format – Single Precision

<table>
<thead>
<tr>
<th>31</th>
<th>30</th>
<th>29</th>
<th>28</th>
<th>27</th>
<th>26</th>
<th>25</th>
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<th>23</th>
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<th>21</th>
<th>20</th>
<th>19</th>
<th>18</th>
<th>17</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
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<td>E7</td>
<td>E6</td>
<td>E5</td>
<td>E4</td>
<td>E3</td>
<td>E2</td>
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<td>M21</td>
<td>M20</td>
<td>M19</td>
<td>M18</td>
<td>M17</td>
<td>M16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>15</th>
<th>14</th>
<th>13</th>
<th>12</th>
<th>11</th>
<th>10</th>
<th>9</th>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>M15</td>
<td>M14</td>
<td>M13</td>
<td>M12</td>
<td>M11</td>
<td>M10</td>
<td>M 9</td>
<td>M 8</td>
<td>M 7</td>
<td>M 6</td>
<td>M 5</td>
<td>M 4</td>
<td>M 3</td>
<td>M 2</td>
<td>M 1</td>
<td>M 0</td>
</tr>
</tbody>
</table>

; Single precision floating point format is a 32 bit format consisting of a 1
;bit sign field, an 8 bit exponent *
; field, and a 23 bit mantissa field. The fields are defined as follows
*
*
; Sign <S>: 0 = positive values; 1 = negative values
*
; Exponent <E7-E0>: offset binary format
; 00 = special cases (i.e. zero)
; 01 = exponent value + 127 = –126
; FE = exponent value + 127 = +127
; FF = special cases (not implemented)
; Mantissa <M22–M0>: fractional magnitude format with implied 1
; 1.M22M21...M1M0
*
; Range: –1.9999998 e+127 to –1.0000000 e–126
; +1.0000000 e–126 to +1.9999998 e+127
; (where e represents 2 to the power of)
; –3.4028236 e+38 to –1.1754944 e–38
; +1.1754944 e–38 to +3.4028236 e+
; (where e represents 10 to the power of)

;*****************************************************************************

Arithmetic and Logical Operations 6-37
Example 6–11. Divide a Floating-Point Number by Another (Continued)

res_hm .usect "flt_div",1
res_lm .usect "flt_div",1
res_exp .usect "flt_div",1
res_sign .usect "flt_div",1
op2_hm .usect "flt_div",1
op2_lm .usect "flt_div",1
op2_se .usect "flt_div",1
op1_se .usect "flt_div",1
op1_hm .usect "flt_div",1
op1_lm .usect "flt_div",1
op1_msw .usect "flt_div",1
op1_lsw .usect "flt_div",1
op2_msw .usect "flt_div",1
op2_lsw .usect "flt_div",1
err_no .usect "flt_div",1

.mmregs
*
*
K_divisor_high .set 4140h
K_divisor_low .set 0000h
K_dividend_high .set 4140h
K_dividend_low .set 0000h

.sect "vectors"
B float_div
NOP
NOP
.text
float_div:
LD #res_hm,DP ; initialize the page pointer
LD #K_divisor_high,A ; load floating #2 – 12
STL A,op2_msw
LD #K_divisor_low,A
STL A,op2_lsw
LD #K_dividend_high,A ; load floating #1 – 12
STL A,op1_msw
LD #K_dividend_low,A
STL A,op1_lsw
**************************************************************************
RSBX C16 ; Insure long adds for later
**************************************************************************
;
**************************************************************************
;
**************************************************************************
;
**************************************************************************
;
**************************************************************************
;
**************************************************************************
;
**************************************************************************
;
**************************************************************************
;
**************************************************************************
;
**************************************************************************

6-38
Example 6–11. Divide a Floating-Point Number by Another (Continued)

STL A,op1_lm ; store low mantissa
AND #07Fh,16,A ; mask off sign & exp to get high mantissa
ADD #080h,16,A ; ADD implied 1 to mantissa
STH A,op1_hm ; store mantissa to stack

DLD op2_msw,A ; load acc a with OP2
BC op2_zero,AEQ ; if OP2 is 0, divide by zero
STH A,–7,op2_se ; store sign and exponent to stack
STL A,op2_lm ; store low mantissa
AND #07Fh,16,A ; mask off sign & exp to get high mantissa
ADD #080h,16,A ; ADD implied 1 to mantissa
STH A,op2_hm ; store mantissa to stack

LD op1_se,A ; load sign and exp of op1 to acc
XOR op2_se,A ; xor with op2 to get sign of result
AND #00100h,A ; mask to get sign
STL A,res_sign ; save sign of result to stack

LD op1_se,A ; Load OP1 sign and exponent
AND #0FFh,A ; Mask OP1 exponent

LD op2_se,B ; Load OP2 sign and exponent
AND #0FFh,B ; Mask OP2 exponent
Example 6–11. Divide a Floating-Point Number by Another (Continued)

ADD #07Fh,A ; Add offset (difference eliminates offset)
SUB B,A ; Take difference between exponents
STL A,res_exp ; Save result exponent on stack

BC underflow,ALT ; branch to underflow handler if exp < 0
SUB #0FFh,A ; test for overflow
BC overflow,AGT ; branch to overflow is exp > 127

DIVISION
Division is implemented by parts. The mantissas for both OP1 and OP2 are left shifted
in the 32 bit field to reduce the effect of secondary and tertiary contributions to
the final result. The left shifted results are identified as OP1’HI, OP1’LO, OP2’HI,
and OP2’LO where OP1’HI and OP2’HI have the xx most significant bits of the mantissas
and OP1’LO and OP2’LO contain the remaining bits * of each mantissa. Let QHI and QLO
represent the two portions of the resultant mantissa. Then

QHI + QLO = \frac{OP1’HI + OP1’LO}{OP2’HI + OP2’LO} = \frac{OP1’HI + OP1’LO}{OP2’HI} \times \frac{1}{1 + \frac{OP2’LO}{OP2’HI}}

Now let X = OP2’LO/OP2’HI
Then by Taylor’s Series Expansion

\frac{1}{1 + x} = 1 - x + x^2 - x^3 + \ldots.

Since OP2’HI contains the first xx significant bits of the OP2 mantissa,*
X = OP2’LO/OP2’HI < 2−yy*; Therefore the X^2 term and all subsequent terms are less
than the least significant
bit of the 24-bit result and can be dropped. The result then becomes

QHI + QLO = \left(\frac{OP1’HI + OP1’LO}{OP2’HI + OP2’LO}\right) \times \left(1 - \frac{OP2’LO}{OP2’HI}\right)

where Q’HI and Q’LO represent the first approximation of the result. Also since
Q’LO and OP2’LO/OP2’HI are less significant the 24th bit of the result, this
product term can be dropped so

QHI + QLO = \left(\frac{OP1’HI + OP1’LO}{OP2’HI + OP2’LO}\right) \times \left(1 - \frac{OP2’LO}{OP2’HI}\right)

that

DLD op1_hm,A ; Load dividend mantissa
SFTL A,6 ; Shift dividend in preparation for division
* DLD op2_hm,B ; Load divisor mantissa
SFTL B,7 ; Shift divisor in preparation for division
DST B,op2_hm ; Save off divisor
* RPT #14 ; QHI = OP1’HI/OP2’HI
SUBC op2_hm,A ; Clear QHI from ACC
STL A,res_hm ; Save QHI
* SUBS res_hm,A ; Clear QHI from ACC
RPT #10 ; Q’LO = OP1’LO / OP2’HI
SUBC op2_hm,A ;
Example 6–11. Divide a Floating-Point Number by Another (Continued)

```
STL A,5,res_lm ; Save Q’LO*
LD res_hm,T ; T = Q’HI
MPYU op2_lm,A ; Store Q’HI * OP2’LO in acc A
SFTL A,-1 ;*
RPT #11 ; Calculate Q’HI * OP2’LO / OP2’HI
SUBC op2_hm,A ; (correction factor)
SFTL A,4 ; Left shift to bring it to proper range
AND #0FFFFh,A ; Mask off correction factor
*
NEGA ; Subtract correction factor
ADDS res_lm,A ; Add Q’LO
ADD res_hm,16,A ; Add Q’HI
*
;*****************************************************************************
; POST–NORMALIZATION ADJUSTMENT AND STORAGE
; Set up to adjust the normalized result. The MSB may be in bit 31. Test this
case and increment the exponent and right shift mantissa 1 bit so result is in
bits 30 through 7. Right shift mantissa by 7 bits. Store low mantissa on stack.
Mask implied 1 and store high mantissa on stack. Test result for underflow and
overflow.
;*****************************************************************************
*
LD res_exp,B ; Load result exponent
EXP A ; Get amount to adjust exp for normalizationNOP
NORM A ; Normalize the result
ST T,res_exp ; Store the exponent adjustment value
SUB res_exp,B ; Adjust exponent (add either zero or one)
SFTL A,-1 ; Pre-scale adjustment for rounding
ADD #1,B ; Adjust exponent
ADD #020h,A ; Add rounding bit
EXP A ; Normalize after rounding NOP
NORM A ;
ST T,res_exp ; Adjust exponent for normalization
SUB res_exp,B ;
STL B,res_exp ; Save exponent
BC underflow,BLEQ ; process underflow if occurs
SUB #0FFh,B ; adjust to check for overflow
BC overflow,BGEQ ; process overflow if occurs
SFTL A,-7 ; Shift right to place mantissa for splitting
STL A,res_lm ; Save result low mantissa
AND #07F00h,8, ; Eliminate implied one
STH A,res_hm ; Save result mantissa on stack
*
;*****************************************************************************
; CONVERSION OF FLOATING POINT FORMAT – PACK
; Load sign.
; Pack exponent.
; Pack mantissa.
;*****************************************************************************
```
Example 6–11. Divide a Floating-Point Number by Another (Continued)

LD res_sign,16,A  ; 0000 000S 0000 0000 0000 0000 0000 0000
ADD res_exp,16,A  ; 0000 000S EEEE EEEE 0000 0000 0000 0000
SFTL A,7          ; SEE EEEE E000 0000 0000 0000 0000 0000
DADD res_hm,A     ; SEE EEEE EMMM MMMM MMMM MMMM MMMM MMMM

;***************************************************************************
*; CONTEXT RESTORE
*;***************************************************************************
return_value
ocl_zero
ret

;***************************************************************************
*; OVERFLOW PROCESSING
*; Push errno onto stack.
*; Load accumulator with return value.
;***************************************************************************
overflow
ST #2,err_no  ; Load error no
SAT A         ; Result exponent = 0FEh
SUB #081h,16,A ; Result high mant = 07Fh
BD return_value ; Branch delayed
LD res_sign,16,B ; Load sign of result
OR B,7,A      ; Pack sign*

;***************************************************************************
*; UNDERFLOW PROCESSING
*; Push errno onto stack.
*; Load accumulator with return value.
;***************************************************************************
underflow
ST #1,err_no  ; Load error no
BD return_value ; Branch delayed
SUB A,A       ; For underflow result = 0
nop

;***************************************************************************
*; DIVIDE BY ZERO
*; Push errno onto stack.
*; Load accumulator with return value.
;***************************************************************************
op2_zero
ST #3,err_no  ; Load error no
SAT A         ; Result exponent = FEh
                ; Result low mant = FFFFh
LD opl_se,16,B ; Load sign and exponent of OP1
AND #100h,16,B ; Mask to get sign of OP1
OR B,7,A      ; Pack sign
BD return_value ; Branch delayed
SUB #081h,16,A ; Result high mant = 7Fh
NOP
6.6 Logical Operations

DSP-application systems perform many logical operations, including bit manipulation and packing and unpacking data. A digital modem uses a scrambler and a descrambler to perform bit manipulation. The input bit stream is in a packed format of 16 bits. Each word is unpacked into 16 words of 16-bit data, with the most significant bit (MSB) as the original input bit of each word. The unpack buffer contains either 8000h or 0000h, depending upon the bit in the original input-packed 16-bit word. The following polynomial generates a scrambled output, where the ♦ sign represents modulus 2 additions from the bitwise exclusive OR of the data values:

Scrambler output = 1 ♦ x⁻¹⁸ ♦ x⁻²³

The same polynomial sequence in the descrambler section reproduces the original 16-bit input sequence. The output of the descrambler is a 16-bit word in packed format.

Example 6–12. Pack/Unpack Data in the Scrambler/Descrambler of a Digital Modem

; Functional Description
; This routine illustrates the pack and unpack of a data stream and also bit manipulation. A digital scrambler and descrambler does the bit manipulation and the input to the scrambler is in unpacked format and the output of the descrambler is in packed 16-bit word.
; scrambler output = 1+x⁻¹⁸+x⁻²³
; additions are modulus 2 additions or bitwise exclusive OR of data values. The same polynomial is used to generate the descrambler output.

.scrambler

scrambler_init:

STM #d_unpack_buffer,UNPACK_BFFR
STM #d_scram_bffr,SCRAM_DATA_23
RPTZ A,#K_BFFR_SIZE
STL A,*SCRAM_DATA_23+
STM #d_scram_bffr*K_BFFR_SIZE-1,SCRAM_DATA_23
Example 6–12. Pack/Unpack Data in the Scrambler/Descrambler of a Digital Modem (Continued)

STM #d_scram_bffr+17,SCRAM_DATA_18
STM #d_de_scram_bffr+K_BFFR_SIZE–1,DE_SCRAM_DATA_23
STM #d_de_scram_bffr+17,DE_SCRAM_DATA_18
LD #d_input_bit,Dp
ST #-K_16+1,d_asm_count
scrambler_task:
; the unpack data buffer has either 8000h or 0000h since the bit stream
; is either 1 or 0
unpack_data:
STM #K_16–1,BRC
RPTB end_loop–1 ; unpack the data into 16-bit
; word
PORTR 1h,d_input_bit
LD d_input_bit,15,A ; mask the lower 15 bits
; the MSB is the serial bit
; stream
STL A,*UNPACK_BFFR ; store the 16 bit word
unpack_16_words
scrambler:
LD *SCRAM_DATA_18–%,A
XOR *SCRAM_DATA_23,A ; A = x^–18+x^–23
XOR *UNPACK_BFFR,A ; A = A+x^0
STL A,*SCRAM_DATA_23–% ; newest sample, for next
; cycle it will be x(n–1)
STL A,*UNPACK_BFFR ; store the scrambled data
scramble_word
descrambler:
LD *DE_SCRAM_DATA_18–%,A
XOR *DE_SCRAM_DATA_23,A ; A = x^–18+x^–23
XOR *UNPACK_BFFR,A ; A = A+x^0
STL A,*DE_SCRAM_DATA_23–% ; newest sample, for next
; cycle it will be x(n–1)
STL A,*UNPACK_BFFR ; store the scrambled data
de_scramble_word
; ASM field shifts the descrambler output MSB into proper bit position
; pack_data
RSBX SXM ; reset the SXM bit
LD d_asm_count,ASM
LD *UNPACK_BFFR+,A
LD A,ASM,A
OR d_pack_out,A ; start pack the data
STL A, d_pack_out
ADDM #1,d_asm_count
pack_word
SSBX SXM ; enable SXM mode
end_loop
NOP ; dummy instructions nothing
; with the code
NOP
.end
Chapter 7

Application-Specific Examples

This chapter shows examples of typical applications for the '54x. Since this DSP is widely used for speech coding and telecommunications, the applications show how some aspects of these functions are implemented.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1 Codebook Search for Excitation Signal in Speech Coding</td>
<td>7-2</td>
</tr>
<tr>
<td>7.2 Viterbi Algorithm for Channel Decoding</td>
<td>7-5</td>
</tr>
</tbody>
</table>
7.1 Codebook Search for Excitation Signal in Speech Coding

A code-excited linear predictive (CELP) speech coder is widely used for applications requiring speech coding with a bit rate under 16K bps. The speech coder uses a vector quantization technique from codebooks to an excitation signal. This excitation signal is applied to a linear predictive-coding (LPC) synthesis filter. To obtain optimum code vectors from the codebooks, a codebook search is performed, which minimizes the mean-square error generated from weighted input speech and from the zero-input response of a synthesis filter. Figure 7–1 shows a block diagram of a CELP-based speech coder.

Figure 7–1. CELP-Based Speech Coder

To locate an optimum code vector, the codebook search uses Equation 7–1 to minimize the mean-square error.

Equation 7–1. Optimum Code Vector Localization

\[ E_i = \sum_{i=0}^{N-1} [p(n) - \gamma i g_i(n)]^2 \]

The variable p(n) is the weighted input speech, \( g_i(n) \) is the zero-input response of the synthesis filter, and \( \gamma_i \) is the gain of the codebook.

The cross-correlation (\( c_i \)) of p(n) and \( g_i(n) \) is represented by Equation 7–2. The energy (\( G_i \)) of \( g_i(n) \) is represented by Equation 7–3.
Equation 7–2. Cross Correlation Variable (c_i)
\[ c_i = \sum_{i=0}^{N-1} g_i \ast p(n) \]

Equation 7–3. Energy Variable (G_i)
\[ G_i = \sum_{i=0}^{N-1} g_i^2 \]

Equation 7–1 is minimized by maximizing \( c_i^2 / G_i \). Therefore, assuming that a code vector with \( i = \text{opt} \) is optimal, Equation 7–4 is always met for any \( i \). The codebook search routine evaluates this equation for each code vector and finds the optimum one.

Equation 7–4. Optimal Code Vector Condition
\[ \left( \frac{c_i^2}{G_i} \right) \leq \left( \frac{c_{\text{opt}}^2}{G_{\text{opt}}} \right) \]

Example 7–1 shows the implementation algorithm for codebook search on '54x. The square (SQR), multiply (MPYA), and conditional store (SRCCD, STRCD, SACCD) instructions are used to minimize the execution cycles. AR5 points to \( c_i \) and AR2 points to \( G_i \). AR3 points to the locations of \( G_{\text{opt}} \) and \( c_{\text{opt}}^2 \). The value of \( i(\text{opt}) \) is stored at the location addressed by AR4.
Example 7–1. Codebook Search

.title "CODEBOOK SEARCH"
.mmregs
.text

SEARCH:
STM  #C,AR5 ;Set C(i) address
STM  #G,AR2 ;Set G(i) address
STM  #OPT,AR3 ;Set OPT address
STM  #IOPT,AR4 ;Set IOPT address
ST  #0,*AR4 ;Initialize lag
ST  #1,*AR3+ ;Initialize Gopt
ST  #0,*AR3- ;Initialize C2opt
STM  #N–1,BRC
RPTB  Srh_End–1
SQR    *AR5+,A  ;A = C(i) * C(i)
MPYA   *AR3+  ;B = C(i)^2 * Gopt
MAS    *AR2+,*AR3–,B  ;B = C(i)^2 * Gopt - G(i) * C2opt, T = G(i)
SRCCD  *AR4,BGEQ ;if(B >= 0) then
     ;iopt = BRC
STRCD  *AR3+,BGEQ ;if(B >= 0) then
     ;Gopt = T
SACCD  A,*AR3–,BGEQ ;if(B >= 0) then
     ;C2opt = A NOP
NOP ;To save current BCR
Srh_End:
RET ;*AR4  ->  optimal index
.end
7.2 Viterbi Algorithm for Channel Decoding

Convolutional encoding with the Viterbi decoding algorithm is widely used in telecommunication systems for error control coding. The Viterbi algorithm requires a computationally intensive routine with many add-compare-select (ACS) iterations. The '54x can perform fast ACS operations because of dedicated hardware and instructions that support the Viterbi algorithm on chip. This implementation allows the channel decoder and the equalizer in communication systems to be used efficiently.

In the global system for mobile communications (GSM) cellular radio, the polynomials in Equation 7–5 are used for convolutional encoding.

**Equation 7–5. Polynomials for Convolutional Encoding**

\[ G_1(D) = 1 + D^3 + D^4 \]
\[ G_2(D) = 1 + D + D^3 + D^4 \]

This convolutional encoding can be represented in a trellis diagram, which forms a butterfly structure as shown in Figure 7–2. The trellis diagram illustrates all possible transformations of convolutional encoding from one state to another, along with their corresponding path states. There are 16 states, or eight butterflies, in every symbol time interval. Two branches are input to each state. Decoding the convolutional code involves finding the optimal path by iteratively selecting possible paths in each state through a predetermined number of symbol time intervals. Two path metrics are calculated by adding branch metrics to two old-state path metrics and the path metric (J) for the new state is selected from these two path metrics.

**Figure 7–2. Butterfly Structure of the Trellis Diagram**
Equation 7–6 defines a branch metric.

*Equation 7–6. Branch Metric*

\[ M = SD(2^i) \times B(J,0) + SD(2^i+1) \times B(J,1) \]

SD(2^i) is the first symbol that represents a soft-decision input and SD(2^i+1) is the second symbol. B(J,0) and B(J,1) correspond to the code generated by the convolutional encoder as shown in Table 7–1.

*Table 7–1. Code Generated by the Convolutional Encoder*

<table>
<thead>
<tr>
<th>J</th>
<th>B(J,0)</th>
<th>B(J,1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>5</td>
<td>-1</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>7</td>
<td>-1</td>
<td>1</td>
</tr>
</tbody>
</table>

The ‘54x can compute a butterfly quickly by setting the ALU to dual 16-bit mode. To determine the new path metric (J), two possible path metrics from 2*J and 2*J+1 are calculated in parallel with branch metrics (M and –M) using the DADST instruction. The path metrics are compared by the CMPS instruction. To calculate the new path metric (J+8), the DSADT instruction calculates two possible path metrics using branch metrics and old path metrics stored in the upper half and lower half of the accumulator. The CMPS instruction determines the new path metric.

The CMPS instruction compares the upper word and the lower word of the accumulator and stores the larger value in memory. The 16-bit transition register (TRN) is updated with every comparison so you can track the selected path metric. The TRN contents must be stored in memory locations after processing each symbol time interval. The back-track routine uses the information in memory locations to find the optimal path.
Example 7–2 shows the Viterbi butterfly macro. A branch metric value is stored in T before calling the macro. During every butterfly cycle, two macros prevent T from receiving opposite sign values of the branch metrics. Figure 7–3 illustrates pointer management and the storage scheme for the path metrics used in Example 7–2.

In one symbol time interval, eight butterflies are calculated for the next 16 new states. This operation repeats over a number of symbol time intervals. At the end of the sequence of time intervals, the back-track routine is performed to find the optimal path out of the 16 paths calculated. This path represents the bit sequence to be decoded.

*Figure 7–3. Pointer Management and Storage Scheme for Path Metrics*
Example 7–2. Viterbi Operator for Channel Coding

VITRBF .MACRO  ;
    DADST *AR5,A ;A = OLD_M(2*J)+T//OLD_(2*J+1)–T
    DSADT *AR5+,B ;B = OLD_M(2*J)–T//OLD_(2*J+1)+T
    CMPS A,*AR4+ ;NEW_M(J) = MAX(A_HIGH,A_LOW)
                   ;TRN<<1, TRN(0,0) = TC
    CMPS B,*AR3+ ;NEW_M(J+8) = MAX(B_HIGH,B_LOW)
                   ;TRN<<1, TRN(0,) = TC
    .ENDM

VITRBR .MACRO  ;
    DSADT *AR5,A ;A = OLD_M(2*J)–T//OLD_(2*J+1)+T
    DADST *AR5+,B ;B = OLD_M(2*J)+T//OLD_(2*J+1)–T
    CMPS A,*AR4+ ;NEW_M(J) = MAX(A_HIGH,A_LOW)
                   ;TRN<<1, TRN(0,0) = TC
    CMPS B,*AR3+ ;NEW_M(J+8) = MAX(B_HIGH,B_LOW)
                   ;TRN<<1, TRN(0,) = TC
    .ENDM
The bootloader lets you load and execute programs received from a host processor, EPROMs, or other standard memory devices. The '54x devices provide different ways to download the code to accommodate various system requirements. Some applications use a serial interface. If the code exists in external ROM, a parallel interface is appropriate. This chapter uses the '542 as a reference platform for HPI bootloader option platform and '541 for other bootloader options available on '54x.
8.1 Boot Mode Selection

Execution begins at location FF80h of the on-chip ROM if the MP/ME pin of the '54x is sampled low during a hardware reset. This location contains a branch instruction to start the bootloader program that is factory-programmed in ROM. This program sets up the CPU status registers before initiating the bootload. Interrupts are globally disabled (INTM = 1) and internal dual-access and single-access RAMs are mapped into program/data space (OVLY = 1). Seven wait states are initialized for all the program and data spaces. The size of the external memory bank is set to 4K words. It uses one latency cycle when switching between program and data space.

The boot routine reads the I/O port address 0FFFFh by driving the I/O strobe (IS) signal low. The lower eight bits of the word read from I/O port address 0FFFFh specify the mode of transfer. The boot routine selection (BRS) word determines the boot mode. The BRS word uses a source (SRC) field when in parallel EPROM mode and an entry address (ADDR) field when using a warm boot (see Section 8.6, Warm Boot on page 8-12). The six least significant bits and the configuration of CLKX and FSX pins determine whether to use the 8- or 16-bit bootload serial boot option. The BRS word also determines the 8- or 16-bit parallel I/O mode.

The host port interface (HPI) uses interrupt 2 to bootloader (INT2). If INT2 is not latched, the boot routine skips HPI boot mode (see Section 8.2, Host Port Interface (HPI) Bootloading Sequence on page 8-4). It reads the lower eight bits from the I/O address, 0FFFFh, to determine the boot mode. Figure 8–1 illustrates the boot mode selection process.
Figure 8–1. Boot Mode Selection Process

Boot Mode Selection

Initialization

Test INT2: HPI boot?

Yes

HPI boot mode

Begin execution @ hpiram

No

Read BRS word from I/O @ address OFFFFh

BRS = xxxx xx00?

Yes

I/O boot mode

BRS = xxxx 1000?

No

16-bit parallel I/O mode

Yes

BRS = xxxx 1100?

No

8-bit parallel I/O mode

Serial boot modes

BRS = xx00 0000?

Yes

Configure BSP for 8-bit (FSX/CLKX as output) serial port boot mode

No

BRS = xx00 0100?

Yes

Configure BSP for 16-bit (FSX/CLKX as output) serial port boot mode

No

BRS = xx01 0000?

Yes

Configure BSP for 8-bit (FSX/CLKX as input) serial port boot mode

No

BRS = xx01 0100?

Yes

Configure BSP for 16-bit (FSX/CLKX as input) serial port boot mode

No

BRS = xx10 0000?

Yes

Configure TDM for 8-bit (FSX/CLKX as output) serial port boot mode

No

BRS = xx10 0100?

Yes

Configure TDM for 16-bit (FSX/CLKX as output) serial port boot mode

Parallel EPROM Boot Modes

BRS = xxxx xx01?

Yes

8-bit parallel EPROM mode

No

16-bit parallel EPROM mode

Warm boot (BRS = xxxx xx11)

Warm boot mode
8.2 Host Port Interface (HPI) Boot Loading Sequence

The HPI is an 8-bit parallel port that interfaces a host processor to the '542. The host processor and the '542 exchange information via on-chip, shared memory. The host interrupts the CPU by writing to the HPI control register (HPIC). The CPU interrupts the host by asserting the host interrupt (HINT) signal. The host can acknowledge or clear this signal. The signal determines whether the HPI boot option is selected by asserting HINT low. This signal is tied to the external interrupt INT2 input pin if HPI boot mode is selected. (Instead of tying HINT to INT2, you can send a valid interrupt to the INT2 input pin within 30 CLOCKOUT cycles after the '542 fetches the reset vector.)

Asserting HINT low sets the corresponding interrupt flag register (IFR) bit. The bootloader waits for 20 CLKOUT cycles after asserting HINT and reads bit 2 of IFR. If the bit is set (indicating that INT2 is recognized), the bootloader transfers control to the start address of the on-chip HPI RAM (1000h in program space) and executes code from that point. If bit 2 of the IFR is not set, the boot routine skips HPI boot mode and reads BRS from the I/O address, 0FFFFh, in I/O space. The lower eight bits of this word specify the mode of transfer. The bootloader ignores the rest of the bits.

If HPI boot mode is selected, the host must download the code to on-chip HPI RAM before the HPI brings the device out of reset. The bootloader keeps HPI in shared-access mode (SMODE = 1) during the entire operation. Once HINT is asserted low by the bootloader, it stays low until a host controller clears it by writing to HPIC.
8.3 16-Bit/8-Bit Parallel Boot

The parallel boot option is used when the code is stored in EPROMs (8 or 16 bits wide). The code is transferred from data to program memory. The six most significant bits (MSBs) of the source address are specified by the SRC field of the BRS word, as shown in Figure 8–2.

Figure 8–2. 16-Bit EPROM Address Defined by SRC Field

If 16-bit parallel mode is selected, data is read in 16-bit words from the source address and incremented by 1 after every read operation. The destination address and the length of the code are specified by the first two 16-bit words. The length is defined as:

\[
\text{Length} = \text{number of 16-bit words to be transferred} - 1
\]

The number of 16-bit words specified by length does not include the first two words read (destination and length parameters), starting from the source address. This is shown in Figure 8–3. The code is transferred from data memory (source address) to program memory (destination address). At least a 10-cycle delay occurs between a read from EPROM and a write to the destination address. This ensures that if the destination is external memory, like fast SRAM, there is enough time to turn off the source memory (EPROM) before the write operation is performed. After the code is transferred to program memory, the '541 branches to the destination address. This occurs for both for 16-bit and 8-bit parallel boot options.

Figure 8–3. Data Read for a 16-Bit Parallel Boot

Notes:
1) \( \text{Destination}_{16} \) = 16-bit destination
2) \( \text{Length}_{16} = N - 1 \)
3) \( \text{Code word (N)}_{16} = N \) 16-bit words to be transferred
If the 8-bit parallel boot option is selected (see Figure 8–4), two consecutive memory locations (starting at the source address) are read to make one 16-bit word. The high-order byte must be followed by the low-order byte. Data is read from the lower eight data lines, ignoring the upper byte on the data bus. The destination address is a 16-bit word that constitutes the address in program space where the boot code is transferred. The length is defined as:

\[
\text{Length} = \text{number of 16-bit words to be transferred} - 1 = (\text{number of bytes to be transferred} / 2) - 1
\]

**Figure 8–4. Data Read During 8-Bit Parallel Boot**

<table>
<thead>
<tr>
<th>7</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination&lt;sub&gt;h&lt;/sub&gt;</td>
<td>Destination&lt;sub&gt;i&lt;/sub&gt;</td>
</tr>
<tr>
<td>Length&lt;sub&gt;h&lt;/sub&gt; = N –1</td>
<td>Length&lt;sub&gt;i&lt;/sub&gt; = N –1</td>
</tr>
<tr>
<td>Code word (1)&lt;sub&gt;h&lt;/sub&gt;</td>
<td>Code word (1)&lt;sub&gt;i&lt;/sub&gt;</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Code word (N)&lt;sub&gt;h&lt;/sub&gt;</td>
<td>Code word (N)&lt;sub&gt;i&lt;/sub&gt;</td>
</tr>
</tbody>
</table>

**Notes:**
1) Destination<sub>h</sub> and Destination<sub>i</sub> represent high and low bytes of destination address
2) Length<sub>h</sub> and Length<sub>i</sub> represent high and low bytes of a 16-bit word that specifies the length N of the code that follows it.
3) N<sub>h</sub> and N<sub>i</sub> bytes constitute N words to be transferred.
Figure 8–5 shows the parallel boot sequence, both for the 16- and 8-bit options.

Figure 8–5. 8-Bit/16-Bit Parallel Boot

Start

Load and save 16-bit EPROM address (SRC)

Read DA

Read & copy code length to BRC

Code Length

Read code word from SRC and save code word in PM

Increment SRC

Increment PM

Decrement code length

Branch to DA

Start executing code

8-bit read DA, code length, code word from SRC

Read HB from SRC

Read LB from SRC

16-bit read DA, code length, code word from SRC

Read 16-bit word from SRC

Read 16-bit word from SRC
8.4 I/O Boot

The I/O boot mode provides asynchronous transfer code from I/O address 0h to internal/external program memory. Each word can be 16 or 8 bits long. The '541 communicates with external devices using the BIO and XF handshake lines. The handshake protocol shown in Figure 8–6 is required to successfully transfer words from I/O address 0h.

**Figure 8–6. Handshake Protocol**

![Handshake Protocol Diagram]

Figure 8–6 shows a data transfer initiated by the host, which drives the BIO pin low. When BIO goes low, the '541 inputs data from I/O address 0h, drives the XF pin high to indicate to the host that the data has been received, and writes the input data to the destination address. The '541 then waits for the BIO pin to go high before driving the XF pin low. The low status of the XF line can be polled by the host for the next data transfer.

If 8-bit transfer mode is selected, the lower eight data lines are read from I/O address, 0h. The upper byte on the data bus is ignored. The '541 reads two 8-bit words to form a 16-bit word. The low byte of each 16-bit word must follow the high byte. Figure 8–7 shows the I/O boot sequence, both for the 16- and 8-bit options.

For both 8- and 16-bit I/O, the first two 16-bit words received by the '541 must be the destination and length of the code, respectively. A minimum delay of 10 clock cycles occurs between the rising edge of XF and the write to the destination address. This allows the processor sufficient time to turn off its data buffers before the '541 initiates the write operation if the destination is external memory. The '541 accesses the external bus only when XF is high.
Figure 8–7. 8-Bit/16-Bit I/O Boot Mode

8-bit/16-bit parallel I/O mode

Handshake with host

Read D/A from I/O 0h

Handshake with host

Read code length from I/O 0h

Handshake with host

Read D/A from I/O 0h

Transfer data from DM into PM and increment PM

Yes

Code length 0

No

Decrement code length

Branch to DA

Start executing code

8-bit read DA, code length, code word from I/O 0h

Handshake with host

Read HB from I/O 0h

Handshake with host

Read LB from I/O 0h

16-bit handshake & read DA, code length, code word from I/O 0h

Handshake with host

Read 16-bit word from I/O 0h
### 8.5 Standard Serial Boot

The '541 serial boot option can use either the buffered serial port (BSP) or time-division multiplexed (TDM) serial port in standard mode during booting. Eight modes are available for the serial boot option (see Figure 8–1, Boot Mode Selection Process, on page 8-3). The word length (8- or 16-bit) and the configuration of the CLKX/FSX pins determines the correct mode to use. For 8-bit operation, set the following bits:

- Receive reset signal, RRST (to take serial port 0 out of reset)
- Transmit mode bit, TXM
- Clock mode bit, MCM (so that CLKX is driven by an on-chip clock source)
- Frame sync mode bit, FSM (frame sync pulses must be supplied externally on the FSR pin)
- Format bit, FO (so that data is transferred in an 8-bit length)

This translates to a value of 3Ch to the SPC register, which puts the serial port in reset. The RRST and XRST of SPC register are set to 1 to take the serial port out of reset for configuring CLKX/FSX as output pins in 8-bit mode. Then a value of FCh is written to the SPC register for 16-bit mode, FO = 0. This writes 38h to the SPC register to put the serial port in reset. It also writes a 1 to both RRST and XRST to pull the serial port register out of reset and configure CLKX/FSX as output pins, and a value of F8h is written to the SPC register.

To drive the CLKX and FSX pins as inputs, the MCM and TXM bits are disabled and the serial port is configured for 8- and 16-bit mode options. The external flag, XF, sends a signal that the '541 is ready to respond to and receive from the serial port. The XF flag is set high at reset and is driven low to initiate reception. No frame sync pulses can appear on FSR before XF goes low. For the buffered serial port, the BSP control extension register (BSPCE) is initialized to set the CLKX to 1/4 of the CLKOUT signal. Figure 8–8 shows the serial boot sequence.
Configure SPC register to put in reset and then pull out of reset. Configure BSPCE register

Read DA from SP

Read code length from SP

Read code word from SP and save the code word in DM

Transfer data from DM into PM and increment PM

Code length 0?

Yes

8-bit read DA, code length, code word from SP

Read HB from SP

Read LB from SP

No

Branch to DA

Decrement code length

Start executing code

16-bit read DA, code length, code word from SP

Read 16-bit word from SP
8.6 Warm Boot

The '541 transfers control to the entry address if the warm boot option is specified. The warm boot option can be used after a warm device reset or if the program has already been transferred to internal or external memory by other means, such as a direct memory access (DMA). For a warm boot, the six MSBs at the entry point of the code are specified by the SRC or ADDR fields of the BRS word, as shown in Figure 8–9.

Figure 8–9. Warm Boot Address Specified in BRS Word

<table>
<thead>
<tr>
<th>ADDR</th>
<th>15</th>
<th>10</th>
<th>9</th>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: ADDR = 6-bit page address

Example 8–1. Warm Boot Option

```assembly
.title "bootc542"

.symbol definitions

.mmregs
.mmnolist
.def boot
.def endboot
.def bootend
.def bsprcv_isr
.def tdmrcv_isr
.def dest
.def src
.def lngth
.def s8word
.def hbyte
.def state

.boota .set 0184h ; Arbitrary ref (for USR bootcode)

.boot .ref boota ; reserved for ROM Code customer

 Conditional Assembly Flags

C542 .set 1

.pa0 .set 0h ; port address 0h for i/o boot load
.br .set 60h ; boot routine select (configuration word)
.bootmode .set 61h ; boot mode extracted from brs
```
Example 8–1. Warm Boot Option (Continued)

s8word .set 62h ; concatenator for 8–bit serial load
hbyte .set 63h ; high byte of 8–bit serial word
p8word .set 64h ; concatenator for 8–bit memory load
src .set 65h ; source address
dest .set 66h ; destination address (dmov from above)
lngth .set 67h ; code length
temp .set 68h ; temporary register
state .set 69h ; serial I/O state vector
nmintv .set 6ah ; non-maskable interrupt vector

* Bit equates
b0 .set 00h
b4 .set 04h
b8 .set 08h
bc .set 0ch
b10 .set 010h
b14 .set 014h
b20 .set 020h
b24 .set 024h
b30 .set 030h
b34 .set 034h
hpiram .set 01000h
int2msk .set 004h ; INT2_ bit position on IFR

**********************************************************
* main program starts here
**********************************************************
.sect "bootload"
.boot
ssbx intm ; disable all interrupts
ld #0, dp
orm #03b00h, @nmintv ; xf=1, mh=1, intm=1, ovms=1, sxms=1
orm #020h, @pmst ; ovly=1
stm #07fffh, swwsr ; 7 wait states for P_,D_, and I_ spaces
stm #0f800h, bscr ; full bank switching
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* HPI boot, simply branch to HPI RAM
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
.if C542
stm #01010b, hpic ; Send HINT_ low
rpt #18 ; wait 20 clockout cycles
nop
bitf @ifr, #int2msk ; Check if INT2_ flag is set
; ThisTEST MUST BE >= 30 cycles from boot?
stm #int2msk, ifr ; Clear INT2_ bit in ifr if INT2_ latched
bcd endboot, tc ; If yes, branch to HPI RAM
st #hpiram, @dest
.endif
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* Read Configuration Byte
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
portr #0ffffh, @brs ; brs <-- boot load configuration word
ld @brs, 8, a ; get boot value in acc AL
and #0fc00h, a ; throw away 2 LSBS
Example 8–1. Warm Boot Option (Continued)

```
stl a, @src ; save as source address
ldu @brs, a ; determine bootload method
and #3, a ; if 2 LSBs == 00
bc ser_io, aeq ; use serial or parallel I/O
sub #2, a ; if 2 LSBs == 01
bc par08, alt ; load from 8-bit memory
bc par16, aeq ; load from 16-bit memory
bc par16, aeq ; load from 16-bit memory

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* Warm-boot, simply branch to source address      *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
warmboot
  delay @src ; dest <–– src
endboot
  ld @dest, a ; branch to destination address
  bacc a

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*       Bootload from 16-bit memory             *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
par16
  mvdk @src, ar1 ; ar1 points at source memory (Data)
  ld *ar1+, a ; load accumulator A with destination
  stl a, @dest ; save to scratchpad
  stlm a, ar2 ; current destination in block repeat
  ld *ar1+, a ; get the length
  stlm a, brc ; update block repeat counter register
  nop ; brc latency
  rptb xfr16-1 ; read object data
  mvdk *ar1+, ar3 ; ar3 <–– junkbyte.low byte
  andm #0ffh, @ar3 ; ar3 <–– low byte
  or @ar3, a ; acc A <–– high byte.low byte
  stl a, @dest ; save to scratchpad for endboot
  stlm a, ar2 ; ar2 points at destination
  ld *ar1+, 8, a ; get number of 16-bit words
  mvdk *ar1+, ar3 ; ar3 <–– junkbyte.low byte
  andm #0ffh, @ar3 ; ar3 <–– low byte
  or @ar3, a ; acc A <–– high byte.low byte

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*       Bootload from 8-bit memory, MS byte first       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
par08
  mvdk @src, ar1 ; ar1 points at source memory (Data)
  ld *ar1+, 8, a ; load accumulator A with destination
  mvdk *ar1+, ar3 ; ar3 <–– junkbyte.low byte
  andm #0ffh, @ar3 ; ar3 <–– low byte
  or @ar3, a ; acc A <–– high byte.low byte
  stl a, @dest ; save to scratchpad for endboot
  stlm a, ar2 ; ar2 points at destination
  ld *ar1+, 8, a ; get number of 16-bit words
  mvdk *ar1+, ar3 ; ar3 <–– junkbyte.low byte
  andm #0ffh, @ar3 ; ar3 <–– low byte
  or @ar3, a ; acc A <–– high byte.low byte
```
Example 8–1. Warm Boot Option (Continued)

```assembly
  stlm a, brc ; update block repeat counter register
  nop ; brc update latency
  rptb eloop4-1
  ld *ar1+, 8, a ; acc A <-- high byte
  mvdk *ar1+, ar3 ; ar3 <-- junkbyte.low byte
  andm #0ffh, @ar3 ; ar3 <-- low byte
  or @ar3, a ; acc A <-- high byte.low byte
  stl a, @p8word
  ldm ar2, a ; acc A <-- destination address
  nop ; 10 cycles b/w read & write
  writa @p8word ; write object data to destination
  add @#1, a
  stlm a, ar2 ; update destination address
eloop4
  b endboot

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *

ser_io
  ld @brs, a
  and #0fh, a ; clear except lower 4 bits
  stl a, @bootmode ; save only boot mode
  cmpm @bootmode, #b8 ; test for io boot 8
  bc pasync08, tc ; if set, perform parallel I/O bootloader
  cmpm @bootmode, #bc ; test bit #3 of configuration word
  bc pasync16, tc ; if set, perform parallel I/O bootloader

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *

*       Bootload from serial port       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *

ser
  ld @brs, a
  and #3fh, a ; clear except lower 6 bits
  stl a, @bootmode ; save only boot mode
  cmpm @bootmode, #b0 ; test bit #0 of bootmode word
  bcd bsp08int, tc ; if set, then 8–bit serial with int BCLKX, BFSX
  andm #0ff01h, @spc ; clear bits 1–7
  cmpm @bootmode, #b4 ; test bit #2 of bootmode word
  bc bsp16int, tc ; if set, then 16–bit serial with int BCLKX, BFSX
  cmpm @bootmode, #b10 ; test bit #4 of bootmode word
  bc bsp08ext, tc ; if set, then 8–bit serial with ext BCLKX, BFSX
  cmpm @bootmode, #b14 ; test bit #4&2 of bootmode word
  bc bsp16ext, tc ; if set, then 16–bit serial with ext BCLKX, BFSX
  cmpm @bootmode, #b20 ; test bit #5 of bootmode word
  bcd tdm08int, tc ; if set, then 8–bit serial with int TCLKX, TFSX
  andm #0ff00h, @tspc ; clear bits 0–7
  cmpm @bootmode, #b24 ; test bit #5&2 of bootmode word
  bc tdm16int, tc ; if set, then 16–bit serial with int TCLKX, TFSX
  cmpm @bootmode, #b30 ; test bit #5&4 of bootmode word
  bc tdm08ext, tc ; if set, then 8–bit serial with ext TCLKX, TFSX
  cmpm @bootmode, #b34 ; test bit #5&4&2 of bootmode word
  bc tdm16ext, tc ; if set, then 16–bit serial with ext TCLKX, TFSX
  b bootend

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *

*       Bootload from Buffered Serial Port (BSP)       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```
Example 8–1. Warm Boot Option (Continued)

bsp16ext
orm #0008h, @spc ; configure sport and put in reset
stm #0003h, spce ; CLKKV=3,FSP=CLKP=FE=FIG=PCM=BXE=HLTX=BRE=HLTR=0
bd bspself1
st #bspadd16, @state ; 16-bit service routine addr

bsp08ext
orm #0008h, @spc ; configure sport and put in reset
stm #0003h, spce ; CLKKV=3,FSP=CLKP=FE=FIG=PCM=BXE=HLTX=BRE=HLTR=0
bd bspself1
st #bspadd8_1, @state ; 8-bit service routine addr

bsp16int
orm #0038h, @spc ; configure sport and put in reset
stm #0003h, spce ; CLKKV=3,FSP=CLKP=FE=FIG=PCM=BXE=HLTX=BRE=HLTR=0
bd bspself1
st #bspadd16, @state ; 16-bit service routine addr

bsp08int
orm #0038h, @spc ; configure sport and put in reset
stm #0003h, spce ; CLKKV=3,FSP=CLKP=FE=FIG=PCM=BXE=HLTX=BRE=HLTR=0
st #bspadd8_1, @state ; 8-bit service routine addr

bspself1
orm #0080h, @spc ; take sport out of reset
rsbx xf ; signal ready-to-receive
* Poll for receive data ready

bspin
rsbx tc ; clear flag

bsprcv_isr
ld @state, a ; vector to the sport receive routine
bacc a
* Load destination address (16-bit serial mode)
bspadd16
mvdk @drr, ar1 ; get destination addr into ar1
mvkd ar1, @dest ; save destination addr
bd bspin
st #bspplen16, @state ; next service routine
* Load end address (16-bit serial mode)
bsplen16
ldm drr, a ; get length in words
add @dest, a ; add destination address
stlm a, ar0 ; save end address
bd bspin
st #bspisr16, @state ; next service routine
* Bootload 16-bit serial data
bspisr16
ldu @ar1, a ; get the destination address
cmp eq, ar1 ; check for RAM full condition
bcd bspin, ntc ; spin if transfer not complete
writa @drr ; write object word at destination addr
mar *ar1+ ; increment destination addr
b endboot
Example 8–1. Warm Boot Option (Continued)

* Load destination address (8-bit serial mode)
bspadd8_1
  ld  @drr, 8, a ; acc A <-- junkbyte.high byte
  and #0ff00h, a ; acc A <-- high.byte
  stl a, @hbyte ; save high byte
  bd bspin
  st #bspadd8_2, @state ; next service routine
bspadd8_2
  ldu @drr, a ; acc A <-- junkbyte.low byte
  and #0ffh, a ; acc A <-- low byte
  or @hbyte, a ; acc A <-- high byte.low byte
  stlm a, ar1 ; save destination address
  stl a, @dest
  bd bspin
  st #bsplen8_1, @state ; next service routine
* Load end address (8-bit serial mode)
bsplen8_1
  ld  @drr, 8, a ; acc A <-- high byte
  stl a, @hbyte ; save high byte
  bd bspin
  st #bsplen8_2, @state ; next service routine
bsplen8_2
  ldu @drr, a ; acc A <-- junkbyte.low byte
  and #0ffh, a ; acc A <-- low byte
  or @hbyte, a ; acc A <-- high byte.low byte
  add @dest, a ; add destination address
  stlm a, ar0 ; save end address
  bd bspin
  st #bspisr8_1, @state ; next service routine
* Bootload 8-bit serial data
bspisr8_1
  ld  @drr, 8, a ; acc A <-- high byte
  stl a, @hbyte ; save high byte
  bd bspin
  st #bspisr8_2, @state ; next service routine
bspisr8_2
  ldu @drr, a ; acc A <-- junkbyte.low byte
  and #0ffh, a ; acc A <-- low byte
  or @hbyte, a ; acc A <-- high byte.low byte
  stl a, @s8word ; save 16-bit word
  ldm arl, a ; get destination addr
  cmpr eq, arl ; check for RAM full condition
  bcd endboot, tc ; exit if RAM full
  writa @s8word ; copy word to pmem[<ar1>]
  mar *ar1+
  bd bspin
  st #bspisr8_1, @state ; next service routine
Example 8–1. Warm Boot Option (Continued)

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * 
* Bootload from TDM Serial Port (TDM) * 
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * 

tdm16ext
  orm  #0008h, @tspc ; configure sport and put in reset
  bd   tdmself1
  st   #tdmadd16, @state ; 16-bit service routine addr

tdm08ext
  orm  #000ch, @tspc ; configure sport and put in reset
  bd   tdmself1
  st   #tdmadd8_1, @state ; 8-bit service routine addr

tdm16int
  orm  #0038h, @tspc ; configure sport and put in reset
  bd   tdmself1
  st   #tdmadd16, @state ; 16-bit service routine addr

tdm08int
  orm  #003ch, @tspc ; configure sport and put in reset
  st   #tdmadd8_1, @state ; 8-bit service routine addr

tdmself1
  orm  #0080h, @tspc ; take sport out of reset
  rsbx xf ; signal ready-to-receive

* Poll for receive data ready

tdmspin
  rsbx tc ; clear flag

tdmspinn
  bcd  tdmspinn, ntc ; begin receive data routine
  bitf @tspc, #0400h ; if rrdy = 1

tdmrcv_isr
  ld   @state, a ; vector to the sport receive routine
  bacc a

* Load destination address (16-bit serial mode)

tdmadd16
  mvdk @trcv, ar1 ; get destination addr into ar1
  mvd @dest, ar0 ; save destination addr
  bd   tdmspin
  st   #tdmlen16, @state ; next service routine

* Load end address (16-bit serial mode)

tdmlen16
  ldm  trcv, a ; get length in words
  add  @dest, a ; add destination address
  stlm a, ar0 ; save end address
  bd   tdmspin
  st   #tdmisr16, @state ; next service routine

* Bootload 16-bit serial data

tdmisr16
  ldu  @ar1, a ; get the destination address
  cmpr eq, ar1 ; check for RAM full condition
  bcd  tdmspin, ntc ; spin if transfer not complete
  writa @trcv ; write object word at destination addr
  mar  *ar1+ ; increment destination addr
  b    endboot
Example 8–1. Warm Boot Option (Continued)

* Load destination address (8-bit serial mode)

```
  tdmadd8_1
    ld  @trcv, 8, a     ; acc A <–– junkbyte.high byte
    and #0ff00h, a     ; acc A <–– high.byte
    stl a, @hbyte      ; save high byte
    bd  tdmspin
    st #tdmadd8_2, @state ; next service routine

  tdmadd8_2
    ldu @trcv, a       ; acc A <–– junkbyte.low byte
    and #0ffh, a       ; acc A <–– low byte
    or  @hbyte, a      ; acc A <–– high byte.low byte
    stlm a, arl        ; save destination address
    stl a, @dest       ; dest len = dest addr
    bd  tdmspin
    st #tdmlen8_1, @state ; next service routine

* Load end address (8-bit serial mode)

  tdmlen8_1
    ld  @trcv, 8, a     ; acc A <–– high byte
    stl a, @hbyte      ; save high byte
    bd  tdmspin
    st #tdmlen8_2, @state ; next service routine

  tdmlen8_2
    ldu @trcv, a       ; acc A <–– junkbyte.low byte
    and #0ffh, a       ; acc A <–– low byte
    or  @hbyte, ad     ; acc A <–– high byte.low byte
    add @dest, a       ; add destination address
    stlm a, ar0        ; save end address
    bd  tdmspin
    st #tdmisr8_1, @state ; next service routine

* Bootload 8-bit serial data

  tdmisr8_1
    ld  @trcv, 8, a     ; acc A <–– high byte
    stl a, @hbyte      ; save high byte
    bd  tdmspin
    st #tdmisr8_2, @state ; next service routine

  tdmisr8_2
    ldu @trcv, a       ; acc A <–– junkbyte.low byte
    and #0ffh, a       ; acc A <–– low byte
    or  @hbyte, a      ; acc A <–– high byte.low byte
    stlm a, @s8word    ; save 16-bit word
    ldm arl, a         ; get destination addr
    cmpr eq, arl       ; check for RAM full condition
    bcd endboot, tc    ; exit if RAM full
    writa @s8word      ; copy word to pmem[<arl>]
    mar *arl+          ; next service routine
    bd  tdmspin
    st #tdmisr8_1, @state ; next service routine
```
Example 8–1. Warm Boot Option (Continued)

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* Bootload from parallel I/O port (pa0)
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* Bootload from I/O port (16-bit parallel)

call handshake
portr pa0, @dest ; read word from port to destination

call handshake
portr pa0, @lngth ; read word from port to length

mvdk @lngth, ar1 ; ar1 <-- code length
ldu @dest, a ; acc A <-- destination address

loop16

call handshake ; read word from port to temp
ssbx xf ; acknowledge word as soon as it’s read
rpt #8
nop ; 10 cycles delay between xf and write
writa @temp ; write word to destination
add #1, a ; increment destination address
banz loop16, *ar1– ; loop if ar1 is not zero
ldu @dest, a ; branch to destination address
bacc a

* Bootload from I/O port (8-bit parallel), MS byte first pasync08
* get destination address from 1st two byte

call handshake
portr pa0, @hbyte
ld @hbyte, 8, a ; read high byte from port
stl a, @hbyte ; save high byte

portr pa0, @dest
ldu @dest, a ; read low byte from port
and #0ffh, a ; clear upper byte
or @hbyte, a ; combine high and low byte
stl a, @dest ; save destination address

* get code length from 2nd two byte

call handshake
portr pa0, @hbyte
ld @hbyte, 8, a ; read high byte from port
stl a, @hbyte ; save high byte

portr pa0, @lngth
ld @lngth, a ; read low byte from port
and #0ffh, a ; clear upper byte
or @hbyte, a ; combine high and low byte
stl a, @lngth ; save code length
stlm a, arl ; arl <-- code length
ldu @dest, a ; acc B <-- destination address
Example 8–1. Warm Boot Option (Continued)

```
loop08
    call  handshake
    portr pa0, @hbyte
    ld    @hbyte, 8, a       ; read high byte from port
    stl   a, @hbyte          ; save high byte
    call  handshake
    portr pa0, @temp
    ssbx  xf                    ; acknowledge byte as soon as it’s read
    ldu   @temp, a            ; read low byte from port
    and   #0ffh, a            ; clear upper byte
    or    @hbyte, a           ; combine high and low byte
    stl   a, @temp            ; save code word
    ld    b, a                ; acc A <--> destination address
    nop
    ; 10 cycles delay between xf and write
    writa @temp                ; write code word to program memory
    add   #1, a                ; increment destination address
    ld    a, b                 ; save new destination address
    banz loop08, *ar1–         ; loop if ar1 not zero
    ldu   @dest, a             ; branch to destination address
    bacc a
* Handshake with BIO signal using XF

handshake
    ssbx xf                      ; acknowledge previous data word

biohigh
    bc   biohigh,bio              ; wait till host sends request
    rsbx xf                          ; indicate ready to receive new data

biolow
    rc   bio                        ; wait till new data ready
    b    biolow

bootend
.end
```
This chapter describes the communication interface between the '54x EVM and its host. The system passes data between the target and host, while maintaining real-time operation. The system can be driven by interrupts, polled, or a mixture of the two.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.1 Communication Channels</td>
<td>9-2</td>
</tr>
<tr>
<td>9.2 Handshake and Data Transfer</td>
<td>9-6</td>
</tr>
</tbody>
</table>
9.1 Communication Channels

The host communicates to the '54x EVM via 38 16-bit I/O locations. Each I/O location is defined by an offset to an I/O page 0 address, shown in Table 9–1. There are two independent communication channels, A and B, through which the host and target can communicate. The status/control registers on both the host and target provide system-level control and status information.

Table 9–1. '54x EVM Host-Interface Register Usage

<table>
<thead>
<tr>
<th>I/O Offset From Base Address</th>
<th>Register</th>
<th>Size</th>
<th>Register Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x0800</td>
<td>Channel A</td>
<td>16</td>
<td>Read/write</td>
</tr>
<tr>
<td>0x0804</td>
<td>Channel B</td>
<td>16</td>
<td>Read/write</td>
</tr>
<tr>
<td>0x0808</td>
<td>Status/control</td>
<td>16</td>
<td>Read/write</td>
</tr>
</tbody>
</table>

The host writes to channel A (offset 0x0800) and overwrites the current value. An interrupt 1 (INT1) signal is generated to the target, which sets the channel A transmit status bit, AXST, to 1 in the host control register (HCR) and sets the channel A receive status bit, ARST, to 1 in the target control register (TCR). The host reads from the same location, which clears the ARST bit in HCR and clears AXST in TCR. Channel B is a 64-word deep, bidirectional FIFO register that transfers both data and commands. Host write to 0x0804 is buffered by the FIFO. Data is ignored if the FIFO is full. Figure 9–1 shows the HCR and Table 9–2 describes the bits.

Figure 9–1. Host Control Register (HCR) Diagram

9-2

PRELIMINARY
Table 9–2. Host Control Register (HCR) Bit Summary

<table>
<thead>
<tr>
<th>Bit</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>RESET</td>
<td>Software reset. If RESET = 1, the target processor and emulation logic are reset but the host/target communication flags are not reset.</td>
</tr>
<tr>
<td>14</td>
<td>MP/MC</td>
<td>Microprocessor/microcomputer mode select. The EVM powers up in microcomputer mode.</td>
</tr>
<tr>
<td>13</td>
<td>BTIE</td>
<td>Channel B target interrupt enable. If BTIE = 1, channel A receive conditions generate a host interrupt.</td>
</tr>
<tr>
<td>12</td>
<td>ATIE</td>
<td>Channel A target interrupt enable. If ATIE = 1, channel A receive conditions generate a host interrupt.</td>
</tr>
<tr>
<td>11</td>
<td>HBIO</td>
<td>Host BIO input to target processor</td>
</tr>
<tr>
<td>10</td>
<td>BRST2</td>
<td>Channel B receive status bit 2. If BRST2 =1, the target has written to channel B, forcing an interrupt. The BRST2 flag is cleared when the host reads its channel B.</td>
</tr>
<tr>
<td>9–8</td>
<td>BRST</td>
<td>Channel B receive status:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BRST</th>
<th>Channel B Receive Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0</td>
<td>Buffer empty</td>
</tr>
<tr>
<td>0 1</td>
<td>Buffer less than half full</td>
</tr>
<tr>
<td>1 0</td>
<td>Buffer half or more than full</td>
</tr>
<tr>
<td>1 1</td>
<td>Buffer full</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bit</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>REV1</td>
<td>Card revision status bit 1</td>
</tr>
<tr>
<td>6</td>
<td>REV0</td>
<td>Card revision status bit 0</td>
</tr>
<tr>
<td>5</td>
<td>XF</td>
<td>External flag from target processor (status)</td>
</tr>
<tr>
<td>4</td>
<td>BIO</td>
<td>BIO input to target processor</td>
</tr>
</tbody>
</table>
Table 9–2. Host Control Register (HCR) Bit Summary (Continued)

<table>
<thead>
<tr>
<th>Bit</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3–2</td>
<td>BXST</td>
<td>Channel B transmit status:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>BXST</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Bit 3</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Bit 2</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Channel B Transmit Status</strong></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>Buffer empty</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>Buffer less than half full</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>Buffer half or more than full</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Buffer full</td>
</tr>
<tr>
<td>1</td>
<td>ARST</td>
<td>Channel A receive status. If ARST = 1, the target has written to its channel A register. The ARST flag is cleared when the host reads channel A.</td>
</tr>
<tr>
<td>0</td>
<td>AXST</td>
<td>Channel A transmit status. If AXST = 1, host has written to its channel A register. The AXST flag is cleared when the target reads channel A.</td>
</tr>
</tbody>
</table>

The EVM supports two communication channels, configured as six I/O ports for host/target communication and 16 I/O ports for user expansion. Channel A is a single 16-bit bidirectional register mapped into two I/O port locations. Channel B is a single, bidirectional, 64-deep, FIFO buffer that is mapped into two I/O port locations. A status I/O port provides target control and general-purpose control, status, and discrete-bit I/O. Figure 9–3 shows the TCR and Table 9–3 describes the bits.

Figure 9–2. '54x EVM Port Usage

<table>
<thead>
<tr>
<th>Port Address</th>
<th>Name</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x0010</td>
<td>Channel A</td>
<td>Communications</td>
</tr>
<tr>
<td>0x0012</td>
<td>Channel B</td>
<td>Communications</td>
</tr>
<tr>
<td>0x0014</td>
<td>Status</td>
<td>Target status/control</td>
</tr>
</tbody>
</table>

Figure 9–3. Target Control Register (TCR) Diagram

```
15 14 13 12 11–8 7 6 5–4 3–2 1 0
| AICRST | USR-BOT2 | USR-BOT1 | USR-BOT0 | Reserved | USR-BIN1 | USR-BIN0 | BRST | BXST | ARST | AXST |
```
Table 9–3. Target Control Register (TCR) Bit Summary

<table>
<thead>
<tr>
<th>Bit</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>AICRST</td>
<td>If AICRST = 0, the analog interface circuit is reset</td>
</tr>
<tr>
<td>14</td>
<td>USR-BOT2</td>
<td>User discrete output bit 2</td>
</tr>
<tr>
<td>13</td>
<td>USR-BOT1</td>
<td>User discrete output bit 1</td>
</tr>
<tr>
<td>12</td>
<td>USR-BOT0</td>
<td>User discrete output bit 0</td>
</tr>
<tr>
<td>11–8</td>
<td>–</td>
<td>Reserved</td>
</tr>
<tr>
<td>7</td>
<td>USR-BIN1</td>
<td>User discrete input bit 1</td>
</tr>
<tr>
<td>6</td>
<td>USR-BIN0</td>
<td>User discrete input bit 0</td>
</tr>
<tr>
<td>5–4</td>
<td>BRST</td>
<td>Channel B receive status: Channel B receive status:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bit 5</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>Buffer empty</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>Buffer less than half full</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>Buffer half or more than full</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Buffer full</td>
</tr>
<tr>
<td>3–2</td>
<td>BXST</td>
<td>Channel B transmit status: Channel B transmit status:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bit 3</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>Buffer empty</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>Buffer less than half full</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>Buffer half or more than full</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Buffer full</td>
</tr>
<tr>
<td>1</td>
<td>ARST</td>
<td>Channel A receive status. If ARST = 1, the host has written to its channel A register. The ARST flag is cleared when the target reads channel A.</td>
</tr>
<tr>
<td>0</td>
<td>AXST</td>
<td>Channel A transmit status. If AXST = 1, target has written to its channel A register. The AXST flag is cleared when the host reads channel A.</td>
</tr>
</tbody>
</table>

Note: For further register and I/O information, see the TMS320C54x Evaluation Module Technical Reference.
9.2 Handshake and Data Transfer

Example 9–1 through Example 9–4 show how to communicate between the host and the target through both channels, A and B. The communication involves two steps: a handshake and a data transfer. Channel A sends commands between the host and the target and channel B uses the FIFO buffer to transfer data, either 64 or 32 words at a time. A buffer of 256 samples is transferred from target to the host. Data is sent 32 words at a time from the target, except for the first FIFO, where the first 64 words are sent to the host. The data is transferred from the target to the FIFO whenever an INT1 signal occurs. This is generated when the host writes to channel A. The XF line on the host control sets up a handshake between the host and the target. Figure 9–4 illustrates the sequence of events in a handshake and Figure 9–5 illustrates the sequence of events in a data transfer.
Figure 9–4. Handshake Protocol

**Host action**

Read channel B until the FIFO is empty. Write command to channel A (AXST = 1, generates INT1).

**Target action**

ARST = 1, since host has written to channel A polls IFR Read channel B until the FIFO is empty. Read channel A for the command send by host (ARST = 0). Send a handshake command to host through channel A (AXST = 1). Set XF to low.

AXST = 0, target has read the command; poll XF bit. ARST = 1, target has written a command to channel A. Read handshake command from channel A (ARST = 0).

AXST = 0, since host has read the command.
Example 9–1. Handshake — Target Action

*************************************************************************
* This file includes the TCR register configuration of EVM
*************************************************************************
K_AIC_RST .set 0b << 15 ; if AICRST=0, aic is reset
K_USR_BOT .set 000b << 12 ; User discrete output bits
          ; 0,1,2
K_RESRV   .set 0000b << 8 ; Reserved bits
K_USR_BIN .set 00b << 6 ; User discrete input bits 0,1
K_RCV_BRST .set 00b << 4 ; Channel B receive status regs
         ; buffer half or more K_XMT_BXST
K_XMT_BXST .set 11b << 2 ; Ch B transmit status register
         ; buffer half or more K_RCV_ARST
K_RCV_ARST .set 0b << 1 ; Ch A receive register
K_XMT_AXST .set 0b << 1 ; Ch A transmit register
K_TCR_HIGH .set K_AIC_RST|K_USR_BOT|K_RESRV
K_TCR_LOW  .set K_USR_BIN|K_RCV_BRST|K_XMT_BXST|K_RCV_ARST|K_XMT_AXST
K_TCR      .set K_TCR_HIGH|K_TCR_LOW
*************************************************************************
* this includes I/O address of CH_A, CH_B and different commands that’s been
* passed between host and the target
*************************************************************************
K_0       .set 0h ; constant 0
K_FIFO_FULL .set 0xFF ; Full FIFO command written by target
K_FIFO_EMPTY .set 0xEE ; Empty FIFO command
          ; written by host
K_AXST_CLEAR .set 0xAE ; Clear AXST empty command
          ; written by the target
K_HANDSHAKE_CMD .set 0xAB ; handshake CMD written by host
K_CHB      .set 12h ; Use Channel B as I/O interface
          ; to 54x EVM for sending data
K_CHA      .set 10h ; Use Channel A as I/O interface
          ; to 54x EVM for send command
          ; to host
K_TRGCR_ADDR .set 14h ; Target status control register
          ; I/O address location
          ; 0h
K_AXST     .set 1h ; used to check the control bits
K_ARST     .set 2h ; check if K_FIFO_SIZE
K_BXST     .set 0Ch ; its a 64 FIFO
K_FIFO_SIZE .set 64 ; Frame size
K_FRAME_SIZE .set 256 ; Frame size
K_HOST_FLAG .set 1 ; if 0, then host interface
          ; is disabled
; TEXAS INSTRUMENTS INCORPORATED
.include "target.inc"
.include "init_54x.inc"
.include "interrupt.inc"
.ref FIFO_DP
.ref d_command_reg
.ref d_command_value
.def evm_handshake
Example 9–1. Handshake — Target Action (Continued)

; Functional Description
;
; This initiates the handshake between the host (PC) and the target (DSP).
; The host writes a command to CH A. This generates an INT1 on the target.
; The AXST bit on HCR is set to 1. The INT1 bit in IFR is polled if it is set
; then it is cleared to clear pending interrupts. The FIFO is cleared
; by reading from the FIFO. The command from host is read thru CH A and ARST
; on TCR is cleared. Another command from target is written to CH A,
; which sets AXST. Also sets XF low. The host polls XF line.
; The host reads CH A which clears ARST on host side and AXST on target side.
;
;---------------------------------------------------------------
;
.sect "handshake"
evma_handshake:
LD #0,DP ; Poll for INT1
BITF IFR,02h ; Poll for INT1
BC evm_handshake,NTC ; ARST = 1
STM #K_INT1,IFR ; clear the pending interrupt
LD #FIFO_DP,DP
RPT #K_FIFO_SIZE–1
PORTR K_CHB,d_command_reg ; assures that FIFO is empty to
PORTR K_CHA,d_command_value ; ARST = 0

; read the command from
; to acknowledge INT1
; check FIFO empty
; branch occurs
; indicate of FIFO empty

; read the command send by hosts
; send to a command to clear AXST
; write command to command reg A
; AXST = 1
; XF = 0

RSBX XF
RET
.sect "handshake"

PRELIMINARY
Example 9–2. Handshake — Host Action

/*
This function initializes the data buffer and reads the FIFO so that FIFO
is empty when the real data transfers starts
______________________________________________________*/

void initialize_slave(void)
{
    int j;
    for (j=0; j < 64; j++)
        dataa[j] = inport(BDAT_REG); /* read data from data reg. */
    for (j=0; j < 256; j++)
        dataa[j] = 0;
    outport(CONT_REG, inport(CONT_REG) & 0xf7ff);
}
/*
This initiates the handshake between the target and host. The host writes a command
to target which sets the AXST flag to 1. The INT1 is generated whenever
host writes to CH A. On the target side, INT1 is polled and reads the CH A.
This clears ARST on target side. A command is written to Ch A on target after
emptying the FIFO that sets AXSt =1. Later sets XF to go low. On host XF is polled
and then reads CH A that clears ARST to 0 and AXST to 0 on the target side
*/

int receive_clear_AXST(void) /* RECEIVE COMMAND FROM EVM */
{
    command = 0xAB;
    outport (ADAT_REG,command);
    while(inport(CONT_REG) & AXST); /* write command to evm */
    while(!(inport(CONT_REG) & ARST)); /* wait for evm to send command*/
    reply = inport(ADAT_REG); /* read command into reply */
    while ((reply & 0xAE) !=0xAE);
    return(reply); /* return command for process’g*/
}
/*---------------------------------------------------------------*/
Figure 9–5. Data Transfer Protocol

Handshake and Data Transfer

PRELIMINARY

Host action

Target action

FIFO empty (BXST)
(Read first 64 data from target into FIFO
Send a command to host through channel A
(AXST = 1)
Initialize counter to 1, since 64 data has already
written to FIFO)
})
else
{
discard the FIFO since there is a overrun on the input
buffer
}

AXST = 0, since host has read the
command

Send a command to target after reading the
FIFO through channel A (AXST = 1)
Generates INT1

if (64 < count < 256)
{
Read the FIFO half-full command through
channel A (ARST = 0)
Send a command to target after reading the
FIFO through channel A (AXST = 1)
Generates INT1
}
else
ARST = 0
send data to screen

R...
Handshake and Data Transfer

Example 9–3. Data Transfer — Target Action

; TEXAS INSTRUMENTS INCORPORATED

.include "target.inc"

.d_output_addr

FIFO_DP .usect "fifo_var",0
d_command_reg .usect "fifo_var",1
d_command_value .usect "fifo_var",1
d_fifo_count .usect "fifo_var",1
d_fifo_ptr .usect "fifo_var",1

.def fifo_host_transfer
.def FIFO_DP
.def d_command_reg
.def d_command_value
.def d_fifo_ptr
.def d_fifo_count

; Functional Description
; This routine transfers a FIFO(64) of data to host thru CH B.
; In the process, after transferring data from DSP to FIFO sends a command
; to host thru CH A. The host acknowledges and sends a command to target (DSP)
; thru CH A.
; The host transfer can be disabled by setting the K_HOST_FLAG =0

.asg AR7,OUTBUF_P
.asg AR7,SV_RSTRE_AR7
.sect "fifo_fil"

fifo_host_transfer:
LD #FIFO_DP,DP
.if K_HOST_FLAG =1
PORTR K_TRGCR_ADDR,d_command_reg ; while (port14 & BXST)
BITF d_command_reg,K_BXST
BC fifo_discard,TC ; FIFO discard
MVDK d_output_addr,OUTBUF_P ; load PING/PONG bfr address
RPT #K_FIFO_SIZE–1 ; write first set of 64 data
.to FIFO
PORTW *OUTBUF_P+,K_CHB ; Fill FIFO
ST #K_FIFO_FULL,d_command_value
PORTW d_command_value, K_CHA ; write command to comnd reg A
ST #1,d_fifo_count ; start counting for transfers
MVKD OUTBUF_P,d_fifo_ptr ; save the fifo_ptr

fifo_discard

.endif
RET
.end
Example 9–4. Data Transfer — Host Action

```c
command_FIFO = receive_command_FIFO_FULL();
for (fifo_size=0; fifo_size < 64; fifo_size++)
dataa[fifo_size+count] = inport(BDAT_REG);
send_command_new_FIFO(command);
for (count=64; count< 256; count++)
{
    command_FIFO = receive_command_FIFO_FULL(); /* command from target*/
    for (fifo_size=0; fifo_size < 32; fifo_size++)
dataa[fifo_size+count] = inport(BDAT_REG);  /* read 32 word fifo*/
    count = count+31;
    send_command_new_FIFO(command); /* send command to target*/
}
int receive_command_FIFO_FULL(void)
    /* RECEIVE COMMAND FROM EVM */
{
    while(!(inport(CONT_REG) & ARST));         /* wait for evm to send command*/
    reply = inport(ADAT_REG);                  /* read command into reply     */
    while ((reply & 0xFF) !=0xFF);
    return(reply);                             /* return command for process'g*/
}

/*____________________________________________________________________________*/
/* This function sends a command to target for a new set of data from FIFO*/
void send_command_new_FIFO(command)
    unsigned int command;
{
    command = 0xEE;
    outport (ADAT_REG,command);
    while(inport(CONT_REG) & AXST);
}
```
This chapter contains complete code examples for routines that are excerpted in previous chapters of this book. These routines have been developed using a '54x EVM platform. These programs demonstrate applications that use a host interface and run in real time. You may download them to use in developing your own applications.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.1 Running the Applications</td>
<td>10-2</td>
</tr>
<tr>
<td>10.2 Application Code</td>
<td>10-4</td>
</tr>
</tbody>
</table>
10.1 Running the Applications

The host communicates to the '54x EVM through 16-bit I/O locations. Each I/O location is defined by an offset to an I/O page 0 address. The offset used for these applications is 0x240 + 0x800 for channel A, 0x240 + 0x804 for channel B, and 0x240 + 0x808 for the target/status control register, where 0x240 is the base address of the host. Check your PC system documentation to make sure that I/O space 0x240 does not conflict with other I/O devices. If the EVM is mapped to other than space 0x240, the base addresses of the control and status registers must be modified in the file host.h.

The '54x assembler assembles code and generates object files. The linker command file links the object files and generates a file named main.out, using common object file format (COFF). You must load main.out into the EVM debugger command window with the LOAD command and compile the host software using a Borland C compiler. This generates the file, master.exe. that contains graphic routines that display data transferred from the target to the host.

To run the target application, load main.out into the EVM debugger. To start the program on the target side, press the F5 function key. If you halt the program with the escape key or use the halt command in the debugger window, the program remains in the handshake loop waiting for the host to send a command. Press the F5 function key to continue. To run the host application, execute master.exe at the DOS prompt or a window command line. When master.exe is executed by the host, it displays the message:

Graphics: No error. Press any key to halt.

When you press this key, the graphics window opens and displays data for the task the target has initiated. The default task is an oscilloscope routine. To change to a different task, go to the debugger window, halt the program, and in the command window, type:

e *present_command = x

where x = 1, 2, 3, 4, 5 or 6, and present_command has one of the following values:

1 = oscilloscope
2 = Low-pass finite impulse response (FIR) filter using MAC instruction
3 = Low-pass infinite impulse response (IIR) filter using biquad sections
4 = Lowpass FIR filtering using FIRS instruction
5 = System identification using adaptive filtering with least mean squares (LMS) instruction
6 = 256-point real fast Fourier transform (FFT)
You can view the output of the present task in the graphics window.

To exit the host application, press F3. Communication is lost if at any time the target code is reloaded or reset in the command window while the host executable is running in the background. This means that if you attempt to reset or reload the code in the debugger window and you press F5, the computer locks up. This occurs because there is no handshake between the host and the target. To unlock, reload and run the code (press F5) on the target side. On the host side, quit the window and rerun the executable.

The adaptive filter can be tested in two steps. The initial step size d_mu = 0 in the first step. If the present task is changed at the debugger window with the command e *present_command = 5, runs with d_mu = 0. Thus, the system is not identified since the coefficients of the adaptive filter are not updated. In the second step the step size can be changed by typing e *d_mu = 0x1000 at the command window. In this case, the system is identified and the filter coefficients are adapted using the LMS algorithm. In both cases the error signal can be observed both on host and also from the output of the 'AC01.
10.2 Application Code

Table 10–1 lists programs appropriate for running on a target system and tells you where to look for them in this chapter.

Table 10–1. Target Files

<table>
<thead>
<tr>
<th>Title</th>
<th>File Name</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vector Table Initialization</td>
<td>vectors.asm</td>
<td>10-6</td>
</tr>
<tr>
<td>Main Program That Calls Different Functions</td>
<td>main.asm</td>
<td>10-16</td>
</tr>
<tr>
<td>Memory Allocation for Entire Application</td>
<td>memory.asm</td>
<td>10-10</td>
</tr>
<tr>
<td>Processor Initialization</td>
<td>init_54x.asm</td>
<td>10-22</td>
</tr>
<tr>
<td>Initialization of Variables, Pointers, and Buffers</td>
<td>prcs_int.asm</td>
<td>10-29</td>
</tr>
<tr>
<td>Initialization of Serial Port 1</td>
<td>init_ser.asm</td>
<td>10-33</td>
</tr>
<tr>
<td>'AC01 Initialization</td>
<td>init_aic.asm</td>
<td>10-38</td>
</tr>
<tr>
<td>'AC01 Register Configuration</td>
<td>aic_cfg.asm</td>
<td>10-42</td>
</tr>
<tr>
<td>Receive Interrupt Service Routine</td>
<td>rcv_int1.asm</td>
<td>10-46</td>
</tr>
<tr>
<td>Task Scheduling</td>
<td>task.asm</td>
<td>10-51</td>
</tr>
<tr>
<td>Echo the Input Signal</td>
<td>echo.asm</td>
<td>10-56</td>
</tr>
<tr>
<td>Low-Pass FIR Filtering Using MAC Instruction</td>
<td>fir.asm</td>
<td>10-59</td>
</tr>
<tr>
<td>Low-Pass Biquad IIR Filter</td>
<td>iir.asm</td>
<td>10-69</td>
</tr>
<tr>
<td>Low-Pass Symmetric FIR Filtering Using FIRS Instruction</td>
<td>sym_fir.asm</td>
<td>10-64</td>
</tr>
<tr>
<td>Adaptive Filtering Using LMS Instruction</td>
<td>adapt.asm</td>
<td>10-74</td>
</tr>
<tr>
<td>256-Point Real FFT Initialization</td>
<td>rfft.asm</td>
<td>10-84</td>
</tr>
<tr>
<td>Bit Reversal Routine</td>
<td>bit_rev.asm</td>
<td>10-87</td>
</tr>
<tr>
<td>256-Point Real FFT Routine</td>
<td>fft.asm</td>
<td>10-91</td>
</tr>
<tr>
<td>Unpack 256-Point Real FFT Output</td>
<td>unpack.asm</td>
<td>10-97</td>
</tr>
<tr>
<td>Compute the Power Spectrum of the Complex Output of the 256-Point Real FFT</td>
<td>power.asm</td>
<td>10-103</td>
</tr>
</tbody>
</table>
Table 10–2 lists programs appropriate for running on a host system and tells you where to look for them in this chapter.

Table 10–2. Communication Interface Files

<table>
<thead>
<tr>
<th>Title</th>
<th>File Name</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handshake Between Host and Target</td>
<td>hand_shk.asm</td>
<td>10-25</td>
</tr>
<tr>
<td>Interrupt 1 Service Routine</td>
<td>hst_int1.asm</td>
<td>10-111</td>
</tr>
<tr>
<td>Data Transfer from FIFO</td>
<td>fifo.asm</td>
<td>10-106</td>
</tr>
<tr>
<td>Main Function Call on Host Side</td>
<td>master.c</td>
<td>10-118</td>
</tr>
<tr>
<td>Function Calls on Host Side</td>
<td>host.c</td>
<td>10-116</td>
</tr>
<tr>
<td>Display the Data on the Screen</td>
<td>view2.c</td>
<td>10-123</td>
</tr>
<tr>
<td>Graphic Drivers Routine</td>
<td>graphic2.c</td>
<td>10-121</td>
</tr>
</tbody>
</table>

Example 10–28 on page 10-124 shows the linker command that links all object files together to produce a single executable COFF object module. This file establishes the memory configuration for the entire application, using the ’541’s memory map. Example 10–29 on page 10-127 shows the configuration of the memory map for a ’541 device used by an EVM debugger.
Example 10–1. Vector Table Initialization

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
; Archives: PVCS
; Filename: vectors.asm
; Version: 1.0
; Status: draft ( )
; proposal (X) accepted ( ) dd-mm-yy/?acceptor.
;
; AUTHOR Padma P. Mallela
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477;
; IPR statements description (can be collected).
;
; (C) Copyright 1996. Texas Instruments.
; All rights reserved.
;
; Change history:
;
; VERSION DATE / AUTHORS COMMENT
; 1.0 July–24–96 / P.Mallela original created
;
;
; 1. ABSTRACT
;
; 1.1 Function Type
; a. Core Routine
; b. Subroutine
;
; 1.2 Functional Description
; This file contains vector table of 541
;
; 1.3 Specification/Design Reference (optional)
;
; 1.4 Module Test Document Reference
; Not done
;
; 1.5 Compilation Information
; Compiler: TMS320C54X ASSEMBLER
; Version: 1.02 (PC)
; Activation: asm500 –s vectors.asm
;
; 1.6 Notes and Special Considerations
;
; This code is written for 541 device. The code is tested on
; C54x EVM
Example 10–1. Vector Table Initialization (Continued)

```c
};
};
2. VOCABULARY
;
2.1 Definition of Special Words, Keywords (optional)
;
2.2 Local Compiler Flags
;
2.3 Local Constants
;
);
;
3. EXTERNAL RESOURCES
;
3.1 Include Files
.include "init_54x.inc"
.include "main.inc"
3.2 External Data
.ref SYSTEM_STACK
3.3 Import Functions
.ref main_start
.ref receive_int1
.ref host_command_int
);
;
4. INTERNAL RESOURCES
;
4.1 Local Static Data
;
4.2 Global Static Data
;
4.3 Dynamic Data
;
4.4 Temporary Data
;
4.5 Export Functions
;
5. SUBROUTINE CODE
 HeaderBegin

5.1 reset

5.2 Functional Description
 This function initializes the vector table of 541 device

5.3 Activation
 Activation example:

 Reentrancy: No
 Recursive: No
```
Example 10–1. Vector Table Initialization (Continued)

; 5.4 Inputs
; 5.5 Outputs
; 5.6 Global
; 5.7 Special considerations for data structure
; 5.8 Entry and Exit conditions
;
; 5.9 Execution
; Execution time: ?cycles
; Call rate: not applicable for this application
;
; Note: UM – Used & Modified, U – Used, NU – Not Used
;
; 5.10 Code

.sect "vectors"
reset:     BD main_start        ;RESET vector
STM        #SYSTEM_STACK,SP
nmi:       RETE
        NOP
        NOP
        NOP ;NMI

; software interrupts
sint17     .space 4*16
sint18     .space 4*16
sint19     .space 4*16
sint20     .space 4*16
sint21     .space 4*16
sint22     .space 4*16
sint23     .space 4*16
sint24     .space 4*16
sint25     .space 4*16
sint26     .space 4*16
sint27     .space 4*16
sint28     .space 4*16
sint29     .space 4*16
sint30     .space 4*16
int0:      RETE
        NOP
        NOP ; INT0
        NOP

10-8
**Example 10–1. Vector Table Initialization (Continued)**

```
int1:       BD       host_command_int1    ; Host interrupt
            PSHM      ST0
            PSHM      ST1    ; INT1

int2:       RETE
            NOP
            NOP
            NOP

tint:       RETE
            NOP
            NOP
            NOP
            ; TIMER

rint0:      RETE
            NOP
            NOP
            NOP
            ; Serial Port Receive
            ; Interrupt 0

xint0:      RETE
            NOP
            NOP
            NOP
            ; Serial Port Transmit
            ; Interrupt 0

rint1:      BD       receive_int1        ; Serial Port Receive
            PSHM      ST0
            PSHM      ST1    ; Interrupt 1

xint1:      RETE
            NOP
            NOP
            NOP
            ; Serial Port Transmit
            ; Interrupt 1

int3:       RETE
            NOP
            NOP
            NOP
            ; INT3

.end
```

*---*
Example 10–2. Memory Allocation for Entire Application

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
;
; Archives: PVCS
; Filename: memory.asm
; Version: 1.0
; Status : draft ( )
; proposa (X)
; accepted ( ) dd-mm-yy/?acceptor.
;
; AUTHOR Padma P. Mallela
;
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
; IPR statements description (can be collected).
;
; (C) Copyright 1996. Texas Instruments. All rights reserved.
;
; Change history:
;
; VERSION   DATE     /    AUTHORS            COMMENT
; 1.0       July-24–96 /    P.Mallela      original created
;
; 1. ABSTRACT
;
; 1.1 Function Type
; a.Core Routine
; b.Subroutine
;
; 1.2 Functional Description
; This file contains main function
;
; 1.3 Specification/Design Reference (optional)
;
; 1.4 Module Test Document Reference
; Not done
;
; 1.5 Compilation Information
; Compiler: TMS320C54X ASSEMBLER
; Version: 1.02 (PC)
; Activation: asm500 –s memory.asm
;
; 1.6 Notes and Special Considerations
;
; This code is written for 541 device. The code is tested on C54x EVM
;
; 10-10
Example 10–2. Memory Allocation for Entire Application (Continued)

```c
};

2. VOCABULARY

2.1 Definition of Special Words, Keywords (optional)

2.2 Local Compiler Flags

2.3 Local Constants

};

3. EXTERNAL RESOURCES

3.1 Include Files
    .mmregs
    .include "defines.inc"
    .include "main.inc"

3.2 External Data

3.3 Import Functions

4. INTERNAL RESOURCES

4.1 Local Static Data

4.2 Global Static Data

4.3 Dynamic Data

4.4 Temporary Data

4.5 Export Functions

5. SUBROUTINE CODE

HeaderBegin

5.1 main_start

5.2 Functional Description

Memory configuration of the application

5.3 Activation

Activation example:

    Reentrancy:    No
    Recursive:     No

5.4 Inputs
```
Example 10–2. Memory Allocation for Entire Application (Continued)

; 5.5 Outputs
; 5.6 Global
; 5.7 Special considerations for data structure
; 5.8 Entry and Exit conditions
; 
; |DP|OVM|SXM|C16|FRCT|ASM|AR0|AR1|AR2|AR3|AR4|AR5|AR6|AR7|A |B |BK|BRC| T|TRN|
; |  |   |   |   |    |   |   |   |   |   |   |   |   |   |  |  |  |   |  |   |
; in |U | 1 |NU |NU |NU  |NU |NU |NU |NU |NU |NU |NU |NU |NU |NU|NU|NU|NU |NU|NU |
; out|U | 1 | 1 |NU | 1  |NU |NU |NU |NU |NU |NU |NU |NU |NU |NU|NU|NU|NU |NU|NU |
; 
; Note : UM – Used & Modified, U – Used, NU – Not Used
; 5.9 Execution
; Execution time: ?cycles
; Call rate: not applicable for this application
; 
;---------------------------------------------

; 5.10 Code
STACK          .usect   "stack",K_STACK_SIZE
SYSTEM_STACK   .set     K_STACK_SIZE+STACK

input_data     .usect   "inpt_buf",K_FRAME_SIZE*2 ; input data array
output_data    .usect   "outdata",K_FRAME_SIZE*2  ; output data array
; this section of variables are used in receive_int1 routine and related routines
RCV_INT1_DP    .usect   "rcv_vars",0
D_RCV_IN_PTR   .usect   "rcv_vars",1              ; save/restore input bffr ptr
D_XMT_OUT_PTR  .usect   "rcv_vars",1              ; save/restore output bffr ptr
d_frame_flag   .usect   "rcv_vars",1
D_INDEX_COUNT  .usect   "rcv_vars",1
; System Coefficients
scoff          .sect    "coeffh"
.include "impulse.h"

; RAM location for the System coefficient
hcoff          .usect   "bufferh", H_FILT_SIZE
wcoff          .usect   "bufferw", ADPT_FILT_SIZE ;

; RAM location for the input data
xh             .usect   "bufferx", H_FILT_SIZE    ; input data for system
xw             .usect   "bufferp", ADPT_FILT_SIZE ; input data for adaptive filter

; RAM location for filter outputs, residual error
; and temporary location for the new input sample.
ADAPT_DP       .usect   "adpt_var",0
d_primary      .usect   "adpt_var",1
d_output       .usect   "adpt_var",1
d_output       .usect   "adpt_var",1
d_mu           .usect   "adpt_var",1
d_mu_e         .usect   "adpt_var",1
d_new_x        .usect   "adpt_var",1
d_adapt_count  .usect   "adpt_var",1
Example 10–2. Memory Allocation for Entire Application (Continued)

; the 16 tap FIR coefficients
COFF_FIR_START .sect    "coff_fir"                ; filter coefficients
    .word 6Fh
    .word 0F3h
    .word 269h
    .word 50Dh
    .word 0C99h
    .word 0FF8h
    .word 11EBh
    .word 11EBh
    .word 0FF8h
    .word 0C99h
    .word 8A9h
    .word 8A9h
    .word 269h
    .word 0F3h
    .word 6Fh
COFF_FIR_END

; circular buffers for coefficients and data buffers
fir_coff_table .usect    "fir_coff", 20
    d_data_buffer   .usect    "fir_bfr", 40

; variables used in FIR routine
FIR_DP          .usect    "fir_vars",0
    d_filin         .usect    "fir_vars",1
    d_filout        .usect    "fir_vars",1

; variables used in IIR routine
IIR_DP          .usect    "iir_vars",0
    d_iir_d        . usect    "iir_vars",3*2
    d_iir_y         .usect    "iir_vars",1

iir_table_start
    ; second-order section # 01
    .word -26778            ; A2
    .word 29529             ; A1/2
    .word 19381             ; B2
    .word -23184            ; B1
    .word -19381            ; B0

    ; second-order section # 02
    .word -30497            ; A2
    .word 31131             ; A1/2
    .word 11363             ; B2
    .word -20735            ; B1
    .word 11363             ; B0

iir_table_end
iir_coff_table .usect    "coff_iir",16
; symmetric FIR filter coeffs
Example 10–2. Memory Allocation for Entire Application (Continued)

FIR_COFF .sect "sym_fir" ; filter coefficients
    .word 6Fh
    .word 0F3h
    .word 269h
    .word 50Dh
    .word 8A9h
    .word 0C99h
    .word 0FF8h
    .word 11EBh

; circular buffers used in symmetric filter routine
d_datax_buffer .usect "cir_bfr",20
d_datay_buffer .usect "cir_bfr1",20
.include "ref_tsk.inc"
task_list .sect "task_tbl" ; calls the tasks itself
    .word do_nothing
    .word echo_task ; Echo routine
    .word fir_task ; FIR routine
    .word iir_task
    .word sym_fir_task
    .word adapt_task
    .word rfft_task
task_init_list .sect "task_int" ; has the initialization of tasks
    .word do_nothing
    .word no_echo_init_task ; there is no init in this case
    .word fir_init
    .word iir_init
    .word sym_fir_init
    .word adapt_init
    .word do_nothing

; variables used in task handling routine
TASK_VAR_DP .usect "tsk_vars",0
present_command .usect "tsk_vars",1
last_command .usect "tsk_vars",1
d_task_addr .usect "tsk_vars",1
d_task_init_addr .usect "tsk_vars",1
d_buffer_count .usect "tsk_vars",1
d_output_addr .usect "tsk_vars",1
d_input_addr .usect "tsk_vars",1

; Set start addresses of buffers
fft_data .usect "fft_bfr", 4*K_FFT_SIZE ; fft data processing buffer
    .sect "sin_tbl"
sine_table .copy twiddle1 ; sine table
sine .usect "twid_sin",K_FFT_SIZE
    .sect "cos_tbl"
cos_table .copy twiddle2 ; cosine table
cosine .usect "twid_cos",K_FFT_SIZE

; Define variables for indexing input data and twiddle tables
FFT_DP .usect "fft_vars",0
d_grps_cnt .usect "fft_vars",1 ; (# groups in current stage)-1
d_twid_idx .usect "fft_vars",1
; index of twiddle tables
d_data_idx .usect "fft_vars",1 ; index of input data table
Example 10–2. Memory Allocation for Entire Application (Continued)

; variables used for host interface
FIFO_DP .usect "fifo_var",0
d_command_reg .usect "fifo_var",1
d_command_value .usect "fifo_var",1
d_fifo_count .usect "fifo_var",1
d_fifo_ptr .usect "fifo_var",1

; Filename : defines.inc
; this include file defines all the variables, buffers and pointers used for the entire
; application
.def STACK,SYSTEM_STACK
.def input_data, output_data
.def scoff, hcoff, wcoff, xh, xw
.def ADAPT_DP, d_primary, d_output, d_error
.def d_mu, d_mue, d_new_x, d_adapt_count
.def fir_coff_table, d_data_buffer
.def FIR_DP, d_filin, d_filout
.def COFF_FIR_START, COFF_FIR_END
.def IIR_DP, d_iir_d, d_iir_y
.def iir_coff_table
.def COFF_FIR_START, COFF_FIR_END
.def d_datax_buffer, d_datay_buffer
.def FIR_COFF
.def TASK_VAR_DP, present_command, last_command
.def d_task_addr, d_task_init_addr, d_buffer_count, d_output_addr
.def RCV_INTL_DP
.def d_rcv_in_ptr, d_xmt_out_ptr
.def d_frame_flag, d_index_count
.def fft_data, sine, cosine
.def FFT_DP, d_grps_cnt, d_twid_idx, d_data_idx
.def cos_table, sine_table
.def FIFO_DP
.def d_command_reg
.def d_fifo_count
.def d_fifo_ptr
; Filename: ref_tsk.inc
; this includes all the task scheduling table referenced labels
.ref do_nothing, echo_task, fir_task, iir_task
.ref sym_fir_task, fir_init, iir_init, sym_fir_init
.ref no_echo_init_task, fir_init, iir_init, sym_fir_init
.ref adapt_init
.def task_init_list, task_list
Example 10–3. Main Program That Calls Different Functions

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
;
; Archives: PVCS
; Filename: main.asm
; Version: 1.0
; Status : draft ( )
; proposal (X)
; accepted  ( ) dd-mm-yy/?acceptor.
;
; AUTHOR Padma P. Mallela
;
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
; IPR statements description (can be collected).
;
; (C) Copyright 1996. Texas Instruments. All rights reserved.
;
; Change history:
;
; VERSION      DATE     /     AUTHORS           COMMENT
;          1.0     July-24–96  /    P.Mallela      original created
;
; 1. ABSTRACT
;
; 1.1 Function Type
; a.Core Routine
; b.Subroutine
;
; 1.2 Functional Description
; This file contains main function
;
; 1.3 Specification/Design Reference (optional)
;
; 1.4 Module Test Document Reference
; Not done
;
; 1.5 Compilation Information
; Compiler: TMS320C54X ASSEMBLER
; Version: 1.02 (PC)
; Activation: asm500 –s main.asm
;
; 1.6 Notes and Special Considerations
;
; This code is written for 541 device. The code is tested on C54x EVM
Example 10–3. Main Program That Calls Different Functions (Continued)

;
{ 2. VOCABULARY

  2.1 Definition of Special Words, Keywords (optional)

  2.2 Local Compiler Flags

  2.3 Local Constants

};

{ 3. EXTERNAL RESOURCES

  3.1 Include Files

    .include "init_54x.inc"

  3.2 External Data

    .ref    d_frame_flag

    .ref    RCV_INT1_DP

  3.3 Import Functions

    .ref    aic_init,serial_init,init_54,init_bffr_ptr_var

    .ref    task_handler,evm_handshake,fifo_host_transfer

};

{ 4. INTERNAL RESOURCES

  4.1 Local Static Data

  4.2 Global Static Data

  4.3 Dynamic Data

  4.4 Temporary Data

  4.5 Export Functions

    .def    main_start

};

5. SUBROUTINE CODE

HeaderBegin
=================================================================================================
HeaderEnd

  5.1 main_start

  5.2 Functional Description

    This is the main function that calls other functions.

  5.3 Activation

    Activation example:
Example 10–3. Main Program That Calls Different Functions (Continued)

```assembly
;            BD      main_start
;            PSHM    ST0
;            PSHM    ST1
;
;            Reentrancy: No
;            Recursive : No
;
; 5.4 Inputs
;
; 5.5 Outputs
;
; 5.6 Global
;
; 5.7 Special considerations for data structure
;
; 5.8 Entry and Exit conditions
;
; |DP|OVM|SXM|C16|FRCT|ASM|AR0|AR1|AR2|AR3|AR4|AR5|AR6|AR7|A |B |BK|BRC| T|TRN|
;|  |   |   |   |    |   |   |   |   |   |   |   |   |   |  |  |  |   |  |   |
in |U | 1 | 1 |NU | 1  |NU |NU |NU |NU |NU |NU |NU |NU |NU |NU|NU|NU|NU |NU|NU |
;out|U | 1 | 1 |NU | 1  |NU |NU |NU |NU |NU |NU |NU |NU |NU |NU|NU|NU|NU |NU|NU |
;
; Note : UM – Used & Modified, U – Used, NU – Not Used
;
; 5.9 Execution
;     Execution time: ?cycles
;     Call rate: not applicable for this application
;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

;HeaderEnd
;
; 5.10 Code
;  .sect "main_prg"
***************************************************************************
* The code initializes the 541 device, handshake between Target (DSP) *
* and the host (PC). Zeros all buffers, variables and init. pointers *
* Initializes serial port, programs AC01 registers for selecting sampling *
* rate, gains etc..
***************************************************************************
main_start:
  CALL init_54 ; initialize ST0,ST1 PMST and
               ; other registers
  .if K_HOST_FLAG = 1
  CALL evm_handshake ; EVM host handshake
  .endif
  CALL init_bffr_ptr_var ; init tables,vars,bffrs,ptr
  CALL serial_init ; initialize serial_port 1
  CALLD aic_init ; Configures AC01
  LD  #0,DP
  NOP
```
Example 10–3. Main Program That Calls Different Functions (Continued)

* After enabling interrupts from the above, the real processing starts here.
* After collecting 256 samples from AC01 a flag (d_frame_flag is set).
* Handles the task initiated by the user and transfers the data to the
  host. Keeps the sequence forever !!!!

```
start_loop
LD   #RCV_INT1_DP,DP       ; restore the DP loop:
BITF d_frame_flag,1       ; if 256 samples are received
BC   loop,NTC             ; if not just loop back
CALL task_handler         ; handles task scheduling
CALL fifo_host_transfer   ; EVM HOST interface
B   loop
.end
```

* Includes all the constants — main.inc

```
K_0                     .set   0                ; constant
K_FIR_INDEX             .set   1                ; index count
K_FIR_BFFR              .set   16               ; FIR buffer size
K_neg1                  .set   –1h              ; index count
K_BIQUAD                .set   2                ; there are 2 bi-quad sections
K_IIR_SIZE              .set   10               ; each bi-quad has 5 coeffs
K_STACK_SIZE            .set   200               ; stack size
K_FRAME_SIZE            .set   256               ; PING/PONG buffer size
KFRAME_FLAG             .set   1                ; set after 256 collected
H_FILT_SIZE             .set   128               ; H(z) filter size
ADPT_FILT_SIZE          .set   128               ; W(z) filter size
K_mu                    .set   0h               ; initial step constant
K_HOST_FLAG             .set   1                ; Enable EVM_HOST interface
K_DEFAULT_AC01          .set   1h               ; default AC01 init
```

* This include file sets the FFT size for the 'C54x Real FFT code
* Note that the Real FFT size (i.e. the number of points in the
  original real input sequence) is 2N; whereas the FFT size is
* the number of complex points formed by packing the real inputs,
* which is N. For example, for a 256-pt Real FFT, K_FFT_SIZE
* should be set to 128 and K_LOGN should be set to 7.

```
K_FFT_SIZE             .set   128              ; # of complex points (=N)
K_LOGN                 .set   7                ; # of stages (=logN/log2)
K_ZERO_BR              .set   0
K_TWID_TBL_SIZE        .set   128              ; Twiddle table size
K_DATA_ID_1            .set   2                ; Data index for Stage 1
K_DATA_ID_2            .set   4                ; Data index for Stage 2
K_DATA_ID_3            .set   8                ; Data index for Stage 3
K_FLY_COUNT_3          .set   4                ; Butterfly counter for Stage 3
K_TWID_ID_3            .set   32               ; Twiddle index for Stage 3
```
Example 10–3. Main Program That Calls Different Functions (Continued)

FILENAME: INIT54x.INC

This include file contains all the initial values of ST0, ST1, PMST, SWWSR, BSCR registers

ST0 Register Organization

<table>
<thead>
<tr>
<th>15</th>
<th>13</th>
<th>12</th>
<th>11</th>
<th>10</th>
<th>9</th>
<th>8</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ARP</td>
<td>C</td>
<td>OVA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TC</td>
<td>C</td>
<td>OVB</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DP</td>
<td></td>
</tr>
</tbody>
</table>

K_ARP .set 000b<<13 ; ARP can be addressed from 00b –111b

K_TC .set 1b<<12 ; TC = 1 at reset

K_C .set 1b<<11 ; C = 1 at reset

K_OVA .set 1b<<10 ; OVA = 0 at reset, Set OVA

K_OVB .set 1b<<9 ; OVB = 0 at reset, Set OVB

K_DP .set 000000000b<<0 ; DP is cleared to 0 at reset

K_ST0 .set K_ARP|K_TC|K_C|K_OVA|K_OVB|K_DP

ST1 Register Organization

<table>
<thead>
<tr>
<th>15</th>
<th>14</th>
<th>13</th>
<th>12</th>
<th>11</th>
<th>9</th>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BRAF</td>
<td>CPL</td>
<td>XF</td>
<td>HM</td>
<td>INTM</td>
<td>OVM</td>
</tr>
</tbody>
</table>

K_BRAF .set 0b << 15 ; BRAF = 0 at reset

K_CPL .set 0b << 14 ; CPL = 0 at reset

K_XF .set 1b << 13 ; XF = 1 at reset

K_HM .set 0b << 12 ; HM = 0 at reset

K_INTM .set 1b << 11 ; INTM

K_ST1_RESR .set 0b << 10 ; reserved

K_OVM .set 1b << 9 ; OVM = 0 at reset

K_SXM .set 1b << 8 ; SXM = 1 at reset

K_C16 .set 0b << 07 ; C16 = 0 at reset

K_FRCT .set 1b << 06 ; FRCT = 0 at reset, Set FRCT

K_CMPT .set 0b << 05 ; CMPT = 0 at reset

K_ASM .set 000000b << 00 ; ASM = 0 at reset

K_ST1_HIGH .set K_BRAF|K_CPL|K_XF|K_HM|K_INTM|K_ST1_RESR|K_OVM|K_SXM

K_ST1_LOW .set K_C16|K_FRCT|K_CMPT|K_ASM

K_ST1 .set K_ST1_HIGH|K_ST1_LOW
Example 10–3. Main Program That Calls Different Functions (Continued)

*PMST Register Organization

<table>
<thead>
<tr>
<th>15 7 6 5 4 3 2 1 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPTR MP/MC OVLY AVIS DROM CLKOFF Reserved</td>
</tr>
</tbody>
</table>

K_IPTR .set 111111111b << 07 ; 111111111b at reset
K_MP_MC .set 1b << 06 ; 1 at reset
K_OVLY .set Ob << 05 ; OVLY = 0 at reset
K_AVIS .set Ob << 04 ; AVIS = 0 at reset
K_DROM .set Ob << 03 ; DROM = 0 at reset
K_CLKOFF .set Ob << 02 ; CLKOFF = 0 at reset
K_PMST_RESR .set OOb << 0 ; reserved

; for 548 bit 0 = SMUL ; saturation on multiply
; bit 1 = SST = saturation on store

K_PMST .set K_IPTR|K_MP_MC|K_OVLY|K_AVIS|K_DROM|K_CLKOFF|K_PMST_RESR

*SWWSR Register Organization

<table>
<thead>
<tr>
<th>15 14 12 11 9 8 6 5 3 2 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserved</td>
</tr>
</tbody>
</table>

K_SWWSR_IO .set 2000h ; set the I/O space

*Bank Switching Control Register (BSCR) Organization

<table>
<thead>
<tr>
<th>15 12 11 10 2 1 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNKCMP</td>
</tr>
</tbody>
</table>

K_BNKCMP .set 0000b << 12 ; bank size = 64K
K_PS_DS .set 0b << 11
K_BSCR_RESR .set 000000000b <<2 ; reserved space
K_BH .set 0b << 1 ; BH = 0 at reset
K_EXIO .set 0b << 0 ; EXIO = 0 at reset
K_BSCR .set K_BNKCMP|K_PS_DS|K_BSCR_RESR|K_BH|K_EXIO
Example 10–4. Processor Initialization

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
;
; Archives:    PVCS
; Filename:    init_54x.asm
; Version:     1.0
; Status :     draft ( )
; proposal     (X)
; accepted     ( ) dd-mm-yy/?acceptor.
;
; AUTHOR       Padma P. Mallela
;
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
; IPR statements description (can be collected).
;
; (C) Copyright 1996. Texas Instruments. All rights reserved.
;
; Change history:
;
; VERSION      DATE     /     AUTHORS           COMMENT
; 1.0      July-29-96  /    P.Mallela      original created
;
;
; 1. ABSTRACT
;
; 1.1 Function Type
; a.Core Routine
; b.Subroutine
;
; 1.2 Functional Description
; This file contains initialization of the processor
;
; 1.3 Specification/Design Reference (optional)
;
; 1.4 Module Test Document Reference
; Not done
;
; 1.5 Compilation Information
; Compiler:   TMS320C54X ASSEMBLER
; Version:    1.02 (PC)
; Activation:  asm500 -s init_54x.asm
;
; 1.6 Notes and Special Considerations
;
; This code is written for 541 device. The code is tested on C54x EVM
Example 10–4. Processor Initialization (Continued)

```c
};
;
};

2. VOCABULARY
;
2.1 Definition of Special Words, Keywords (optional)
    –
2.2 Local Compiler Flags
    –
2.3 Local Constants
    –
};
;
};

3. EXTERNAL RESOURCES
;
3.1 Include Files
    .mregs
    .include "init_54x.inc"
3.2 External Data
3.3 Import Functions
};
;
};

4. INTERNAL RESOURCES
;
4.1 Local Static Data
    –
4.2 Global Static Data
    –
4.3 Dynamic Data
    –
4.4 Temporary Data
    –
4.5 Export Functions
    .def init_54
};

5. SUBROUTINE CODE
;
    HeaderBegin

;==============================================================================
;––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––

5.1 init_54
;
5.2 Functional Description
    Initializes the processor from a reset state

5.3 Activation
    Activation example:
    CALL init_54
    Reentrancy: No
    Recursive: No
,
5.4 Inputs
```
Example 10–4. Processor Initialization (Continued)

; 5.5 Outputs
; 5.6 Global
; 5.7 Special considerations for data structure
; 5.8 Entry and Exit conditions
; |DP|OVM|SXM|C16|FRCT|ASM|AR0|AR1|AR2|AR3|AR4|AR5|AR6|AR7|A|B|BK|BRC|T|TRN|
; |   |   |   |   |    |   |   |   |   |   |   |   |   |   |  |  |  |   |  |   |
; in NU NU NU NU NU NU NU NU NU NU NU NU NU NU NU NU |
; out NU NU NU NU NU NU NU NU UM UM NU NU NU NU NU NU |
; Note : UM – Used & Modified, U – Used, NU – Not Used
; 5.9 Execution
; Execution time: ?cycles
; Call rate: not applicable for this application
; HeaderEnd
; 5.10 Code
.sect "main_prg"
.init_54:
; Init.the s/w wait state reg.for 2 wait states for I/O operations
STM      #K_SWSR_IO, SWSR ; 2 wait states for I/O operations
; wait states for Bank Switch
STM      #K_BSCR, BSCR ; 0 wait states for BANK SWITCH
; initialize the status and control registers
STM      #K_ST0, ST0
STM      #K_ST1, ST1
RETD
STM      #K_PMST, PMST
.end
Example 10–5. Handshake Between Host and Target

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
;
; Archives:    PVCS
; Filename:    hand_shk.asm
; Version:     1.0
; Status :     draft ( )
; proposal    (X)
; accepted    ( ) dd-mm-yy/?acceptor.
;
; AUTHOR       Padma P. Mallela
;
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
; IPR statements description (can be collected).
;
; (C) Copyright 1996. Texas Instruments. All rights reserved.
;
; Change history:
;
; VERSION       DATE     /     AUTHORS           COMMENT
; 1.0     July-26–96   /    P.Mallela      original created
;
; 1. ABSTRACT
;
; Function Type
; a.Core Routine
; b.Subroutine
;
; 1.2 Functional Description
; This file contains one subroutine:
; 1) evm_handshake
;
; 1.3 Specification/Design Reference (optional)
; called by main.asm depending upon if K_HOST_FLAG is set
;
; Module Test Document Reference
; Not done
;
; 1.5 Compilation Information
; Compiler: TMS320C54X ASSEMBLER
; Version: 1.02 (PC)
; Activation: asm500 -s hand_shk.asm
;
; 1.6 Notes and Special Considerations
; -
Example 10–5. Handshake Between Host and Target (Continued)

; 2. VOCABULARY
; 2.1 Definition of Special Words, Keywords (optional)
; -
; 2.2 Local Compiler Flags
; -
; 2.3 Local Constants
; -
;
;
3. EXTERNAL RESOURCES
;
; 3.1 Include Files
   .mmregs
   .include "target.inc"
   .include "init_54x.inc"
   .include "interrupt.inc"
; 3.2 External Data
   .ref FIFO_DP
   .ref d_command_reg
   .ref d_command_value
; 3.3 Import Functions
;
;
4. INTERNAL RESOURCES
;
; 4.1 Local Static Data
; -
; 4.2 Global Static Data
; -
; 4.3 Dynamic Data
; -
; 4.4 Temporary Data
; -
; 4.5 Export Functions
   .def evm_handshake
;
;
5. SUBROUTINE CODE
   HeaderBegin
   ==============================================================
   ==============================================================
   5.1 evm_handshake
   /
Example 10–5. Handshake Between Host and Target (Continued)

; 5.2 Functional Description
; This initiates the handshake between the host (PC) and the target (DSP).
; The host writes a command to CH A. This generates an INT1 on the target.
; The AXST bit on HCR is set to 1. The bit in IFR is polled if it is set
; then it is cleared to clear pending interrupts. The FIFO is cleared
; by reading from the FIFO. The command from host is read thru CH A and
; ARST on TCR is cleared. Another command from target is written to CH A,
; which sets AXST. Also sets XF low. The host polls XF line. The host reads
; CH A which clears ARST on host side and AXST on target side.
;
; 5.3 Activation
; Activation example:
; CALL    evm_handshake
; Reentrancy: No
; Recursive : No
;
; 5.4 Inputs
; NONE
; 5.5 Outputs
; NONE
;
; 5.6 Global
; Data structure: d_command_reg
; Data Format: 16-bit variable
; Modified: Yes
; Description: command from host is read thru CH A
;
; Data structure: d_command_value
; Data Format: 16-bit variable
; Modified: Yes
; Description: holds the command value
;
; 5.7 Special considerations for data structure
;
; 5.8 Entry and Exit conditions
;
; 5.9 Execution
; Execution time: ?cycles
; Call rate: not applicable for this application
;
Example 10–5. Handshake Between Host and Target (Continued)

; HeaderEnd
; 5.10 Code
.sect "handshake"
evm_handshake:
   LD   #0,DP
   BITF IFR,02h ; Poll for INT1
   BC   evm_handshake,NTC ; ARST = 1
   STM  #K_INT1,IFR ; clear the pending interrupt
   LD   #FIFO_DP,DP
   RPT  #K_FIFO_SIZE-1
   PORTR K_CHB,d_command_reg ; assures that FIFO is empty to
   PORTR K_CHA,d_command_value ; ARST = 0
   target_handshake_command: ; read the command from HOST
   ; to acknowledge INT1
   PORTR K_TRGCR_ADDR,d_command_reg ; while (port14 & ARST)
   BITF d_command_reg,K_ARST ; check FIFO empty
   BC   target_handshake_command,TC ; branch occurs
   LD   #K_HANDSHAKE_CMD,A ; indicate of FIFO empty
   SUB  d_command_value,A
   bad_handshake_command
   BC   bad_handshake_command,ANEQ ; read the command send by hosts
   ST   #K_AXST_CLEAR,d_command_reg ; send to a command to clear AXST
   PORTW d_command_reg, K_CHA ; write command to command reg A
   RSBX XF ; AXST = 1
   ; XF = 0
   RET
.end
Example 10–6. Initialization of Variables, Pointers, and Buffers

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
;
; Archives: PVCS
; Filename: prcs_int.asm
; Version: 1.0
; Status : draft ( )
; proposal ( )
; accepted ( ) dd-mm-yy/?acceptor.
;
; AUTHOR Padma P. Mallela
;
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
; (C) Copyright 1996. Texas Instruments. All rights reserved.
;
; Change history:
;
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<th>COMMENT</th>
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<td>1.0</td>
<td>July-29-96</td>
<td>P.Mallela</td>
<td>original created</td>
</tr>
</tbody>
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1. ABSTRACT

1.1 Function Type
a.Core Routine
b.Subroutine

1.2 Functional Description
This file contains initialization of buffers, pointers and variables

1.3 Specification/Design Reference (optional)

1.4 Module Test Document Reference
Not done

1.5 Compilation Information
Compiler: TMS320C54X ASSEMBLER
Version: 1.02 (PC)
Activation: asm500 -s prcs_int.asm

1.6 Notes and Special Considerations

This code is written for 541 device. The code is tested on C54x EVM
Example 10–6. Initialization of Variables, Pointers, and Buffers (Continued)

```c
};
;
2. VOCABULARY
};
2.1 Definition of Special Words, Keywords (optional)
    –
2.2 Local Compiler Flags
    –
2.3 Local Constants
    –
};
};
3. EXTERNAL RESOURCES
};
3.1 Include Files
    .mmregs
    .include "main.inc"
3.2 External Data
    .ref input_data,output_data
    .ref present_command
    .ref d_rcv_in_ptr,d_xmt_out_ptr
    .ref RCV_INT1_DP
    .ref d_buffer_count
3.3 Import Functions
};
};
4. INTERNAL RESOURCES
};
4.1 Local Static Data
    –
4.2 Global Static Data
    –
4.3 Dynamic Data
    –
4.4 Temporary Data
    –
4.5 Export Functions
    .def init_bffr_ptr_var
};
5. SUBROUTINE CODE
};
HeaderBegin
================================================================================

5.1 init_bffr_ptr
};
5.2 Functional Description
    This routine initializes all the buffers, pointers and variables
================================================================================
;
Example 10–6. Initialization of Variables, Pointers, and Buffers (Continued)

; 5.3 Activation
;    Activation example:
;        CALL    init_bfr_ptr_var
;        Reentrancy:  No
;        Recursive :  No
;
; 5.4 Inputs
;    NONE
; 5.5 Outputs
;    NONE
; 5.6 Global
;
;    Data structure:  AR2
;    Data Format:    16-bit input buffer pointer
;    Modified:       Yes
;    Description:    initialize to the starting address
;
;    Data structure:  AR3
;    Data Format:    16-bit output buffer pointer
;    Modified:       Yes
;    Description:    initialize to the starting address
;
;    Data structure:  present_command
;    Data Format:    16-bit variable
;    Modified:       Yes
;    Description:    holds the present command
;
;    Data structure:  input_data
;    Data Format:    16-bit array
;    Modified:       Yes
;    Description:    address of the input data buffer
;
;    Data structure:  output_data
;    Data Format:    16-bit array
;    Modified:       Yes
;    Description:    address of the output data buffer
;
;    Data structure:  d_rcv_in_ptr
;    Data Format:    16-bit var
;    Modified:       Yes
;    Description:    holds the starting address of input bfr
;
;    Data structure:  d_xmt_out_ptr
;    Data Format:    16-bit variable
;    Modified:       Yes
;    Description:    holds the starting address of output bfr
;
; 5.7 Special considerations for data structure
;
Example 10–6. Initialization of Variables, Pointers, and Buffers (Continued)

; 5.8 Entry and Exit conditions
;
; in | DP | OVM | SXM | C16 | FRCT | AR0 | AR1 | AR2 | AR3 | AR4 | AR5 | AR6 | AR7 | A | B | BK | BRC | T | TRN |
; 0  1  1  NU  1  NU  NU  NU  NU  NU  NU  NU  NU  0  NU  NU  NU  NU  | 0  1  1  NU  1  NU  UM  UM  UM  NU  NU  NU  UM  0  NU  NU  NU  NU  |
; out| 2  1  1  NU  1  NU  UM  UM  UM  NU  NU  NU  UM  0  NU  NU  NU  NU  |
; Note : UM – Used & Modified, U – Used, NU – Not Used
;
; 5.9 Execution
; Execution time: ?cycles
; Call rate: not applicable for this application
;==============================================================================

; 5.10 Code

; zero pad pointer
; get frame input data pointer
; get frame output data pointer
; zero pad

init_bffr_ptr_var:
STM #RCV_INT1_DP,AR2 ; init all vars to 0
RPTZ A,K_FRAME_SIZE/2-1 ; this may need mods if all vars
STM #input_data,GETFRM_IN_P ; input buffer ptr
STM #output_data,GETFRM_OUT_P ; output buffer ptr
LD #RCV_INT1_DP,DP
MVKD GETFRM_IN_P,d_rcv_in_ptr ; holds present in. bffr ptr
MVKD GETFRM_OUT_P,d_xmt_out_ptr ; holds present out bffr ptr
ST #3,present_command ; initialize present command
STM #input_data,ZRPAD_P ; reset the buffer count
RPTZ A,2*K_FRAME_SIZE-1 ; zeropad both bottom 256 in-
put_data
STM A, *ZRPAD_P+ ; and fft_data buffers
STM #output_data,ZRPAD_P
RPTZ A,2*K_FRAME_SIZE-1
STL A, *ZRPAD_P+
RET
Example 10–7. **Initialization of Serial Port 1**

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
;
; Archives:    PVCS
; Filename:    init_ser.asm
; Version:     1.0
; Status :     draft     ( )
;             proposal   (X)
;             accepted   ( ) dd-mm-yy/?acceptor.
;
; AUTHOR     Padma P. Mallela/Ramesh A Iyer
;
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
; IPR statements description (can be collected).
;
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;
; Change history:
;
<table>
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<tr>
<td>1.0</td>
<td>July-29–96</td>
<td>P.Mallela</td>
<td>original created</td>
</tr>
</tbody>
</table>
;
1. ABSTRACT

1.1 Function Type
   a.Core Routine
   b.Subroutine

1.2 Functional Description
   This file contains the initialization of the serial port 1

1.3 Specification/Design Reference (optional)

1.4 Module Test Document Reference
   Not done

1.5 Compilation Information
   Compiler:    TMS320C54X  ASSEMBLER
   Version:     1.02 (PC)
   Activation:  asm500 -s init_ser.asm

1.6 Notes and Special Considerations
{
   This code is written for 541 device. The code is tested on C54x EVM ;
Example 10–7. Initialization of Serial Port 1 (Continued)

```c
;
2. VOCABULARY
;
2.1 Definition of Special Words, Keywords (optional)
2.2 Local Compiler Flags
2.3 Local Constants
;
2.1 Include Files
.include "interrupt.inc"
.include "init_ser.inc"
;
3. EXTERNAL RESOURCES
;
3.1 Include Files

3.2 External Data
NONE
;
3.3 Import Functions
NONE
;
4. INTERNAL RESOURCES
;
4.1 Local Static Data
AIC_VAR_DP .usect "aic_vars",0
aic_in_rst .usect "aic_vars",1
aic_out_of_rst .usect "aic_vars",1
;
4.2 Global Static Data
;
4.3 Dynamic Data
;
4.4 Temporary Data
;
4.5 Export Functions
.def serial_init
;
5. SUBROUTINE CODE
HeaderBegin
==============================================================================

5.1 serial_init
;
5.2 Functional Description
This routine initializes the serial port 1 of 541. The serial port is put in reset by writing 0's to RRST and XRST bits and pulled out of reset by writing 1's to both RRST and XRST bits. This routine also puts the AC01 in reset and after 12 cycles the AC01 is pulled out of reset. The serial port initialization is done during the 12 cycle latency of the AC01 init.
```

PRELIMINARY
Example 10–7. Initialization of Serial Port 1 (Continued)

};
}; 5.3 Activation
    Activation example:
    CALL     serial_init
    Reentrancy: No
    Recursive : No

5.4 Inputs

5.5 Outputs

5.6 Global
    Data structure: aic_in_rst
    Data Format: 16-bit variable
    Modified: Yes
    Description: holds the value to put AC01 in reset state
    Data structure: aic_out_of_reset
    Data Format: 16-bit variable
    Modified: Yes
    Description: holds the value to put AC01 out of reset state

5.7 Special considerations for data structure
    -

5.8 Entry and Exit conditions

|DP|OVM|SXM|C16|FRCT|ASM|AR0|AR1|AR2|AR3|AR4|AR5|AR6|AR7|A |B |BK|BRC| T|TRN|
|---|---|---|---|----|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
in | 0 | 1 | 1 | NU | 1  | NU | NU | NU | NU | NU | NU | NU | NU | NU | NU | NU |
|out| U | 1 | 1 | NU | 1  | NU | NU | NU | NU | NU | NU | NU | NU | NU | NU | NU |

Note : UM – Used & Modified, U – Used, NU – Not Used

5.9 Execution
    Execution time: ?cycles
    Call rate: not applicable for this application

5.10 Code

.serial_init:
    LD     #AIC_VAR_DP,DP    ; initialize DP for aic_reset
    ST     #K_0, aic_in_rst  ; bit 15 = 0 of TCR resets AIC
    PORTW  aic_in_rst,K_TRGCR_ADDR  ; write to address 14h (TCR)

*We need at least 12 cycles to pull the AIC out of reset.

==============================================================================

HeaderEnd

5.10 Code

.sect "ser_cfg"

serial_init:

LD     #AIC_VAR_DP,DP    ; initialize DP for aic_reset
ST     #K_0, aic_in_rst  ; bit 15 = 0 of TCR resets AIC
PORTW  aic_in_rst,K_TRGCR_ADDR  ; write to address 14h (TCR)

*We need at least 12 cycles to pull the AIC out of reset.

==============================================================================
Example 10–7. Initialization of Serial Port 1 (Continued)

```assembly
STM  #K_SERIAL_RST, SPC1    ; reset the serial port with
     ; 0000 0000 0000 1000
STM  #K_SERIAL_OUT_RST, SPC1 ; bring ser.port out of reset
     ; 0000 0000 1100 1000
RSBX  INTM
LD    #0,DP
ORM   #(K_RINT1|K_INT1),IMR ; Enable RINT1,INT1
     ; 0000 0000 0100 0010
LD    #AIC_VAR_DP,DP ; restore DP
STM   #(K_RINT1),IFR ; clear RINT1
STM   #K_0,DXR1        ; 0000 0000 0100 0000
; Pull the AC01 out of reset – the AC01 requires that it be held in reset for
; 1 MCLK, which is equivalent to 96.45ns (based on an MCLK of 10.368MHz)
ST    #K_8000, aic_out_of_rst ; bit 15 = 1 brings AIC from
     ; reset
RETD
PORTW aic_out_of_rst, K_TRGCR_ADDR ; AIC out of reset
.end
```

* FILENAME: "INIT_SER.INC"

<table>
<thead>
<tr>
<th>15</th>
<th>14</th>
<th>13</th>
<th>12</th>
<th>11</th>
<th>10</th>
<th>9</th>
<th>8</th>
</tr>
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<tr>
<td>FREE</td>
<td>SOFT</td>
<td>RSRFULL</td>
<td>XSREEMPTY</td>
<td>XRDY</td>
<td>RRDY</td>
<td>IN1</td>
<td>IN0</td>
</tr>
<tr>
<td>-----</td>
<td>-----</td>
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<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
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<tr>
<td>RRST</td>
<td>XSRST</td>
<td>TXM</td>
<td>MCM</td>
<td>FSM</td>
<td>FO</td>
<td>DLB</td>
<td>RES</td>
</tr>
</tbody>
</table>

* This include file includes the SPC1 register configuration

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<thead>
<tr>
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<th>Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Reserved</td>
<td>Always read as 0</td>
</tr>
<tr>
<td>1</td>
<td>DLB</td>
<td>Digital loop back: 0 -&gt; Disabled, 1_Enabled</td>
</tr>
<tr>
<td>2</td>
<td>FO</td>
<td>Format bit: 0 -&gt; data transferred as 8 bit bytes, 1 -&gt; 16 bit words</td>
</tr>
<tr>
<td>3</td>
<td>FSM</td>
<td>Frame sync pulse: 0 -&gt; serial port in continuous mode, 1 -&gt; FSM</td>
</tr>
<tr>
<td>4</td>
<td>MCM</td>
<td>Clock mode bit: 0 -&gt; CLKX obtained from CLKX pin 1 -&gt; CLKX</td>
</tr>
<tr>
<td>5</td>
<td>TXM</td>
<td>Transmit mode bit: 0 -&gt; Frame sync pulses generated externally and supplied on FSX pin, 1 -&gt; Internally generated frame sync pulses out on FSX pin</td>
</tr>
<tr>
<td>6</td>
<td>XRSRST</td>
<td>Transmit reset bit: 0 -&gt; reset the serial port, 1 -&gt; bring serial port out of reset</td>
</tr>
<tr>
<td>7</td>
<td>RRSRST</td>
<td>Receive reset bit: 0 -&gt; reset the serial port, 1 -&gt; bring serial port out of reset</td>
</tr>
<tr>
<td>8</td>
<td>IN0</td>
<td>Read-only bit reflecting the state of the CLKR pin</td>
</tr>
<tr>
<td>9</td>
<td>IN1</td>
<td>Read-only bit reflecting the state of the CLKX pin</td>
</tr>
<tr>
<td>10</td>
<td>RRDY</td>
<td>Transition from 0 to 1 indicates data is ready to be read</td>
</tr>
<tr>
<td>11</td>
<td>XRDY</td>
<td>Transition from 0 to 1 indicates data is ready to be sent</td>
</tr>
</tbody>
</table>
Example 10–7. Initialization of Serial Port 1 (Continued)

;12 XSREMPHY Transmit shift register empty (Read–only) 0 -> transmitter has experienced underflow
;13 RSRFUL Receive shift register full flag (Read–only): 0 -> Receiver has experienced overrun
;14 SOFT Soft bit – 0 -> immediate stop, 1 -> stop after word completion
;15 FREE Free run bit: 0 -> behaviour depends on SOFT bit, 1 -> free run regardless of SOFT bit

; The system has the following configuration:
; Uses 16-bit data => FO = 0
; Operates in burst mode => FSM = 1
; CLKX is derived from CLKX pin => MCM = 0
; Frame sync pulses are generated externally by the AIC => TXM = 0
; Therefore, to reset the serial port, the SPC field would have
; 0000 0000 0000 1000
; To pull the serial port out of reset, the SPC field would have
; 0000 0000 1100 1000

K_0             .set     00000000b << 8    ; bits 15–8 to 0 at reset
K_RRST          .set     0b << 7           ; first write to SPC1 is 0
K_XRST          .set     0b << 6           ; second write to SPC1 is 0
K_TXM           .set     0b << 5           ; Frame Sync mode
K_MCM           .set     0b << 4
K_FSM             .set     1b << 3           ; Frame Sync mode
K_ZERO            .set     000b << 0
K_SERIAL_RST      .set     K_0|K_RRST|K_XRST|K_TXM|K_MCM|K_FSM|K_ZERO
K_RRST1           .set    1b << 7             ; second write to SPC1 register
K_XRST1           .set    1b << 6             ; second write to SPC1
K_SERIAL_OUT_RST  .set    K_0|K_RRST1|K_XRST1|K_TXM|K_MCM|K_FSM|K_ZERO
K_TRGCR_ADDR      .set    14h                 ; Target/Status I/O address

K_0               .set    0h
K_8000            .set    8000h               ; set bit 15 to pull AIC out
K_TRGCR_ADDR      .set    14h                 ; of reset

* FILENAME: INTERRUPT.INC

* This file includes the IMR and IFR configuration

K_IMR_RESR        .set    00000000b << 9       ; reserved space
K_INT3            .set    1b << 8             ; disable INT3
K_XINT1           .set    1b << 7             ; disable transmit interrupt 1
K_RINT1           .set    1b << 6             ; enable receive interrupt 1
K_XINT0           .set    1b << 5             ; disable transmit interrupt 0
K_RINT0           .set    1b << 4             ; disable receive interrupt
K_TINT            .set    1b << 3             ; disable timer interrupt
K_INT2            .set    1b << 2             ; disable INT2
K_INT1            .set    1b << 1             ; disable INT1
K_INT0            .set    1b << 1             ; enable INT0
Example 10–8. 'AC01 Initialization

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
;
; Archives: PVCS
; Filename: init_aic.asm
; Version: 1.0
; Status : draft ( )
; proposal (X)
; accepted ( ) dd-mm-yy/?acceptor.
;
; AUTHOR Padma P. Mallela/Ramesh A. Iyer
;
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
{ IPR statements description (can be collected). }

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{ Change history:

<table>
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<th>VERSION</th>
<th>DATE</th>
<th>AUTHORS</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>July-29-96/</td>
<td>P.Mallela</td>
<td>original created</td>
</tr>
</tbody>
</table>

1. ABSTRACT

1.1 Function Type
   a. Core Routine
   b. Subroutine

1.2 Functional Description
   This file contains the initialization of AC01

1.3 Specification/Design Reference (optional)

1.4 Module Test Document Reference
   Not done

1.5 Compilation Information
   Compiler: TMS320C54X ASSEMBLER
   Version: 1.02 (PC)
   Activation: asm500 -s init_aic.asm

1.6 Notes and Special Considerations
   This code is written for 541 device. The code is tested on C54x EVM ;

10-38
Example 10–8. 'AC01 Initialization (Continued)
{
    2. VOCABULARY
    -
    2.1 Definition of Special Words, Keywords (optional)
    -
    2.2 Local Compiler Flags
    -
    2.3 Local Constants
    -
}
{
    3. EXTERNAL RESOURCES
    -
    3.1 Include Files
        .mmregs
        .include "interrupt.inc"
    -
    3.2 External Data
        NONE
    -
    3.3 Import Functions
        .ref wrt_cnfg                           ; initializes AC01
    -
}
{
    4. INTERNAL RESOURCES
    -
    4.1 Local Static Data
    -
    4.2 Global Static Data
    -
    4.3 Dynamic Data
    -
    4.4 Temporary Data
    -
    4.5 Export Functions
        .def aic_init
    -
}
{
    5. SUBROUTINE CODE
    HeaderBegin
    ===============================================================================
    ...
    ===============================================================================
    5.1 aic_init
    5.2 Functional Description
    This routine disables IMR and clears any pending interrupts before
    initializing AC01. The wrt_cnfg function configures the AC01
    ...
    5.3 Activation
    Activation example:
        CALL aic_init
    Reentrancy: No
    Recursive : No
Example 10–8. 'AC01 Initialization (Continued)

; 5.4 Inputs
; 5.5 Outputs
; 5.6 Global
; 5.7 Special considerations for data structure
; 5.8 Entry and Exit conditions
;
| DP | OVM | SXM | C16 | FRCT | ASM | AR0 | AR1 | AR2 | AR3 | AR4 | AR5 | AR6 | AR7 | A | B | BK | BRC | T | TRN |
|----|-----|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|   |   |    |    |   |     |
| 0  | 0   | 1   | 1   | NU   | 1   | NU  | NU  | NU  | NU  | NU  | NU  | NU  | NU  |  |  |  |  |   |     |
| 0  | 1   | 1   | 1   | NU   | 1   | NU  | NU  | NU  | NU  | NU  | NU  | NU  | NU  |  |  |  |  |   |     |

Note: UM – Used & Modified, U – Used, NU – Not Used

5.9 Execution
Execution time: ?cycles
Call rate: not applicable for this application

HeaderEnd
5.10 Code
.sect "aic_cfgn"
aic_init:
    CALLD wrt_cnfg ; initialize AC01
    ANDM (#(~K_RINT1|K_INT1),IMR ; disable receive_int1,INT1
    ORM #(K_RINT1|K_INT1),IMR ; enable the RINT1, INT1
    RETD
    STM (K_RINT1),IFR ; service any pending interrupt
.end

**************************************************************************
* This file includes the AC01 registers initialization
* All registers have 2 control bits that initiates serial communication
* There are 2 communication modes – primary and secondary communications
* During primary communication the control bits D00 and D01 are 11 to request
* for a secondary communication. In the secondary serial communications the
* control bits D15 and D14 perform same control function as primary.
* The R/W~ bit at reset is set to 0 placing the device in write mode.
**************************************************************************
K_NOP_ADDR .set 0 << 8
K_REG_0 .set K_NOP_ADDR
K_A_ADDR .set 1 << 8 ; REG 1 address
K_REG_1 .set 36 ;
K_REG_2 .set K_A_ADDR|K_REG_1 ; FCLK = 144KHz => A = 24h
K_B_ADDR .set 2 << 8 ; REG 2 address
K_REG_3 .set 18 ;
K_REG_4 .set K_B_ADDR|K_REG_3 ; Sampling rate = 8KHz
K_REG_5 .set 3 << 8 ; Register 3 address
K_REG_6 .set 0 ;
Example 10–8. ‘AC01 Initialization (Continued)

K_REG_3 .set K_AA_ADDR|K_AA_REG; ; no shift
K_GAIN_ADDR .set 4 << 8 ; Register 4 address
K_MONITOR_GAIN .set 00b << 4 ; Monitor output gain = squelch
K_ANLG_IN_GAIN .set 01b << 2 ; Analog input gain = 0dB
K_ANLG_OUT_GAIN .set 01b << 0 ; Analog output gain = 0dB
K_REG_4 .set K_GAIN_ADDR|K_MONITOR_GAIN|K_ANLG_IN_GAIN|K_ANLG_OUT_GAIN
K_ANLG_CNFR_ADDR .set 5 << 8 ; Register 5 address
K_ANLG_RESRV .set 0 << 3 ; Must be set to 0K_HGH_FILTER .set 0 << 2 ; High pass filter is enabled
K_ENBL_IN .set 01b << 0 ; Enables IN+ and IN-
K_REG_5 .set K_ANLG_CNFR_ADDR|K_ANLG_RESRV|K_HGH_FILTER|K_ENBL_IN
K_DGTL_CNFR_ADDR .set 6 << 8 ; Register 6 address
K_ADC_DAC .set 0 << 5 ; ADC and DAC is inactive
K_FSD_OUT .set 0 << 4 ; Enabled FSD output
K_16_BIT_COMM .set 0 << 3 ; Normal 16-bit mode
K_SECND_COMM .set 0 << 2 ; Normal secondary communication
K_SOFT_RESET .set 0 << 1 ; Inactive reset
K_POWER_DWN .set 0 << 0 ; Power down external
K_REG_HIGH_6 .set K_DGTL_CNFR_ADDR|K_ADC_DAC|K_FSD_OUT|K_16_BIT_COMM
K_REG_LOW_6 .set K_SECND_COMM|K_SOFT_RESET|K_POWER_DWN
K_FRME_SYN_ADDR .set 7 << 8 ; Register 7 address
K_FRME_SYN .set 0 << 8 ;
K_REG_7 .set K_FRME_SYN_ADDR|K_FRME_SYN
K_FRME_NUM_ADDR .set 8 << 8 ; Register 8 address
K_FRME_NUM .set 0 << 8 ;
K_REG_8 .set K_FRME_NUM_ADDR|K_FRME_NUM
; primary word with D01 and D00 bits set to 11 will cause a
; secondary communications interval to start when the frame
; sync goes low next
K_SCND_CONNTR .set 11b << 0 ; Secondary comm.bits
AIC_REG_START_LIST .sect "aic_reg" ; includes the aic table
AIC_REG_END_LIST
K_XRDY .set 0800h ; XRDY bit in SPC1
AIC_REG_END_LIST
K_XRDY .set 0800h ; XRDY bit in SPC1
aic_init:
CALLD wrt_cnfr ; initialize AC01
ANDM #(~K_RINT1),IMR ; disable receive_int1
ORM #(K_RINT1|K_INT1),IMR ; enable the RINT1, INT1
RETD
STM #(K_RINT1),IFR ; service any pending interrupt
.end
Example 10–9. ’AC01 Register Configuration

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
;
; Archives: PVCS
; Filename: aic_cfg.asm
; Version: 1.0
; Status : draft ( )
; proposal (X)
; accepted ( ) dd-mm-yy/?acceptor.
;
; AUTHOR Padma P. Mallela/Ramesh A. Iyer
;
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
;
; IPR statements description (can be collected).
;
; (C) Copyright 1996. Texas Instruments. All rights reserved.
;
; Change history:
;
; VERSION      DATE     /    AUTHORS           COMMENT
; 1.0     July–25–96  /   P.Mallela      original created
;
;
1. ABSTRACT

1.1 Function Type
   a.Core Routine
   b.Subroutine

1.2 Functional Description
   This file contains the AC01 initialization

1.3 Specification/Design Reference (optional)

1.4 Module Test Document Reference
   Not done

1.5 Compilation Information
   Compiler: TMS320C54X ASSEMBLER
   Version: 1.02 (PC)
   Activation: asm500 -s aic_cfg.asm

1.6 Notes and Special Considerations


Example 10-9.  ‘AC01 Register Configuration (Continued)

};
;
2. VOCABULARY
;
2.1 Definition of Special Words, Keywords (optional)
-
2.2 Local Compiler Flags
-
2.3 Local Constants
-
);
;
3. EXTERNAL RESOURCES
;
3.1 Include Files
    .mmregs
    .include "aic_cfg.inc"
;
3.2 External Data
;
3.3 Import Functions
;
);
;
4. INTERNAL RESOURCES
;
4.1 Local Static Data
-
4.2 Global Static Data
-
4.3 Dynamic Data
-
4.4 Temporary Data
-
4.5 Export Functions
    .def wrt_cnfg
;
);
5. SUBROUTINE CODE
;
    HeaderBegin

===============================================

===============================================

5.1 wrt_cnfg
;
;
5.2 Functional Description
;
    Writes new configuration data into the AC01. Assuming a system
    which processes speech signals and * requires the following parameters
    Low pass filter cut-off frequency = 3.6 kHz
    Sampling rate = 8000 Hz
    Assume the Master clock MCLK = 10.368 MHz
    This example demonstrates how to program these parameters –
    the registers affected are:
    Register A which determines the division of the MCLK frequency
    to generate the internal filter clock FCLK.
    It also determines the -3 dB corner frequency of the low-pass filter
    Register B which determines the division of FCLK to generate
    the sampling (conversion) frequency
Example 10–9. ‘AC01 Register Configuration (Continued)

It also determines the -3dB corner frequency of the high-pass filter

5.3 Activation
Activation example:
CALLD wrt_cnf
STM #K_RINT1,IFR

Reentrancy: No
Recursive: No

5.4 Inputs
NONE

5.5 Outputs
NONE

5.6 Global
Data structure: AR1
Data Format: 16-bit pointer
Modified: No
Description: indexes the table

5.7 Special considerations for data structure

5.8 Entry and Exit conditions

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<th>OVM</th>
<th>SXM</th>
<th>C16</th>
<th>FRCT</th>
<th>ASM</th>
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<th>AR2</th>
<th>AR3</th>
<th>AR4</th>
<th>AR5</th>
<th>AR6</th>
<th>AR7</th>
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<td>UM</td>
</tr>
</tbody>
</table>

Note: UM – Used & Modified, U – Used, NU – Not Used

5.9 Execution
Execution time: ?cycles
Call rate: not applicable for this application

5.10 Code

```
.coinc AR1,AIC_REG_P
    .sect "aic_cnf" wrt_cnf:
    STM #aic_reg_tble,AIC_REG_P ; init AR1
    RPT #AIC_REG_END_LIST-AIC_REG_START_LIST
    MVPD #AIC_REG_START_LIST,*AIC_REG_P+ ; move the table
    STM #aic_reg_tble,AIC_REG_P ; init AR1
    STM #K_REG_0,DXR1 ; primary data word –
                        ; a jump start!
```

PRELIMINARY
Example 10–9. ‘AC01 Register Configuration (Continued)

```assembly
wait_xrdy
    BITF   SPC1,K_XRDY                  ; test XRDY bit in SPC1
    BC     wait_xrdy,NTC                ; loop if not set
    STM    #K_SCND_CONTRL,DXR1          ; send primary word with
                                           ; D01-D00 = 11 to
                                           ; signify secondary communication
    LD     *AIC_REG_P+,A                ; gives the # of registers to be
                                           ; initialized
    STLM   A,BRC
    NOP
    RPTB   aic_cfg_complte-1
wait_xrdy1
    BITF   SPC1,K_XRDY                  ; test XRDY bit in SPC1
    BC     wait_xrdy1,NTC               ; loop if not set
    LD     *AIC_REG_P+,A                ; Read the register contents
    STLM   A,DXR1
wait_xrdy2
    BITF   SPC1,K_XRDY                  ; test XRDY bit in SPC1
    BC     wait_xrdy2,NTC               ; loop if not set
    STM    #K_SCND_CONTRL,DXR1          ; set to read the next register
    aic_cfg_complte                     ; contents
wait_xrdy3
    BITF   SPC1,K_XRDY                  ; test XRDY bit in SPC1
    BC     wait_xrdy3,NTC               ; loop if not set
    RET
```
Example 10–10. Receive Interrupt Service Routine

`; TEXAS INSTRUMENTS INCORPORATED
`; DSP Data Communication System Development / ASP
`; Archives: PVCS
`; Filename: rcv_int1.asm
`; Version: 1.0
`; Status : draft ( )
`; proposal (X)
`; accepted ( ) dd-mm-yy/?acceptor.
`; AUTHOR Padma P. Mallela
`; Application Specific Products
`; Data Communication System Development
`; 12203 SW Freeway, MS 701
`; Stafford, TX 77477
`;{ IPR statements description (can be collected).
`;}
`; (C) Copyright 1996. Texas Instruments. All rights reserved.
`;{
`; Change history:
`;{
`; VERSION      DATE     /    AUTHORS           COMMENT
`;          1.0     July-29–96  /   P.Mallela      original created
`;}
`;{
`; 1. ABSTRACT
`;{
`; 1.1 Function Type
`; a.Core Routine
`; b.Subroutine
`;{
`; 1.2 Functional Description
`; This file contains interrupt service routine INT1:
`; receive_int1
`; 1.3 Specification/Design Reference (optional)
`;{
`; 1.4 Module Test Document Reference
`; Not done
`;{
`; 1.5 Compilation Information
`; Compiler: TMS320C54X ASSEMBLER
`; Version: 1.02 (PC)
`; Activation: asm500 -s rcv_int1.asm
`;{
`; 1.6 Notes and Special Considerations
`; -
`;{

10-46
Example 10–10. Receive Interrupt Service Routine (Continued)

```assembly
; 2. VOCABULARY
;
; 2.1 Definition of Special Words, Keywords (optional)
;
; 2.2 Local Compiler Flags
;
; 2.3 Local Constants
;
;
;
3 EXTERNAL RESOURCES

3.1 Include Files
    .mmregs
    .include "INTERRUPT.INC"
    .include "main.inc"

3.2 External Data
    .ref d_frame_flag
    .ref d_index_count
    .ref d_rcv_in_ptr,d_xmt_out_ptr
    .ref RCV_INT1_DP

3.3 Import Functions

;
;
;
4 INTERNAL RESOURCES

4.1 Local Static Data
;

4.2 Global Static Data
;

4.3 Dynamic Data
;

4.4 Temporary Data
;

4.5 Export Functions
    .def receive_int1

5. SUBROUTINE CODE

HeaderBegin

==============================================================================

5.1 receive_int1

5.2 Functional Description
    This routine services receive interrupt1. Accumulator A, AR2 and AR3
    are pushed onto the stack since AR2 and AR3 are used in other
    applications. A 512 buffer size of both input and output uses circular
    addressing. After every 256 collection of input samples a flag is set to
    process the data. A PING/PONG buffering scheme is used such that upon
    processing PING buffer, samples are collected in the PONG buffer and vice
    versa.
```

---
Example 10–10. Receive Interrupt Service Routine (Continued)

; 5.3 Activation
; Activation example:
; BD receive_int1
; PSHM ST0
; PSHM ST1
; Reentrancy: No
; Recursive : No
;
; 5.4 Inputs
; NONE
;
; 5.5 Outputs
; NONE
;
; 5.6 Global
; Data structure: AR2
; Data Format: 16-bit input buffer pointer
; Modified: Yes
; Description: either point to PING/PONG buffer. Upon entering
; AR2 is pushed onto stack and the address is restored
; through d_rcv_in_ptr
;
; Data structure: AR3
; Data Format: 16-bit output buffer pointer
; Modified: Yes
; Description: either point to PING/PONG buffer. Upon entering
; AR3 is pushed onto stack and the address is restored
; through d_rcv_in_ptr
;
; Data structure: d_index_count
; Data Format: 16-bit var
; Modified: Yes
; Description: holds the number samples that has been collected from
; AC01
;
; Data structure: d_frame_flag
; Data Format: 16-bit variable
; Modified: Yes
; Description: flag is set if 256 samples are collected
;
; Data structure: d_rcv_in_ptr
; Data Format: 16-bit var
; Modified: Yes
; Description: holds the input buffer address where the newest
; sample is stored
;
; Data structure: d_xmt_out_ptr
; Data Format: 16-bit variable
; Modified: Yes
; Description: holds the output buffer address where the oldest
; sample is sent as output
Example 10–10. Receive Interrupt Service Routine (Continued)

; 5.7 Special considerations for data structure
; -
; 5.8 Entry and Exit conditions

;|DP|OVM|SXM|C16|FRCT|ASM|AR0|AR1|AR2|AR3|AR4|AR5|AR6|AR7|A |B |BK|BRC| T|TRN
;|  |   |   |   |    |   |   |   |   |   |   |   |   |   |  |  |  |   |  |
;in|U | 1 | 1 |NU | 1  |NU |NU |NU |U  |U  |NU |NU |NU |NU |U |NU|NU|NU |NU|NU
;out|U | 1 | 1 |NU | 1  |NU |NU |NU |U  |U  |NU |NU |NU |NU |U |NU|U |NU |NU|NU

Note: UM – Used & Modified, U – Used, NU – Not Used

; 5.9 Execution
; Execution time: ?cycles
; Call rate: not applicable for this application

;HeaderEnd
; 5.10 Code
.asg AR2,GETFRM_IN_P ; get frame input data pointer
.asg AR3,GETFRM_OUT_P ; get frame output data pointer
.asg AR2,SAVE_RSTORE_AR2
.asg AR3,SAVE_RSTORE_AR3
.sect "main_prg"
receive_int1:
PSHM AL
PSHM AH
PSHM AG
PSHM SAVE_RSTORE_AR2
PSHM SAVE_RSTORE_AR3
PSHM BK
PSHM BRC
STM #2*K_FRAME_SIZE,BK ; circular buffr size of in,out arrays
LD #RCV_INT1_DP,DP ; init. DP
MVDK d_rcv_in_ptr,GETFRM_IN_P ; restore input circular bffr ptr
MVDK d_xmt_out_ptr,GETFRM_OUT_P ; restore output circular bffr ptr
ADDM #1,d_index_count ; increment the index count
LD #K_FRAME_SIZE,A
SUB d_index_count, A
BC get_samples,AGT ;check for a frame of samples
frame_flag_set
ST #K_FRAME_FLAG,d_frame_flag ; set frame flag
ST #0,d_index_count ; reset the counter
Example 10–10. Receive Interrupt Service Routine (Continued)

get_samples
   LDM DDR1,A ; load the input sample
   STL A,*GETFRM_IN_P+% ; write to buffer
   LD *GETFRM_OUT_P+%A ; if not true, then the filtered
   AND #0fffch,A ; signal is send as output
   STLM A,DXR1 ; write to DXR1
   MVKD GETFRM_IN_P,d_rcv_in_ptr ; save input circular buffer ptr
   MVKD GETFRM_OUT_P,d_xmt_out_ptr ; save out circular bfr ptr
   POPM BRC
   POPM BK
   POPM SAVE_RSTORE_AR3
   POPM SAVE_RSTORE_AR2
   POPM AG
   POPM AH
   POPM AL
   POPM ST1
   POPM ST0
   RETE ; return and enable interrupts
Example 10–11. Task Scheduling

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
;
; Archives: PVCS
; Filename: task.asm
; Version: 1.0
; Status: draft ( )
; proposal (X)
; accepted ( ) dd-mm-yy/?acceptor.
;
; AUTHOR Padma P. Mallela
;
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
; IPR statements description (can be collected).
;
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;
;
1. ABSTRACT

1.1 Function Type
a.Core Routine
b.Subroutine

1.2 Functional Description
This file initiates task scheduling

1.3 Specification/Design Reference (optional)

1.4 Module Test Document Reference
Not done

1.5 Compilation Information
Compiler: TMS320C54X ASSEMBLER
Version: 1.02 (PC)
Activation: asm500 -s task.asm

1.6 Notes and Special Considerations

This code is written for 541 device. The code is tested on C54x EVM
Example 10–11. Task Scheduling ( Continued)

```c
};

//
// 2. VOCABULARY
//
// 2.1 Definition of Special Words, Keywords (optional)
//
// 2.2 Local Compiler Flags
//
// 2.3 Local Constants
//
//
//
// 3. EXTERNAL RESOURCES
//
// 3.1 Include Files
// .include    "init_54x.inc"
// .include    "main.inc"
//
// 3.2 External Data
// .ref        d_task_addr,d_task_init_addr
// .ref        d_buffer_count
// .ref        present_command
// .ref        last_command
// .ref        d_output_addr,d_input_addr
// .ref        input_data,output_data
// .ref        d_frame_flag
// .ref        task_init_list,task_list
//
// 3.3 Import Functions
// .ref        echo_task
// .ref        fir_init,fir_task
// .ref        do_nothing,no_echo_init_task
// .ref        fir_init,fir_task
// .ref        iir_init,iir_task
// .ref        sym_fir_task,sym_fir_init
// .ref        adapt_init,adapt_task
// .ref        rfft_task
//
//
// 4. INTERNAL RESOURCES
//
// 4.1 Local Static Data
//
// 4.2 Global Static Data
//
// 4.3 Dynamic Data
//
// 4.4 Temporary Data
//
// 4.5 Export Functions
// .def task_handler

```
Example 10–11. Task Scheduling (Continued)

; 5. SUBROUTINE CODE
; HeaderBegin
;===================================================================================
;
; 5.1 task_handler
;
; 5.2 Functional Description
; This routine handles the task scheduling. The present_command
; can take values 1,2,3,4,5,6. If
; present_command = 1 - Echo program is enabled
; present_command = 2 - FIR is enabled
; present_command = 3 - IIR is enabled
; present_command = 4 - Symmetric FIR is enabled
; present_command = 5 - Adaptive filter is enabled
; present_command = 6 - FFT is enabled
; For every cycle the program checks if the current task is same
; as previous task if it is, then no initialization is done.
; If its not then circular buffers, variables pointers are initialized
; depending upon the task.
;===================================================================================
;
; 5.3 Activation
; Activation example:
; CALL    task_handler
; Reentrancy:    No
; Recursive :    No
;
; 5.4 Inputs
;
; Data structure: present_command
; Data Format:  16–bit variable
; Modified:    Yes
; Description: holds the present command
;
; 5.5 Outputs
;
; Data structure: AR6
; Data Format:  16–bit input buffer pointer
; Modified:    Yes
; Description: either point to PING/PONG buffer
;
; Data structure: AR7
; Data Format:  16–bit output buffer pointer
; Modified:    Yes
; Description: either point to PING/PONG buffer
;
; 5.6 Global
;
; Data structure: last_command
; Data Format:  16–bit variable
; Modified:    Yes
; Description: holds the last command
Example 10–11. Task Scheduling (Continued)

```c
; Data structure: d_frame_flag
; Data Format: 16-bit variable
; Modified: Yes
; Description: gets reset after 256 samples
;
; Data structure: d_buffer_count
; Data Format: 16-bit variable
; Modified: Yes
; Description: used to load either PING/PONG bffr addresses
;
; Data structure: input_data
; Data Format: 16-bit array
; Modified: Yes
; Description: address of the input data buffer
;
; Data structure: output_data
; Data Format: 16-bit array
; Modified: Yes
; Description: address of the output data buffer
;
; Data structure: d_input_addr
; Data Format: 16-bit variable
; Modified: Yes
; Description: holds either PING/PONG address
;
; Data structure: d_output_addr
; Data Format: 16-bit variable
; Modified: Yes
; Description: holds either PING/PONG address
;
; Data structure: d_task_addr
; Data Format: 16-bit variable
; Modified: Yes
; Description: holds the task program address
;
; Data structure: d_task_init_addr
; Data Format: 16-bit variable
; Modified: Yes
; Description: holds the task init. address
;
5.7 Special considerations for data structure

5.8 Entry and Exit conditions

<table>
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<tr>
<th>DP</th>
<th>OVM</th>
<th>SXM</th>
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Note: UM – Used & Modified, U – Used, NU – Not Used
```
Example 10–11. Task Scheduling (Continued)

; 5.9 Execution
; Execution time: ?cycles
; Call rate: not applicable for this application
;
;==============================================================================
;HeaderEnd
; 5.10 Code
.asg AR6,INBUF_P ; PING/PONG input buffer
.asg AR7,OUTBUF_P ; PING/PONG output buffer
.sect "task_hnd"
task_handler:
; ST #K_0,d_frame_flag ; reset the frame flag
ADDM #1,d_buffer_count
LD #input_data,A ; load PING input address
LD #output_data,B ; load PING output address
BITF d_buffer_count,2 ; check if PING/PONG address
BC reset_buffer_address,NTC ; needs to be loaded
ADD #K_FRAME_SIZE,A ; PONG input address
ADD #K_FRAME_SIZE,B ; PONG output address
ST #K_0,d_buffer_count ; reset counter
reset_buffer_address
STLM A,INBUF_P ; input buffer address
STL A,d_input_addr ; restore either PING/PONG bffr
STLM B,OUTBUF_P ; output buffer address
STL B,d_output_addr ; restore either PING/PONG bffr
LD present_command,A
SUB last_command,A
BC new_task,ANEQ ; check if PC = LC
LD d_task_addr,A ; task_addr should
; contain previous
; PC = LC
CALA A ; call present task
RET

new_task:
MVKD present_command,last_command ; restore the present command
LD #task_init_list,A ; loads PC init task
ADD present_command,A ; computes the present task
READA d_task_init_addr ; save the PC into task_addr
CALA A ; initializes the present task
LD #task_list,A;
ADD present_command,A ; computes the present task
READA d_task_addr ; save the PC into
; task_addr
LD d_task_addr,A
CALA A
RET
do_nothing:
RET
no_echo_init_task:
RET
.end
Example 10–12. Echo the Input Signal

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
;
; Archives: PVCS
; Filename: echo.asm
; Version: 1.0
; Status : draft ( )
; proposal (X)
; accepted ( ) dd-mm-yy/?acceptor.
;
; AUTHOR Padma P. Mallela
;
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
; (C) Copyright 1996. Texas Instruments. All rights reserved.
;
; Change history:
;
; VERSION DATE / AUTHORS COMMENT
; 1.0 July-24–96 / P.Mallela original created
;
;
; 1. ABSTRACT
;
; 1.1 Function Type
; a.Core Routine
; b.Subroutine
;
; 1.2 Functional Description
; This file contains one subroutines:
; echo_task
;
; 1.3 Specification/Design Reference (optional)
; called by task.asm depending upon the task
;
; 1.4 Module Test Document Reference
; Not done
;
; 1.5 Compilation Information
; Compiler: TMS320C54X ASSEMBLER
; Version: 1.02 (PC)
; Activation: asm500 –s echo.asm
;
; 1.6 Notes and Special Considerations
; –
Example 10–12. Echo the Input Signal (Continued)

{  
    2. VOCABULARY  
    -  
    2.1 Definition of Special Words, Keywords (optional)  
    -  
    2.2 Local Compiler Flags  
    -  
    2.3 Local Constants  
    -  
  }

{  
    3. EXTERNAL RESOURCES  
    -  
    3.1 Include Files  
    .mmregs  
        .include "main.inc"  
    -  
    3.2 External Data  
    -  
    3.3 Import Functions  
  }

{  
    4. INTERNAL RESOURCES  
    -  
    4.1 Local Static Data  
    -  
    4.2 Global Static Data  
    -  
    4.3 Dynamic Data  
    -  
    4.4 Temporary Data  
    -  
    4.5 Export Functions  
    .def echo_task  
  }

{  
    5. SUBROUTINE CODE  
    HeaderBegin
    ===============================================================================  
    5.1 echo_task
    5.2 Functional Description
        This function reads a sample from either PING/PONG buffer and puts it back in the output buffer. This is repeated 256 times i.e., size of the frame. The present command in this case is 1.
    ---------------------------------------------------------------------------  
    5.3 Activation
        Activation example:
            CALL echo_task  
        Reentrancy: No  
        Recursive : No
    
}
Example 10–12. Echo the Input Signal (Continued)

5.4 Inputs

Data structure: AR6
Data Format: 16-bit input buffer pointer
Modified: Yes
Description: either point to PING/PONG buffer

5.5 Outputs

Data structure: AR7
Data Format: 16-bit output buffer pointer
Modified: Yes
Description: either point to PING/PONG buffer

5.6 Global

5.7 Special considerations for data structure

5.8 Entry and Exit conditions

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Note: UM – Used & Modified, U – Used, NU – Not Used

5.9 Execution

Execution time: ?cycles
Call rate: not applicable for this application

5.10 Code

```
  .asg AR6,INBUF_P ; PING/PONG input buffer
  .asg AR7,OUTBUF_P ; PING/PONG output buffer
  .sect "echo_prg"

echo_task:
  STM #K_FRAME_SIZE-1,BRC ; frame size of 256
  RPTB echo_loop-1
  LD *INBUF_P+, A ; load the input value
  STL A, *OUTBUF_P+

echo_loop
  RET ; output buffer
```
Example 10–13. Low-Pass FIR Filtering Using MAC Instruction

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
;
; Archives: PVCS
; Filename: fir.asm
; Version: 1.0
; Status: draft ( )
; proposal (X)
; accepted ( ) dd-mm-yy/?acceptor.
;
; AUTHOR Padma P. Mallela
;
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
{(I)PR statements description (can be collected).
);
(C) Copyright 1996. Texas Instruments. All rights reserved.
;
{
Change history:
;
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}

1. ABSTRACT

1.1 Function Type
   a.Core Routine
   b.Subroutine

1.2 Functional Description
   This file contains two subroutines:
   1) fir_init
   2) fir_task

1.3 Specification/Design Reference (optional)
   called by task.asm depending upon the task thru CALA

1.4 Module Test Document Reference
   Not done

1.5 Compilation Information
   Compiler: TMS320C54X ASSEMBLER
   Version: 1.02 (PC)
   Activation: asm500 -s fir.asm

1.6 Notes and Special Considerations
   -
Example 10–13. Low-Pass FIR Filtering Using MAC Instruction (Continued)

```c
));
); 2. VOCABULARY
);
); 2.1 Definition of Special Words, Keywords (optional)
); 2.2 Local Compiler Flags
); 2.3 Local Constants
);
);
); 3. EXTERNAL RESOURCES
);
); 3.1 Include Files
    .mmregs
      .include "main.inc"
); 3.2 External Data
    .ref d_filin          ; filter input
    .ref d_filout         ; filter output
    .ref d_data_buffer
    .ref fir_task
    .ref COFF_FIR_START,COFF_FIR_END
    .ref fir_coff_table
); 3.3 Import Functions
);
);
); 4. INTERNAL RESOURCES
);
); 4.1 Local Static Data
); 4.2 Global Static Data
); 4.3 Dynamic Data
); 4.4 Temporary Data
);
); 4.5 Export Functions
    .def fir_init          ; initialize FIR filter
    .def fir_filter        ; perform FIR filtering
);
); 5. SUBROUTINE CODE
    HeaderBegin
    -------------------------------------------------------------
    -------------------------------------------------------------
    5.1 fir_init
    5.1.1 Functional Description
      This routine initializes circular buffers both for data and coeffs.
    -------------------------------------------------------------
```
Example 10–13. Low-Pass FIR Filtering Using MAC Instruction (Continued)

; 5.1.2 Activation
; Activation example:
;   CALL fir_init
; Reentrancy: No
; Recursive : No
;
; 5.1.3 Inputs
; NONE
; 5.1.4 Outputs
; NONE
;
; 5.1.5 Global
;
;   Data structure: AR0
;   Data Format: 16-bit index pointer
;   Modified: No
;   Description: uses in circular addressing mode for indexing
;
;   Data structure: AR4
;   Data Format: 16-bit x(n) data buffer pointer
;   Modified: Yes
;   Description: initializes the pointer
;
;   Data structure: AR5
;   Data Format: 16-bit w(n) coeff buffer pointer
;   Modified: Yes
;   Description: initializes the pointer
;
; 5.1.6 Special considerations for data structure
; -
; 5.1.7 Entry and Exit conditions
;
; Note : UM – Used & Modified, U – Used, NU – Not Used
;
; 5.1.8 Execution
; Execution time: ?cycles
; Call rate: not applicable for this application
;
; HeaderEnd
; 5.1.9 Code
;   .asg AR0, FIR_INDEX_P
;   .asg AR4,FIR_DATA_P
;   .asg AR5,FIR_COFF_P
;   .sect "fir_prog"
Example 10–13. Low-Pass FIR Filtering Using MAC Instruction (Continued)

```assembly
fir_init:
  STM #fir_coff_table,FIR_COFF_P ; move FIR coeffs from program
  RPT #K_FIR_BFFR-1 ; move FIR coeffs from program
  MVPD #COFF_FIR_START,*FIR_COFF_P+ ; to data
  STM #K_FIR_INDEX,FIR_INDEX_P
  STM #d_data_buffer,FIR_DATA_P ; load cir_bfr address for the
                                ; recent samples
  RPTZ A,#K_FIR_BFFR
  STL A,*FIR_DATA_P+ ; reset the buffer
  STM #(d_data_buffer+K_FIR_BFFR-1), FIR_DATA_P
RETD

; 5. SUBROUTINE CODE
; HeaderBegin
;==============================================================================
;––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––
; 5.2 fir_task
;
; 5.2.1 Functional Description
;
; This subroutine performs FIR filtering using MAC instruction.
; accumulator A (filter output) = h(n)*x(n–i) for i = 0,1...15
;––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––––
;
; 5.2.2 Activation
; Activation example:
; CALL fir_task
; Reentrancy: No
; Recursive : No
;
; 5.2.3 Inputs
;
; Data structure: AR6
; Data Format: 16-bit input buffer pointer
; Modified: Yes
; Description: either point to PING/PONG buffer
;
; Data structure: AR4
; Data Format: 16-bit data buffer pointer
; Modified: Yes
; Description: uses circular buffer addressing mode to filter
; 16 tap Low-Pass filter - init. in fir_init
;
; Data structure: AR5
; Data Format: 16-bit coefficient buffer pointer
; Modified: Yes
; Description: The 16 tap coeffs comprise the low-pass filter
; init. in fir_init
```
Example 10–13. Low-Pass FIR Filtering Using MAC Instruction (Continued)

; 5.2.4 Outputs
; Data structure: AR7
; Data Format: 16-bit output buffer pointer
; Modified: Yes
; Description: either point to PING/PONG buffer
;
; 5.2.5 Global
; NONE
;
; 5.2.6 Special considerations for data structure
;
; 5.2.7 Entry and Exit conditions
;
; |DP|OVM|SXM|C16|FRCT|ASM|AR0|AR1|AR2|AR3|AR4|AR5|AR6|AR7|A |B |BK|BRC| T|TRN|
; |  |   |   |   |    |   |   |   |   |   |   |   |   |   |  |  |  |   |  |   |
; in |U | 1 | 1 |NU | NU | NU | NU | NU | NU | U | NU | U | UM |NU|NU|NU |NU |NU |
; out|U | 1 | 1 |NU | NU | UM | NU | NU | UM | UM | UM | UM | UM |UM|UM|UM |UM |NU |

; Note: UM – Used & Modified, U – Used, NU – Not Used
;
; 5.2.8 Execution
; Execution time: ?cycles
; Call rate: not applicable for this application
;==============================================================================
;HeaderEnd
;
; 5.2.9 Code
; .asg AR6,INBUF_P
; .asg AR7,OUTBUF_P
; .asg AR4,FIR_DATA_P
; .asg AR5,FIR_COFF_P
; .sect "fir_prog"

fir_task:
; LD    #FIR_DP,DP
STM    #K_FRAME_SIZE–1,BRC               ; Repeat 256 times
RPTBD  fir_filter_loop–1
STM    #K_FIR_BFFR,BK                    ; FIR circular bffr size
LD     *INBUF_P+, A                      ; load the input value

fir_filter:
STL    A,*FIR_DATA_P+%                   ; replace oldest sample with newest
RPTZ   A,(K_FIR_BFFR–1)                  ; sample
MAC    *FIR_DATA_P+0%,*FIR_COFF_P+0%,A   ; filtering
STH    A,*OUTBUF_P+                      ; replace the oldest bffr value

fir_filter_loop
RET
Example 10–14. Low-Pass Symmetric FIR Filtering Using FIRS Instruction

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
;
; Archives: PVCS
; Filename: sym_fir.asm
; Version: 1.0
; Status : draft ( )
; proposal (X)
; accepted ( ) dd-mm-yy/?acceptor.
;
AUTHOR Padma P. Mallela
;
Application Specific Products
Data Communication System Development
12203 SW Freeway, MS 701
Stafford, TX 77477
{
IPR statements description (can be collected).
}
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;
;
; Change history:
;
| VERSION | DATE     / AUTHORS           COMMENT |
|---------|----------/------------------------|
| 1.0     | July-26–96 / P.Mallela      original created |
;
;
1. ABSTRACT

1.1 Function Type
a.Core Routine
b.Subroutine

1.2 Functional Description
This file contains two subroutines:
1) sym_fir_init
2) sym_fir_task

1.3 Specification/Design Reference (optional)
called by task.asm depending upon the task thru CALA

1.4 Module Test Document Reference
Not done

1.5 Compilation Information
Compiler: TMS320C54X ASSEMBLER
Version: 1.02 (PC)
Activation: asm500 –s sym_fir.asm

1.6 Notes and Special Considerations


Example 10–14. Low-Pass Symmetric FIR Filtering Using FIRS Instruction (Continued)

}{
    2. VOCABULARY
}{
    2.1 Definition of Special Words, Keywords (optional)
    -
    2.2 Local Compiler Flags
    -
    2.3 Local Constants
    -
}
}{
    3. EXTERNAL RESOURCES
}{
    3.1 Include Files
    .mmregs
        .include "main.inc"
    3.2 External Data
    .ref    d_datax_buffer
    .ref    d_datay_buffer
    .ref    FIR_COFF
}{
    3.3 Import Functions
}
}{
    4. INTERNAL RESOURCES
}{
    4.1 Local Static Data
    -
    4.2 Global Static Data
    -
    4.3 Dynamic Data
    -
    4.4 Temporary Data
    -
    4.5 Export Functions
        .def    sym_fir_init                    ; initialize symmetric FIR
        .def    sym_fir_task
}{
    5. SUBROUTINE CODE
    
    5.1   sym_fir_init
    5.1.1 Functional Description
    This routine initializes circular buffers both for data and coeffs.
    5.1.2 Activation
    Activation example:
    CALL    sym_fir_init
    Reentrancy:    No
    Recursive:    No
Example 10–14. Low-Pass Symmetric FIR Filtering Using FIRS Instruction (Continued)

; 5.1.3 Inputs
; NONE
; 5.1.4 Outputs
; NONE
; 5.1.5 Global
;
; Data structure: AR0
; Data Format: 16-bit index pointer
; Modified: No
; Description: uses in circular addressing mode for indexing
;
; Data structure: AR4
; Data Format: 16-bit x(n) data buffer pointer for 8 latest samples
; Modified: Yes
; Description: initializes the pointer
;
; Data structure: AR5
; Data Format: 16-bit x(n) data buffer pointer for 8 oldest samples
; Modified: Yes
; Description: initializes the pointer
;
; 5.1.6 Special considerations for data structure
;
; 5.1.7 Entry and Exit conditions
;
; |DP|OVM|SXM|C16|FRCT|ASM|AR0|AR1|AR2|AR3|AR4|AR5|AR6|AR7|A |B |BK|BRC| T|TRN
; |  |   |   |   |    |   |   |   |   |   |   |   |   |   |  |  |  |   |  |
in |U | 1 | 1 |NU | 1  |NU |NU |NU |NU |NU |NU |NU |NU |NU |UM|NU|NU|NU |NU|NU
;out|U | 1 | 1 |NU | 1  |NU |UM |NU |NU |NU |U  |UM |NU |NU |UM|NU|NU|NU |NU|NU
;
; Note : UM – Used & Modified, U – Used, NU – Not Used
;
; 5.1.8 Execution
; Execution time: ?cycles
; Call rate: not applicable for this application
;
/HeaderEnd

; 5.1.9 Code
.
.asg AR0,SYMFIR_INDEX_P
.asg AR4,SYMFIR_DATX_P
.asg AR5,SYMFIR_DATY_P
.sect "sym_fir"
sym_fir_init:
STM  #d_datax_buffer,SYMFIR_DATX_P  ; load cir_bfr address
     ; for the 8 most
     ; recent samples
STM  #d_datay_buffer+K_FIR_BFFR/2–1,SYMFIR_DATY_P
     ; load cir_bfr1 address
     ; for the 8 old samples

PRELIMINARY
Example 10–14. Low-Pass Symmetric FIR Filtering Using FIRS Instruction (Continued)

```assembly
STM     #K_neg1,SYMFIR_INDEX_P          ; index offset –
        ; whenever the pointer
        ; hits the top of the bffr,  
        ; it automatically hits 
        ; bottom address of 
        ; buffer and decrements  
        ; the counter
RPTZ    A,#K_FIR_BFFR
STL     A,* SYMFIR_DATX_P+
STM     #d_datax_buffer, SYMFIR_DATX_P
RPTZ    A,#K_FIR_BFFR
STL     A,* SYMFIR_DATY_P–
RETD
STM     #d_datay_buffer+K_FIR_BFFR/2–1, SYMFIR_DATY_P
```

5. SUBROUTINE CODE

---

5.2 sym_fir_init

5.2.1 Functional Description

This program uses the FIRS instruction to implement symmetric FIR
filter. Circular addressing is used for data buffers. The input scheme
for the data samples is divided into two circular buffers. The first
buffer contains samples from X(–N/2) to X(–1) and the second buffer
contains samples from X(–N) to X(–N/2–1).

5.2.2 Activation

Activation example:

```assembly
CALL    sym_fir_init
```

Reentrancy: No

Recursive: No

5.2.3 Inputs

Data structure: AR6

Data Format: 16-bit input buffer pointer

Modified: Yes

Description: either point to PING/PONG buffer

Data structure: AR4

Data Format: 16-bit data buffer pointer

Modified: Yes

Description: uses circular buffer addressing mode to filter

16 tap Low-Pass filter – init. in sym_fir_init

Data structure: AR5

Data Format: 16-bit coefficient buffer pointer

Modified: Yes

Description: The 16 tap coeffs comprise the low-pass filter

init. in sym_fir_init
Example 10–14. Low-Pass Symmetric FIR Filtering Using FIRS Instruction (Continued)

; 5.2.4 Outputs
;   Data structure: AR7
;   Data Format:  16-bit output buffer pointer
;   Modified:     Yes
;   Description:  either point to PING/PONG buffer
;
; 5.2.5 Global
;    NONE
;
; 5.2.6 Special considerations for data structure
;    
; 5.2.7 Entry and Exit conditions
;     |DP|OVM|SXM|C16|FRCT|ASM|AR0|AR1|AR2|AR3|AR4|AR5|AR6|AR7|A |B |BK|BRC| T|TRN
;     |  |   |   |   |    |   |   |   |   |   |   |   |   |   |  |  |  |   |  |
in   |U | 1 | 1 |NU | 1  |NU |NU |NU |NU |NU |U  |U  |U  | U |UM|NU|NU|NU |NU|NU
;     |  |   |   |   |    |   |   |   |   |   |   |   |   |   |  |  |  |   |  |
;out  |U | 1 | 1 |NU | 1  |NU |UM |NU |NU |NU |UM |UM |NU |NU |UM|UM|NU|UM |NU|NU
;     |  |   |   |   |    |   |   |   |   |   |   |   |   |   |  |  |  |   |  |
; Note: UM – Used & Modified, U – Used, NU – Not Used
;
; 5.2.8 Execution
;     Execution time: ?cycles
;     Call rate:    not applicable for this application
;
;---------------------------------------------------------------------------
;HeaderEnd
;
; 5.2.9 Code
;    .asg AR6,INBUF_P
;    .asg AR7,OUTBUF_P
;    .asg AR4,SYMFIR_DATX_P
;    .asg AR5,SYMFIR_DATY_P
;    .sect "sym_fir"
sym_fir_task:
    STM #K_FRAME_SIZE–1,BRC
    RPTBD sym_fir_filter_loop–1
    STM #K_FIR_BFFR/2,BK
    LD  *INBUF_P+, B
symmetric_fir:
    MVDD  *SYMFIR_DATX_P, *SYMFIR_DATY_P+0% ; move X(–N/2) to X(–N)
    STL  B,*SYMFIR_DATX_P ; replace oldest sample with newest
    ADD  *SYMFIR_DATX_P+0%, *SYMFIR_DATY_P+0%,A ; add X(0)+X(–N/2–1)
    RPTZ B,(#K_FIR_BFFR/2–1)
    FIRS  *SYMFIR_DATX_P+0%, *SYMFIR_DATY_P+0%,FIR_COFF
    MAR  *SYMFIR_DATX_P(2)% ; to load the next newest sample
    MAR  *SYMFIR_DATY_P+
    STH  B,*OUTBUF_P+
sym_fir_filter_loop
    RET
    .end

PRELIMINARY
Example 10–15. Low-Pass Biquad IIR Filter

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
; Archives: PVCS
; Filename: iir.asm
; Version: 1.0
; Status : draft ( )
; proposal (X)
; accepted ( ) dd-mm-yy/?acceptor.
;
; AUTHOR: Padma P. Mallela
;
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
; IPR statements description (can be collected).
;
; (C) Copyright 1996. Texas Instruments. All rights reserved.
;
; Change history:
;
; VERSION  DATE   /  AUTHORS  COMMENT
; 1.0  July–26–96 /  P.Mallela  original created
;
; 1. ABSTRACT
;
; 1.1 Function Type
; a.Core Routine
; b.Subroutine
;
; 1.2 Functional Description
; This file contains two subroutines:
; 1) iir_init
; 2) iir_task
;
; 1.3 Specification/Design Reference (optional)
; called by task.asm depending upon the task thru CALA
;
; 1.4 Module Test Document Reference
; Not done
;
; 1.5 Compilation Information
; Compiler: TMS320C54X ASSEMBLER
; Version: 1.02 (PC)
; Activation: asm500 -s iir.asm
;
; 1.6 Notes and Special Considerations
;
Example 10–15. Low-Pass Biquad IIR Filter (Continued)

```c
;
};
2. VOCABULARY
;
2.1 Definition of Special Words, Keywords (optional)
;
2.2 Local Compiler Flags
;
2.3 Local Constants
;
};

3. EXTERNAL RESOURCES
;
3.1 Include Files
   .mmregs
   .include  "main.inc"
;
3.2 External Data
   .ref    d_iir_y
   .ref    d_iir_d
   .ref    iir_table_start,iir_coff_table
;
3.3 Import Functions
;
};

4. INTERNAL RESOURCES
;
4.1 Local Static Data
;
4.2 Global Static Data
;
4.3 Dynamic Data
;
4.4 Temporary Data
;
4.5 Export Functions
   .def    iir_init
   .def    iir_task
;
};

5. SUBROUTINE CODE
;
HeaderBegin
==============================================================================

5.1 iir_init

5.1.1 Functional Description
   A) This routine initializes buffers both for data and coeffs.

5.1.2 Activation
   Activation example:
   CALL    iir_init
   Reentrancy: No
   Recursive : No
```
Example 10–15. Low-Pass Biquad IIR Filter (Continued)

; 5.1.3 Inputs
; NONE
; 5.1.4 Outputs
; NONE
; 5.1.5 Global
; NONE
; 5.1.6 Special considerations for data structure
; -
; 5.1.7 Entry and Exit conditions
;
; |DP|OVM|SXM|C16|FRCT|ASM|AR0|AR1|AR2|AR3|AR4|AR5|AR6|AR7|A |B |BK|BRC| T|TRN
; |  |   |   |   |    |   |   |   |   |   |   |   |   |   |  |  |  |   |  |
;in |U | 1 | 1 |NU | 1  |NU |NU |NU |NU |NU |NU |NU |NU |NU |UM|NU|NU|NU |NU|NU
;out|U | 1 | 1 |NU | 1  |NU |NU |NU |NU |NU |UM |UM |NU |NU |UM|NU|NU|UM |UM|NU
;
; Note : UM – Used & Modified, U – Used, NU – Not Used
;
; 5.1.8 Execution
; Execution time: ?cycles
; Call rate: not applicable for this application
;
; HeaderEnd
; 5.1.9 Code
; .asg AR5,IIR_DATA_P ; data samples pointer
; .asg AR4,IIR_COFF_P ; IIR filter coeffs pointer
; .sect "iir"
; iir_init:
; STM #iir_coff_table,IIR_COFF_P
; RPT #K_IIR_SIZE-1 ; move IIR coeffs from program
; MVPD #iir_table_start,*IIR_COFF_P+ ; to data
; LD #IIR_DP,DP
; STM #d_iir_d,IIR_DATA_P ;AR5:d(n),d(n-1),d(n-2)
; RTPZ A,#5 ;initial d(n),d(n-1),d(n-2)=0
; STL A,*IIR_DATA_P+
; RET
;
; 5. SUBROUTINE CODE
; HeaderBegin
;===============================================
;
; 5.2 iir_task
;
; 5.2.1 Functional Description
;
; This subroutine performs IIR filtering using biquad sections
; IIR Low pass filter design
; Filter type : Elliptic Filter
; Filter order : 4 order (cascade: 2nd order + 2nd order)
; cut freq. of pass band : 200 Hz
; cut freq. of stop band : 500 Hz
Example 10–15. Low-Pass Biquad IIR Filter (Continued)

```c
; ... ----> + -------> d(n) ----- x -> + ------....
; |    |     |     |
; A1  | B1   |     |
; + <- x -- d(n-1) -- x -> +
; |    |     |     |
; A2  | B2   |     |
; + <- x -- d(n-2) -- x -> +
;-----------------------------------
; 5.2.2 Activation
;   Activation example:
;   CALL    iir_task
;   Reentrancy:    No
;   Recursive :    No
;
; 5.2.3 Inputs
;   Data structure:    AR6
;   Data Format:       16-bit input buffer pointer
;   Modified:          Yes
;   Description:       either point to PING/PONG buffer
;
; 5.2.4 Outputs
;   Data structure:    AR7
;   Data Format:       16-bit output buffer pointer
;   Modified:          Yes
;   Description:       either point to PING/PONG buffer
;
; 5.2.5 Global
;   Data structure:    AR1
;   Data Format:       16-bit index counter
;   Modified:          Yes
;   Description:       checks if 256 samples are processed
;
;   Data structure:    AR5
;   Data Format:       16-bit data buffer pointer
;   Modified:          Yes
;   Description:       inlcudes both feed forward and feedback paths
;
;   Data structure:    AR4
;   Data Format:       16-bit coefficient buffer pointer
;   Modified:          Yes
;   Description:       contains 2 biquad sections
;
;   Data structure:    d_iir_y
;   Data Format:       16-bit variable
;   Modified:          Yes
;   Description:       holds the output of the 2 biquad sections
```
Example 10–15. Low-Pass Biquad IIR Filter (Continued)

; 5.2.6 Special considerations for data structure
;   -
; 5.2.7 Entry and Exit conditions
;
; |DP| OVM | SXM | C16 | FRCT | ASM | AR0 | AR1 | AR2 | AR3 | AR4 | AR5 | AR6 | AR7 | A | B | BK | BRC | T | TRN |
;|  |   |   |   |    |   |   |   |   |   |   |   |   |   |  |  |  |   |  |   |
; in | U | 1 | 1 | NU | 1 | NU | NU | NU | NU | NU | U | U | UM | NU | NU | NU | NU | NU |
; out| U | 1 | 1 | NU | 1 | NU | UM | NU | UM | UM | UM | UM | UM | UM | UM | UM | UM | UM |

Note: UM – Used & Modified, U – Used, NU – Not Used

; 5.2.8 Execution
;   Execution time: ?cycles
;   Call rate: not applicable for this application

;==============================================================================
;HeaderEnd
; 5.2.9 Code
.asg AR5, IIR_DATA_P ; data samples pointer
.asg AR4, IIR_COFF_P ; IIR filter coffs pointer
.asg AR6, INBUF_P
.asg AR7, OUTBUF_P
.asg AR1, IIR_INDEX_P
.sect "iir"

iir_task:
STM #K_FRAME_SIZE–1, BRC ; Perform filtering for 256 samples
RPTB iir_filter_loop–1
LD *INBUF_P+, 8, A ; load the input value

iir_filter:
STM #d_iir_d+5, IIR_DATA_P ; AR5: d(n), d(n–1), d(n–2)
STM #iir_coff_table, IIR_COFF_P ; AR4: coeff of IIR filter A2, A1, B2, B1, B0
STM #K_BIQUAD–1, IIR_INDEX_P
feedback_path:
MAC *IIR_COFF_P+, IIR_DATA_P–, A ; input+d(n–2)*A2
MAC *IIR_COFF_P+, IIR_DATA_P–, A ; input+d(n–2)*A2+d(n–1)*A1/2
MAC *IIR_COFF_P+, IIR_DATA_P–, A ; A = A+d(n–1)*A1/2
STH A, IIR_DATA_P+ ; d(n) = input+d(n–2)*A2+d(n–1)*A1
MAR *IIR_DATA_P+
* Forward path
MPY *IIR_COFF_P+, IIR_DATA_P–, A ; d(n–2)*B2
MAC *IIR_COFF_P+, IIR_DATA_P–, A ; d(n–2)*B2+d(n–1)*B1
DELAY *IIR_DATA_P– ; d(n–2)=d(n–1)
eloop:
BANZD feedback_path, *IIR_INDEX_P–
MAC *IIR_COFF_P+, IIR_DATA_P–, A ; d(n–2)*B2+d(n–1)*B1+d(n)*B0
DELAY *IIR_DATA_P– ; d(n–1)=d(n)
STH A, d_iir_y ; output=d(n–2)*B2+d(n–1)*B1+d(n)*B0
LD d_iir_y, 2, A ; scale the output
STL A, *OUTBUF_P+ ; replace the oldest bffr value
iir_filter_loop
RET
.end
Example 10–16. Adaptive Filtering Using LMS Instruction

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
;
; Archives: PVCS
; Filename: adapt.asm
; Version: 1.0
; Status : draft ( )
; proposal (X)
; accepted ( ) dd-mm-yy/?acceptor.
;
; AUTHOR Padma P. Mallela
;
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
;{ IPR statements description (can be collected).
;}
;(C) Copyright 1996. Texas Instruments. All rights reserved.
;
; Change history:
;
; VERSION DATE / AUTHORS COMMENT
; 1.0 July-24-96 / P.Mallela original created
;
;
; 1. ABSTRACT
;
; 1.1 Function Type
; a.Core Routine
; b.Subroutine
;
; 1.2 Functional Description
; This file contains two subroutines:
; 1) adapt_init
; 2) adapt_task
; 1.3 Specification/Design Reference (optional)
; called by task.asm depending upon the task
;
; 1.4 Module Test Document Reference
; Not done
;
; 1.5 Compilation Information
; Compiler: TMS320C54X ASSEMBLER
; Version: 1.02 (PC)
; Activation: asm500 -s adapt.asm
Example 10–16. Adaptive Filtering Using LMS Instruction (Continued)

; 1.6 Notes and Special Considerations
; -
;

2. VOCABULARY

2.1 Definition of Special Words, Keywords (optional)
-  
2.2 Local Compiler Flags
-  
2.3 Local Constants
-  

3. EXTERNAL RESOURCES

3.1 Include Files
.mmregs
.include "main.inc"

3.2 External Data
.ref ADAPT_DP
.ref d_mu,d_error,d_primary,d_output,d_mu,d_mu_e,d_new_x
.ref scoff,hcoff,wcoff
.ref xh,xw,d_adapt_count

3.3 Import Functions

4. INTERNAL RESOURCES

4.1 Local Static Data
-  
4.2 Global Static Data
-  
4.3 Dynamic Data
-  
4.4 Temporary Data
-  
4.5 Export Functions
.def adapt_init,adapt_task

5. SUBROUTINE CODE

HeaderBegin
==============================================================================

5.1 adapt_init

5.1.1 Functional Description

This subroutine moves filter coefficients from program to data space.
Initializes the adaptive coefficients, buffers, vars, and sets the circular
buffer address for processing.
Example 10–16.  Adaptive Filtering Using LMS Instruction (Continued)

```c

5.1.2 Activation

Activation example:
CALL    adapt_init
Reentrancy: No
 Recursive : No

5.1.3 Inputs
NONE

5.1.4 Outputs
NONE

5.1.5 Global

<table>
<thead>
<tr>
<th>Data structure</th>
<th>AR0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Format</td>
<td>16-bit index pointer</td>
</tr>
<tr>
<td>Modified</td>
<td>No</td>
</tr>
<tr>
<td>Description</td>
<td>uses in circular addressing mode for indexing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data structure</th>
<th>AR1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Format</td>
<td>16-bit pointer</td>
</tr>
<tr>
<td>Modified</td>
<td>Yes</td>
</tr>
<tr>
<td>Description</td>
<td>used in initializing buffers and vars</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Data structure</th>
<th>AR3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Format</td>
<td>16-bit x(n) data buffer pointer for H(z)</td>
</tr>
<tr>
<td>Modified</td>
<td>Yes</td>
</tr>
<tr>
<td>Description</td>
<td>initializes the pointer</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data structure</th>
<th>AR5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Format</td>
<td>16-bit x(n) data buffer pointer for W(z)</td>
</tr>
<tr>
<td>Modified</td>
<td>Yes</td>
</tr>
<tr>
<td>Description</td>
<td>initializes the pointer</td>
</tr>
</tbody>
</table>

5.1.6 Special considerations for data structure

5.1.7 Entry and Exit conditions

5.1.8 Execution

Execution time: ?cycles

Call rate: not applicable for this application
```
Example 10–16. Adaptive Filtering Using LMS Instruction (Continued)

; 5.1.9 Code
    .asg AR0,INDEX_P
    .asg AR1,INIT_P ; initialize buffer pointer
    .asg AR3,XH_DATA_P ; data coeff buffer pointer
    .asg AR5,XW_DATA_P ; data coeff buffer pointer
                   ; for cal.y output
    .sect "filter"

adapt_init:
; initialize input data location, input to hybrid, with Zero.
    STM #xh,INIT_P
    RPTZ A,#H_FILT_SIZE–1
    STL A,*INIT_P+
; initialize input data location, input to adaptive filter, with Zero.
    STM #xw,INIT_P
    RPTZ A,#ADPT_FILT_SIZE–1
    STL A,*INIT_P+
; initialize adaptive coefficient with Zero.
    STM #wcoff,INIT_P
    RPTZ A,#ADPT_FILT_SIZE–1
    STL A,*INIT_P+
; initialize temporary storage locations with zero
    STM #d_primary,INIT_P
    RPTZ A,#6
    STL A,*INIT_P+
; copy system coefficient into RAM location, Rverse order
    STM #hcoff,INIT_P
    RPT #H_FILT_SIZE–1
    MVPD #scoff,*INIT_P+
; LD #ADAPT_DP,DP ;set DP now and not worry about it
    ST #K_mu,d_mu
    STM #1,INDEX_P ; increment value to be used by
                   ; dual address
; associate auxiliary registers for circular computation
    STM #xh+H_FILT_SIZE-1,XH_DATA_P ; last item of hybrid buffer
    RETD
    STM #xw+ADPT_FILT_SIZE–1,XW_DATA_P ; last element of input buffer
; 5. SUBROUTINE CODE
; HeaderBegin
;==============================================================================
; 5.2 adapt_task
;
; 5.2.1 Functional Description
;
; This subroutine performs the adaptive filtering. The newest sample is
; stored in a separate location since filtering and adaptation are performed
; at the same time. Otherwise the oldest sample is overwritten before
; updating the w(N-1) coefficient.
;
; d_primary = xh *hcoff
; d_output = xw *wcoff
Example 10–16. Adaptive Filtering Using LMS Instruction (Continued)

; LMS algorithm:
; w(i+1) = w(i) + d*mu_error*xw(n–i) for i = 0,1,...127 and n = 0,1,.....
; This program can run in two steps
; 1. Initial stepsize, d_mu = 0x0. At this point, the system is not
; identified since the coefficients are not adapted and the error
; signal e (n) is d (n). This is the default mode
; 2. At the EVM debugger command window change the step size
; d_mu – 0x000, with the command e * d_mu = 0x1000
; This changes the stepsize. The error signal e(n) in this case
; is approximately 0 (theoretically) and the system is identified.

; 5.2.2 Activation
; Activation example:
; CALL adapt_task
; Reentrancy: No
; Recursive : No

; 5.2.3 Inputs
; Data structure: AR3
; Data Format: 16-bit x(n) data buffer pointer for H(Z)
; Modified: Yes
; Description: uses circular buffer addressing mode of size 128
; Data structure: AR5
; Data Format: 16-bit x(n) data buffer pointer for W(z)
; Modified: Yes
; Description: uses circular buffer addressing mode of size 128
; Data structure: AR6
; Data Format: 16-bit input buffer pointer
; Modified: Yes
; Description: either point to PING/PONG buffer

; 5.2.4 Outputs
; Data structure: AR7
; Data Format: 16-bit output buffer pointer
; Modified: Yes
; Description: either point to PING/PONG buffer

; 5.2.5 Global
; Data structure: AR2
; Data Format: 16-bit H(z) coeff buffer pointer
; Modified: Yes
; Description: uses circular buffer addressing mode of size 128
; Data structure: AR4
; Data Format: 16-bit W(z) coeff buffer pointer
; Modified: Yes
; Description: uses circular buffer addressing mode of size 128
Example 10–16. Adaptive Filtering Using LMS Instruction (Continued)

; Data structure: d_adapt_count
; Data Format: 16-bit variable
; Modified: Yes
; Description: counter to check for processing 256 samples

; Data structure: d_new_x
; Data Format: 16-bit variable
; Modified: Yes
; Description: holds the newest sample

; Data structure: d_primary
; Data Format: 16-bit variable
; Modified: Yes
; Description: d_primary = xh * hcoeff

; Data structure: d_output
; Data Format: 16-bit variable
; Modified: Yes
; Description: d_output = xw * wcoeff

; Data structure: d_error
; Data Format: 16-bit variable
; Modified: Yes
; Description: d_error = d_primary-d_output

; Data structure: d_mu_e
; Data Format: 16-bit variable
; Modified: Yes
; Description: d_mu_e = mu*d_error

5.2.6 Special considerations for data structure
-
5.2.7 Entry and Exit conditions

<table>
<thead>
<tr>
<th>DP</th>
<th>OVM</th>
<th>SXM</th>
<th>C16</th>
<th>FRCT</th>
<th>ASM</th>
<th>AR0</th>
<th>AR1</th>
<th>AR2</th>
<th>AR3</th>
<th>AR4</th>
<th>AR5</th>
<th>AR6</th>
<th>AR7</th>
<th>A</th>
<th>B</th>
<th>BK</th>
<th>BRC</th>
<th>T</th>
<th>TRN</th>
</tr>
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<tr>
<td>in</td>
<td>U</td>
<td>1</td>
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<td>1</td>
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</tr>
</tbody>
</table>

Note: UM – Used & Modified, U – Used, NU – Not Used

5.2.8 Execution

Execution time: ?cycles
Call rate: not applicable for this application

================================================================================
Example 10–16. Adaptive Filtering Using LMS Instruction (Continued)

; 5.2.9 Code
.asg AR2, H_COFF_P       ; H(Z) coeff buffer pointer
.asg AR3, XH_DATA_P      ; data coeff buffer pointer
.asg AR6, INBUF_P        ; input buffer address pointer
.asg AR7, OUTBUF_P       ; output buffer address pointer
.asg AR4, W_COFF_P       ; W(z) coeff buffer pointer
.asg AR5, XW_DATA_P      ; data coeff buffer pointer
.sect "filter"

adapt_task:
STM #H_FILT_SIZE, BK     ; first circular buffer size
STM #hcoff, H_COFF_P     ; H_COFF_P --> last of sys coeff
ADDM #1, d_adapt_count
LD *INBUF_P+, A          ; load the input sample
STM #wcoff, W_COFF_P     ; reset coeff buffer
STL A, d_new_x          ; read in new data
LD d_new_x, A
RPTZ A, #H_FILT_SIZE–1    ; Repeat 128 times
MAC *H_COFF_P+0%, *XH_DATA_P+0%, A ; mult & acc:a = a + (h * x)
STH A, d_primary        ; primary signal

; start simultaneous filtering and updating the adaptive filter here.
LD d_mu_e, T             ; T = step_size*error
SUB B, B                 ; zero acc B
STM (#(ADPT_FILT_SIZE-2), BRC ; set block repeat counter
RPTBD lms_end–1
MPY *XW_DATA_P+0%, A     ; error * oldest sample
LMS *W_COFF_P, *XW_DATA_P ; B = filtered output (y)
| MPY*XW_DATA_P+0%,A     ; error *x[n-(N-1)]
LMS *W_COFF_P, *XW_DATA_P ; B = accum filtered output y

lms_end
STH A, *W_COFF_P         ; final coeff
MPY *XW_DATA_P, A        ; x(0)*h(0)
MVKD #d_new_x, *XW_DATA_P ; store the newest sample
LMS *W_COFF_P, *XW_DATA_P+0% ; store the filtered output
LD d_primary, A
SUB d_output, A
STL A, d_error           ; store the residual error signal
LD d_mu, T
MPY d_error, A           ; A=u*e
STH A, d_mu_e            ; save the error *step_size
LD d_error, A
STL A, OUTBUF_P+         ; check if a frame of samples
LD #K_FRAME_SIZE, A      ; have been processed
SUB d_adapt_count, A
BC adapt_task, AGT
RETD
ST #K_0, d_adapt_count   ; restore the count
.end
Example 10–16. Adaptive Filtering Using LMS Instruction (Continued)

* This is an input file used by the adaptive filter program.
* The transfer function is the system to be identified by the adaptive filter.

```
.word 0FFFDh
.word 24h
.word 6h
.word 0FFFDh
.word 3h
.word 3h
.word 0FFE9h
.word 7h
.word 12h
.word 1Ch
.word 0FFF3h
.word 0FFE8h
.word 0Ch
.word 3h
.word 1Eh
.word 1Ah
.word 22h
.word 0FFF5h
.word 0FFE5h
.word 0FF1h
.word 0FFC5h
.word 0Ch
.word 0FFE8h
.word 37h
.word 0FFE4h
.word 0FFCAh
.word 1Ch
.word 0FFFDh
.word 21h
.word 0FF7h
.word 2Eh
.word 28h
.word 0FFC6h
.word 53h
.word 0FFB0h
.word 55h
.word 0FF36h
.word 5h
.word 0FFCFh
.word 0FF99h
.word 64h
.word 41h
.word 0FFF1h
.word 0FFDFh
.word 0D1h
.word 6Ch
.word 57h
.word 36h
.word 0A0h
.word 0FE3h
.word 6h
```
Example 10–16. Adaptive Filtering Using LMS Instruction (Continued)

```assembly
.word 0FEC5h
.word 0ABh
.word 185h
.word 0FF6h
.word 93h
.word 1Fh
.word 10Eh
.word 59h
.word 0FEF0h
.word 96h
.word 0FBBh
.word 0FF47h
.word 0FF76h
.word 0FFOBh
.word 0FFAFh
.word 14Bh
.word 0FF3Bh
.word 132h
.word 289h
.word 8Dh
.word 0FE1Dh
.word 0FE1Bh
.word 0D4h
.word 0FF69h
.word 14Fh
.word 2AAh
.word 0FD43h
.word 0F98Fh
.word 451h
.word 13Ch
.word 0FEF7h
.word 0FE36h
.word 80h
.word 0FFBBh
.word 0FC8Eh
.word 10Eh
.word 37Dh
.word 6FAh
.word 1h
.word 0FD89h
.word 198h
.word 0FE4Ch
.word 0FE78h
.word 0F215h
.word 479h
.word 749h
.word 289h
.word 0F667h
.word 304h
.word 5F8h
.word 34Fh
.word 47Bh
.word 0FF7Fh
```
Example 10–16. Adaptive Filtering Using LMS Instruction (Continued)

```
.word  85Bh
.word  0F837h
.word  0F77Eh
.word  0FF80h
.word  0B9Bh
.word  0F03Ah
.word  0EE66h
.word  0FE28h
.word  0FAD0h
.word  8C3h
.word  0F5D6h
.word  14DCh
.word  0F3A7h
.word  0E542h
.word  10F2h
.word  566h
.word  26AAh
.word  15Ah
.word  2853h
.word  0EE95h
.word  93Dh
.word  20Dh
.word  1230h
.word  238Ah
```
Example 10–17. 256-Point Real FFT Initialization

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
; Archives: PVCS
; Filename: rfft.asm
; Version: 1.0
; Status : draft ( )
; proposal (X)
; accepted ( ) dd-mm-yy/?acceptor.
;
; AUTHOR Simon Lau and Nathan Baltz
;
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
; IPR statements description (can be collected).
;
; (C) Copyright 1996. Texas Instruments. All rights reserved.
;
; Change history:
;
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<td>July–17–96</td>
<td>Simon &amp; Nathan</td>
<td>original created</td>
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;
1. ABSTRACT

1.1 Function Type
   a.Core Routine
   b.Subroutine

1.2 Functional Description
   This file contains core routine:
   rfft

1.3 Specification/Design Reference (optional)

1.4 Module Test Document Reference
   Not done

1.5 Compilation Information
   Compiler: TMS320C54X ASSEMBLER
   Version: 1.02 (PC)
   Activation: asm500 –s rfft.asm

1.6 Notes and Special Considerations
   -
Example 10–17. 256-Point Real FFT Initialization (Continued)

```assembly
; 2. VOCABULARY
;
2.1 Definition of Special Words, Keywords (optional)
- 
2.2 Local Compiler Flags
- 
2.3 Local Constants
- 
)
)
3. EXTERNAL RESOURCES

3.1 Include Files
.mmregs
.include "main.inc"
.include "init_54x.inc"

3.2 External Data
.ref bit_rev, fft, unpack
.ref power
.ref sine, cosine
.ref sine_table, cos_table

3.3 Import Functions

4. INTERNAL RESOURCES

4.1 Local Static Data
- 
4.2 Global Static Data
- 
4.3 Dynamic Data
- 
4.4 Temporary Data
- 
4.5 Export Functions
.def rfft_task

5. SUBROUTINE CODE
_HEADERBEGIN
==============================================================================

5.1 rfft

5.2 Functional Description
The following code implements a Radix-2, DIT, 2N-point Real FFT for the
TMS320C54x. This main program makes four function calls, each
corresponds to a different phase of the algorithm. For more details about
how each phase is implemented, see bit_rev.asm, fft.asm, unpack.asm, and
power.asm assembly files.

-----------------------------------------------------------------------------
```
Example 10–17. 256-Point Real FFT Initialization (Continued)

; 5.3 Activation
; Activation example:
; CALL rfft
; Reentrancy: No
; Recursive: No

5.4 Inputs
NONE

5.5 Outputs
NONE

5.6 Global

; Data structure: AR1
; Data Format: 16-bit pointer
; Modified: No
; Description: used for moving the twiddle tables from program to data

5.7 Special considerations for data structure
-

5.8 Entry and Exit conditions

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<th>FRCT</th>
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</tr>
</tbody>
</table>

Note: UM – Used & Modified, U – Used, NU – Not Used

5.9 Execution
Execution time: ?cycles
Call rate: not applicable for this application

5.10 Code
.asg AR1,FFT_TWID_P
.sect "rfft_prg"

rfft_task:
STM #sine,FFT_TWID_P
RPT #K_FFT_SIZE-1
MVPD #sine_table,*FFT_TWID_P+ ; move FIR coeffs from program to data
STM #cosine,FFT_TWID_P
RPT #K_FFT_SIZE-1
MVPD #cos_table,*FFT_TWID_P+ ; move FIR coeffs from program to data
CALL bit_rev
CALL fft
CALL unpack
CALLD power
STM #K_ST1,ST1 ; restore the original contents of ST1 since ASM field has changed
RET ; return to main program
.end
Example 10–18.  Bit Reversal Routine

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP ;
;
; Archives:   PVCS
; Filename:   bit_rev.asm
; Version:    1.0
; Status :    draft    ( )
;            proposal (X)
;            accepted  ( ) dd-mm-yyyy/?acceptor.
;
; AUTHOR     Simon Lau and Nathan Baltz
;
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
; IPR statements description (can be collected).
;
; (C) Copyright 1996. Texas Instruments. All rights reserved.
;
; Change history:
;
; VERSION    DATE     /      AUTHORS              COMMENT
; 1.0        July-17-96 / Simon & Nathan      original created
;
; 1. ABSTRACT
;
; 1.1 Function Type
;     a.Core Routine
;     b.Subroutine
;
; 1.2 Functional Description
;     This file contains one subroutine:
;     bit_rev
;
; 1.3 Specification/Design Reference (optional)
;     called by rfft.asm depending upon the task thru CALA
;
; 1.4 Module Test Document Reference
;     Not done
;
; 1.5 Compilation Information
;     Compiler:  TMS320C54X  ASSEMBLER
;     Version:   1.02 (PC)
;     Activation:  asm500 -s bit_rev.asm
;
; 1.6 Notes and Special Considerations
;     -
Example 10–18. Bit Reversal Routine (Continued)

```c
;
;
2. VOCABULARY
;
2.1 Definition of Special Words, Keywords (optional)
-
2.2 Local Compiler Flags
-
2.3 Local Constants
-
;
3. EXTERNAL RESOURCES
;
3.1 Include Files

.mmregs
.include "main.inc"
;
3.2 External Data

.ref d_input_addr, fft_data
;
3.3 Import Functions
;
4. INTERNAL RESOURCES
;
4.1 Local Static Data
-
4.2 Global Static Data
-
4.3 Dynamic Data
-
4.4 Temporary Data
-
4.5 Export Functions

.def bit_rev
;
5. SUBROUTINE CODE

HeaderBegin

5.1 bit_rev

5.2 Functional Description
This function is called from the main module of the ‘C54x Real FFT code.
It reorders the original 2N-point real input sequence by using
bit-reversed addressing. This new sequence is stored into the data
processing buffer of size 2N, where FFT will be performed in-place
during Phase Two.
```

---

10-88

PRELIMINARY
Example 10–18. Bit Reversal Routine (Continued)

; 5.3 Activation
;   Activation example:
;       CALL    bit_rev
;   Reentrancy:   No
;   Recursive     No
;
; 5.4 Inputs
;   NONE
;
; 5.5 Outputs
;   NONE
;
; 5.6 Global
;
;   Data structure: AR0
;   Data Format: 16-bit index pointer
;   Modified: No
;   Description: used for bit reversed addressing
;
;   Data structure: AR2
;   Data Format: 16-bit pointer
;   Modified: Yes
;   Description: pointer to processed data in bit-reversed order
;
;   Data structure: AR3
;   Data Format: 16-bit pointer
;   Modified: Yes
;   Description: pointer to original input data in natural order
;
;   Data structure: AR7
;   Data Format: 16-bit pointer
;   Modified: Yes
;   Description: starting addressing of data processing buffer
;
; 5.7 Special considerations for data structure
; -
;
; 5.8 Entry and Exit conditions
;
;   |DP|OVM|SXM|C16|FRCT|ASM|AR0|AR1|AR2|AR3|AR4|AR5|AR6|AR7|A |B |BK|BRC| T|TRN|
; in | 1 | 1 | NU | 1 | NU | NU | NU | NU | NU | NU | NU | NU | NU | NU |SU |SU|SU|SU|SU|SU |
; out| 1 | 1 | NU | 1 | NU | UM | UM | UM | UM | UM | UM | UM | UM | UM |SU |SU|SU|SU|SU|SU |

Note: UM – Used & Modified, U – Used, NU – Not Used

; 5.9 Execution
;   Execution time: ?cycles
;   Call rate: not applicable for this application
;
;==============================================================================
;HeaderEnd
Example 10–18. Bit Reversal Routine (Continued)

; 5.10 Code
.asg AR2,REORDERED_DATA
.asg AR3,ORIGINAL_INPUT
.asg AR7,DATA_PROCBUF
.sect "rfft_prg"

bit_rev:
  SSBX FRCT                      ; fractional mode is on
  MVDK d_input_addr,ORIGINAL_INPUT ; AR3 -> 1st original input
  STM #fft_data,DATA_PROC_BUF    ; AR7 -> data processing buffer
  MVMM DATA_PROC_BUF,REORDERED_DATA ; AR2 -> 1st bit-reversed data
  STM #K_FFT_SIZE-1,BRC
  RPTBD bit_rev_end-1
  STM #K_FFT_SIZE,AR0            ; AR0 = 1/2 size of circ buffer
  MVDD *ORIGINAL_INPUT+,*REORDERED_DATA+
  MVDD *ORIGINAL_INPUT-,*REORDERED_DATA+
  MAR *ORIGINAL_INPUT+0B

bit_rev_end:
  RET                          ; return to Real FFT main module

end
Example 10–19. 256-Point Real FFT Routine

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
;
; Archives: PVCS
; Filename: fft.asm
; Version: 1.0
; Status: draft ()
; proposal (X)
; accepted ( ) dd-mm-yy/?acceptor.
;
; AUTHOR Simon Lau and Nathan Baltz
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
; IPR statements description (can be collected).
;
; (C) Copyright 1996. Texas Instruments. All rights reserved.
;
; Change history:
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<td>Simon &amp; Nathan</td>
<td>original created</td>
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</table>

1. ABSTRACT

1.1 Function Type
   a.Core Routine
   b.Subroutine

1.2 Functional Description
   This file contains one subroutine: fft

1.3 Specification/Design Reference (optional)
   called by rfft.asm depending upon the task thru CALA

1.4 Module Test Document Reference
   Not done

1.5 Compilation Information
   Compiler: TMS320C54X ASSEMBLER
   Version: 1.02 (PC)
   Activation: asm500 -s fft.asm

1.6 Notes and Special Considerations
   -
Example 10–19. 256-Point Real FFT Routine (Continued)

```
};
} 2. VOCABULARY
} 2.1 Definition of Special Words, Keywords (optional)
} 2.2 Local Compiler Flags
} 2.3 Local Constants
}
} 3. EXTERNAL RESOURCES
} 3.1 Include Files
 .mmregs
 .include "main.inc"
} 3.2 External Data
 .ref fft_data, d_grps_cnt, d_twid_idx, d_data_idx, sine, cosine
} 3.3 Import Functions

{ 4. INTERNAL RESOURCES
{ 4.1 Local Static Data
{ 4.2 Global Static Data
{ 4.3 Dynamic Data
{ 4.4 Temporary Data
{ 4.5 Export Functions
 .def fft

5. SUBROUTINE CODE
 HeaderBegin
==============================================================================

5.1 fft

5.2 Functional Description
 PHASE TWO  (LogN)-Stage Complex FFT
 This function is called from main module of the ’C54x Real FFT code.
 Here we assume that the original 2N-point real input sequence is al
 ready packed into an N-point complex sequence and stored into the
 data processing buffer in bit-reversed order (as done in Phase One).
 Now we perform an in-place, N-point complex FFT on the data proces
 sing buffer, dividing the outputs by 2 at the end of each stage to
 prevent overflow. The resulting N-point complex sequence will be un-
 packed into a 2N-point complex sequence in Phase Three & Four.

```
Example 10–19. 256-Point Real FFT Routine (Continued)

; 5.3 Activation
; Activation example:
; CALL fft
; Reentrancy: No
; Recursive: No

; 5.4 Inputs
; NONE

; 5.5 Outputs
; NONE

; 5.6 Global

; Data structure: AR0
; Data Format: 16-bit index pointer
; Modified: No
; Description: index to twiddle tables

; Data structure: AR1
; Data Format: 16-bit counter
; Modified: No
; Description: group counter

; Data structure: AR2
; Data Format: 16-bit pointer
; Modified: Yes
; Description: pointer to 1st butterfly data PR,PI

; Data structure: AR3
; Data Format: 16-bit pointer
; Modified: Yes
; Description: pointer to 2nd butterfly data QR,QI

; Data structure: AR4
; Data Format: 16-bit pointer
; Modified: Yes
; Description: pointer to cosine value WR

; Data structure: AR5
; Data Format: 16-bit pointer
; Modified: Yes
; Description: pointer to cosine value WI

; Data structure: AR6
; Data Format: 16-bit counter
; Modified: Yes
; Description: butterfly counter

; Data structure: AR7
; Data Format: 16-bit pointer
; Modified: Yes
; Description: start address of data processing buffer
Example 10–19. 256-Point Real FFT Routine (Continued)

; 5.7 Special considerations for data structure
; -
; 5.8 Entry and Exit conditions

; in | DP | OVM | SXM | C16 | FRCT | AR0 | AR1 | AR2 | AR3 | AR4 | AR5 | AR6 | AR7 | A | B | BK | BRC | T | TRN |
;    | 1  | 1  | 1   | 0   | NU   | 0   | NU  | NU  | NU  | NU  | NU  | NU  | NU  | NU | NU |   |   |   |   |
; out| U  | 1  | 1   | NU  | 1   | -1  | UM  | UM  | UM  | UM  | UM  | UM  | UM  | UM | UM |   |   |   |   |

Note: UM – Used & Modified, U – Used, NU – Not Used

; 5.9 Execution
; Execution time: ?cycles
; Call rate: not applicable for this application

; HeaderEnd

; 5.10 Code

.asg AR1,GROUP_COUNTER
.asg AR2,PX
.asg AR3,QX
.asg AR4,WR
.asg AR5,WI
.asg AR6,BUTTERFLY_COUNTER
.asg AR7,DATA_PROC_BUF ; for Stages 1 & 2
.asg AR7,stAGE_COUNTER ; for the remaining stages
.sect "rfft_prg"
fft:
; Stage 1

STM #K_ZERO_BK,BK ; BK=0 so that ARn+0% == ARn+0
LD #-1,ASM ; outputs div by 2 at each stage
MVMM DATA_PROC_BUF,PX ; PX -> PR
LD *PX,A ; A := PR
STM #fft_data+K_DATA_IDX_1,QX ; QX -> QR
STM #K_FFT_SIZE/2–1,BRC
RPTBD stagelend-1
STM #K_DATA_IDX_1+1,AR0
SUB *QX,16,A,B ; B := PR-QR
ADD *QX,16,A ; A := PR+QR
STH *PX,A ; A := PI
SUB *QX,16,A,B ; B := PI-QI
ADD *QX,16,A ; A := PI+QI
STM A,ASM,*PX+ ; PR' := (PR+QR)/2
ST B,*QX+ ; QR' := (PR-QR)/2
LD *PX,A ; A := PI
STM A,ASM,*PX+ ; PI' := (PI+QI)/2
ST B,*QX+0% ; QI' := (PI-QI)/2
LD *PX,A ; A := next PR
Example 10–19. 256-Point Real FFT Routine (Continued)

stage2end:
; Stage 2

MVMM DATA_PROC_BUF,PX ; PX -> PR
STM #fft_data+K_DATA_IDX_2,QX ; QX -> QR
STM #K_FFT_SIZE/4-1,BRC
LD *PX,A ; A := PR
RPTBD stage2end-1
STM #K_DATA_IDX_2+1,AR0

; 1st butterfly
SUB *QX,16,A,B ; B := PR-QR
ADD *QX,16,A ; A := PR+QR
STH A,ASM,*PX+ ; PR’ := (PR+QR)/2
STM *QX,16,A ; A := PI-QI
ADD *QX,16,A ; A := PI+QI
STM *QX,A

; 2nd butterfly
MAR *QX+
ADD *PX,*QX,A ; A := PR+QI
SUB *PX,*QX-,B ; B := PR-QI
STM *PX,*QX,A ; A := PI-QR
STM B,*QX ; QR’ := (PR-QI)/2
LD *PX,A ; A := PI-QI
STM *PX,A

; 2nd butterfly
ADD *PX+0%,A ; A := PI+QR
LD *PX,A ; A := PR

stage2end:
; Stage 3 thru Stage logN-1

STM #K_TWID_TBL_SIZE,BK ; BK = twiddle table size always
STM #K_TWIDIDX_3,d_twid_idx ; init index of twiddle table
STM #K_TWID_IDX_3,AR0 ; AR0 = index of twiddle table
STM #cosine,WR ; init WR pointer
STM #sine,VI ; init WI pointer
STM #K_LOGN-2-1,STAGE_COUNTER ; init stage counter
STM #K_FFT_SIZE/8-1,d_grps_cnt ; init group counter
STM #K_FLY_COUNT_3-1,BUTTERFLY_COUNTER ; init butterfly counter
STM #K_DATA_IDX_3,d_data_idx ; init index for input data

stage:
STM #fft_data,PX ; PX -> PR
LD d_data_idx,A
ADD *(PX),A
STM A,OX ; QX -> QR
MVDK d_grps_cnt,GROUP_COUNTER ; AR1 contains group counter
Example 10–19. 256-Point Real FFT Routine (Continued)

```assembly
Example 10–19. 256-Point Real FFT Routine (Continued)

group:
  MVMD BUTTERFLY_COUNTER, BRC
  RPTB0 butterflyend-1
  LD *WR, T
  MPY *QX+, A
  MACR *WI+0%, *QX-, A
  ADD *PX, 16, A, B
  ST B, *PX
  || SUB *PX+, B
  || MPY *QX+, A
  || SUB *PX, B
  LD *WR, T
  ST B, *PX+
  || MPY *QX+, A

butterflyend:
; Update pointers for next group
  PSHM AR0
  MVDK d_data_idx, AR0
  MAR *PX+0
  MAR *QX+0
  BANZD group, *GROUP_COUNTER–
  POPM AR0

; Update counters and indices for next stage
  LD d_data_idx, A
  SUB #1, A, B
  STLM B, BUTTERFLY_COUNTER
  STL A, 1, d_data_idx
  LD d_grps_cnt, A
  STL A, ASM, d_grps_cnt
  LD d_twid_idx, A
  STL A, ASM, d_twid_idx
  BANZ D stage, *STAGE_COUNTER–
  MVDK d_twid_idx, AR0

fft_end:
  RET

.end
```
Example 10–20. Unpack 256-Point Real FFT Output

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
; Archives: PVCS
; Filename: unpack.asm
; Version: 1.0
; Status: draft ( )
; proposal (X)
; accepted ( ) dd-mm-yy/?acceptor.

; AUTHOR Simon Lau and Nathan Baltz
;
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
; (C) Copyright 1996. Texas Instruments. All rights reserved.
;
; Change history:
;
; VERSION DATE / AUTHORS COMMENT
; 1.0 July–17–96 / Simon & Nathan original created
;
; 1. ABSTRACT
;
; 1.1 Function Type
; a. Core Routine
; b. Subroutine
;
; 1.2 Functional Description
; This file contains one subroutine:
; unpack
;
; 1.3 Specification/Design Reference (optional)
; called by rfft.asm depending upon the task thru CALA
;
; 1.4 Module Test Document Reference
; Not done
;
; 1.5 Compilation Information
; Compiler: TMS320C54X ASPsembler
; Version: 1.02 (PC)
; Activation: asm500 –s unpack.asm
;
; 1.6 Notes and Special Considerations
;
Example 10–20. Unpack 256-Point Real FFT Output (Continued)

```c

2. VOCABULARY

2.1 Definition of Special Words, Keywords (optional)

2.2 Local Compiler Flags

2.3 Local Constants

3. EXTERNAL RESOURCES

3.1 Include Files

.include "main.inc"

3.2 External Data

.ref fft_data,sine, cosine

3.3 Import Functions

4. INTERNAL RESOURCES

4.1 Local Static Data

4.2 Global Static Data

4.3 Dynamic Data

4.4 Temporary Data

4.5 Export Functions

.def unpack

5. SUBROUTINE CODE

5.1 unpack

5.2 Functional Description

PHASE THREE & FOUR Unpacking to 2N Outputs

This function is called from the main module of the ‘C54x Real FFT code. It first computes four intermediate sequences (RP, RM, IP, IM) from the resulting complex sequence at the end of the previous phase. Next, it uses the four intermediate sequences to form the FFT of the original 2N-point real input. Again, the outputs are divided by 2 to prevent overflow.
```

PRELIMINARY
Example 10–20. Unpack 256-Point Real FFT Output (Continued)

; 5.3 Activation
; Activation example:
; CALL unpack
; Reentrancy: No
; Recursive: No

5.4 Inputs
NONE

5.5 Outputs
NONE

5.6 Global

5.6.1 Phase Three Global

Data structure: AR0
Data Format: 16-bit index pointer
Modified: No
Description: index to twiddle tables

Data structure: AR2
Data Format: 16-bit pointer
Modified: Yes
Description: pointer to R[k], I[k], RP[k], IP[k]

Data structure: AR3
Data Format: 16-bit pointer
Modified: Yes
Description: pointer to R[N-k], I[N-k], RP[N-k], IP[N-k]

Data structure: AR6
Data Format: 16-bit pointer
Modified: Yes
Description: pointer to RM[k], IM[k]

Data structure: AR7
Data Format: 16-bit pointer
Modified: Yes
Description: pointer to RM[n-k], IM[n-k]

5.6.2 Phase Four Global

Data structure: AR0
Data Format: 16-bit index pointer
Modified: No
Description: index to twiddle tables

Data structure: AR2
Data Format: 16-bit counter
Modified: No
Description: pointer to RP[k], IP[k], AR[k], AI[k], AR[0]
Example 10–20. Unpack 256-Point Real FFT Output (Continued)

1. Data structure: AR3
2. Data Format: 16-bit pointer
3. Modified: Yes
4. Description: pointer to RM[k], IM[k], AR[2N-k], AI[2N-k]

- Data structure: AR4
- Data Format: 16-bit pointer
- Modified: Yes
- Description: pointer to cos(k*pi/N), AI[0]

- Data structure: AR5
- Data Format: 16-bit pointer
- Modified: Yes
- Description: pointer to sin(k*pi/N), AR[N], AI[N]

5.7 Special considerations for data structure

5.8 Entry and Exit conditions

5.8.1 Phase Three Entry and Exit Conditions

5.8.2 Phase Four Entry and Exit Conditions

5.9 Execution

5.10 Code

```assembly
.sect "rfft_prg"
unpack:
  ; Compute intermediate values RP, RM, IP, IM
  .asg AR2,XP_k
  .asg AR3,XP_Nminusk
  .asg AR6,XM_k
  .asg AR7,XM_Nminusk
```

10-100
Example 10–20. Unpack 256-Point Real FFT Output (Continued)

```
STM #fft_data+2,XP_k          ; AR2 -> R[k] (temp RP[k])
STM #fft_data+2*K_FFT_SIZE-2,XP_Nminusk   ; AR3 -> R[N-k] (temp RP[N-k])
STM #fft_data+2*K_FFT_SIZE+3,XM_Nminusk   ; AR7 -> temp RM[N-k]
STM #fft_data+4*K_FFT_SIZE-1,XM_k        ; AR6 -> temp RM[k]
STM #-2+K_FFT_SIZE/2,BRC
RPTBD  phase3end-1
STM #3,AR0
ADD *XP_k,*XP_Nminusk,A         ; A := R[k]+R[N-k] = 2*RP[k]
SUB *XP_k,*XP_Nminusk,B         ; B := R[k]–R[N-k] = 2*RM[k]
STH A,ASM,*XP_k+                ; store RP[k] at AR[k]
STH A,ASM,*XP_Nminusk+          ; store RP[N-k]=RP[k] at AR[N-k]
STH B,ASM,*XM_k–                ; store RM[k] at AI[2N-k]
NEG B                           ; B := R[N-k]–R[k] = 2*RM[N-k]
STH B,ASM,*XM_Nminusk–          ; store RM[N-k] at AI[N+k]
ADD *XP_k,*XP_Nminusk,A         ; A := I[k]+I[N-k] = 2*IP[k]
SUB *XP_k,*XP_Nminusk,B         ; B := I[k]–I[N-k] = 2*IM[k]
STH A,ASM,*XP_k+                ; store IP[k] at AI[k]
STH A,ASM,*XP_Nminusk-0         ; store IP[N-k]=IP[k] at AI[N-k]
STH B,ASM,*XM_k–                ; store IM[k] at AI[2N-k]
NEG B                           ; B := I[N-k]–I[k] = 2*IM[N-k]
STH B,ASM,*XM_Nminusk+0         ; store IM[N-k] at AR[N+k]

phase3end:
ST #0,*XM_k–                   ; RM[N/2]=0
ST #0,*XM_k                     ; IM[N/2]=0
; Compute AR[0],AI[0], AR[N], AI[N]
   .asg   AR2,AX_k
   .asg   AR4,IP_0
   .asg   AR5,AX_N
STM #fft_data,AX_k              ; AR2 -> AR[0] (temp RP[0])
STM #fft_data+1,IP_0             ; AR4 -> AI[0] (temp IP[0])
STM #fft_data+2*K_FFT_SIZE+1,AX_N ; AR5 -> AI[N]
ADD *AX_k,*IP_0,A                ; A := RP[0]+IP[0]
SUB *AX_k,*IP_0,B                ; B := RP[0]–IP[0]
STH A,ASM,*AX_k+                ; AR[0] = (RP[0]+IP[0])/2
ST #0,*AX_k                     ; AI[0] = 0
MVDD *AX_k,+,*AX_N–             ; AI[N] = 0
STH B,ASM,*AX_N                 ; AR[N] = (RP[0]–IP[0])/2
; Compute final output values AR[k], AI[k]
   .asg AR3,AX_2Nminusk
   .asg AR4,COS
   .asg AR5,SIN
```

Example 10–20. Unpack 256-Point Real FFT Output (Continued)

STM      #fft_data+4*K_FFT_SIZE-1,AX_2Nminusk ; AR3 -> AI[2N-1] 
          (temp RM[1])
STM      #cosine+K_TWID_TBL_SIZE/K_FFT_SIZE,COS  ; AR4 -> cos(k*pi/N)
STM      #sine+K_TWID_TBL_SIZE/K_FFT_SIZE,SIN    ; AR5 -> sin(k*pi/N)
STM      #K_FFT_SIZE–2,BRC
RPTBD    phase4end-1
STM      #K_TWID_TBL_SIZE/K_FFT_SIZE,AR0       ; index of twiddle tables
LD       *AX_k+,16,A                           ; A := RP[k] || AR2->IP[k]
MACR     *COS,*AX_k,A                          ; A :=A+cos(k*pi/N)
          *IP[k]
MASR     *SIN,*AX_2Nminusk–,A                  ; A := A-sin(k*pi/N)
          *RM[k]
LD       *AX_2Nminusk+,16,B                    ; B := IM[k] || AR3->RM[k]
MASR     *SIN+0%,*AX_k–,B                      ; B := B-sin(k*pi/N)
          *IP[k]
MASR     *COS+0%,*AX_2Nminusk,B                ; B := B-cos(k*pi/N)
          *RM[k]
STH      A,ASM,*AX_k+                         ; AR[k] = A/2
STH      B,ASM,*AX_k+                         ; AI[k] = B/2
NEG      B                                    ; B := -B
STH      B,ASM,*AX_2Nminusk–                  ; AI[2N-k] = -AI[k]
          = B/2
phase4end:
RET                                              ; returntoRealFFTmain module
.end
Example 10–21. Comptuate the Power Spectrum of the Complex Output of the 256-Point Real FFT

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
; Archives: PVCS
; Filename: power.asm
; Version: 1.0
; Status : draft ( )
; proposal (X)
; accepted ( ) dd-mm-yy/?acceptor.
; 
; AUTHOR Simon Lau and Nathan Baltz
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
; { IPR statements description (can be collected).
; }
; (C) Copyright 1996. Texas Instruments. All rights reserved.
; 
; Change history:
; 
; VERSION DATE / AUTHORS COMMENT
; 1.0 July-17-96 / Simon & Nathan original created
; 
; 1. ABSTRACT
; 
; 1.1 Function Type
; a.Core Routine
; b.Subroutine
; 
; 1.2 Functional Description
; This file contains one subroutine:
; power
; 
; 1.3 Specification/Design Reference (optional)
; called by rfft.asm depending upon the task thru CALA
; 
; 1.4 Module Test Document Reference
; Not done
; 
; 1.5 Compilation Information
; Compiler: TMS320C54X ASSEMBLER
; Version: 1.02 (PC)
; Activation: asm500 -s power.asm
; 
; 1.6 Notes and Special Considerations
; 
; PRELIMINARY Application Code Examples 10-103
Example 10–21. **Compute the Power Spectrum of the Complex Output of the 256-Point Real FFT (Continued)**

```c
//
// 2. VOCABULARY
//
// 2.1 Definition of Special Words, Keywords (optional)
//
// 2.2 Local Compiler Flags
//
// 2.3 Local Constants
//
//
// 3. EXTERNAL RESOURCES
//
// 3.1 Include Files
// .mmregs
// .include   "main.inc"
//
// 3.2 External Data
// .ref   fft_data, d_output_addr
//
// 3.3 Import Functions
//
//
// 4. INTERNAL RESOURCES
//
// 4.1 Local Static Data
//
// 4.2 Global Static Data
//
// 4.3 Dynamic Data
//
// 4.4 Temporary Data
//
// 4.5 Export Functions
// .def    power
//
//
5. SUBROUTINE CODE
HeaderBegin
==============================================================================

5.1 power

5.2 Functional Description
PHASE FIVE  Power Spectrum
This function is called from the main module of the 'C54x Real FFT code. It computes the power spectrum of the Real FFT output.

5.3 Activation
Activation example:
CALL    power
Reentrancy:   No
Recursive :   No
```
Example 10–21. **Compute the Power Spectrum of the Complex Output of the 256-Point Real FFT (Continued)**

; 5.4 Inputs
; NONE
; 5.5 Outputs
; NONE
; 5.6 Global
; Data structure: AR2
; Data Format: 16-bit pointer
; Modified: Yes
; Description: pointer to AR[k], AI[k]
; Data structure: AR3
; Data Format: 16-bit pointer
; Modified: Yes
; Description: pointer to output buffer
; 5.7 Special considerations for data structure
; -
; 5.8 Entry and Exit conditions
; |DP|OVM|SXM|C16|FRCT|ASM|AR0|AR1|AR2|AR3|AR4|AR5|AR6|AR7|A |B |BK|BRC| T|TRN|
; |  |   |   |   |    |   |   |   |   |   |   |   |   |   |  |  |  |   |  |   |
;in |U | 1 | 1 |NU | 1  |NU |NU |NU |NU |NU |NU |NU |NU |NU |NU|NU|NU|NU |NU|NU |
;out|U | 1 | 1 |NU | 1  |NU |NU |NU |UM |UM |NU |NU |NU |NU |UM|NU|NU|UM |NU|NU |
; Note: UM – Used & Modified, U – Used, NU – Not Used
; 5.9 Execution
; Execution time: ?cycles
; Call rate: not applicable for this application
;==============================================================================
; HeaderEnd
; 5.10 Code
; .asg AR2,AX
; .asg AR3,OUTPUT_BUF
; .sect "pwr_prog" power:
; MVDK d_output_addr,OUTPUT_BUF ; AR3 points to output buffer
; STM #K_FFT_SIZE*2-1,BRC
; RPTBD power_end-1
; STM #fft_data,AX ; AR2 points to AR[0]
; SQUR *AX+,A ; A := AR^2
; SQURA *AX+,A ; A := AR^2 + AI^2
; STM A,*OUTPUT_BUF+ power_end:
; RET ; return to main program
; .end
Example 10–22. Data Transfer from FIFO

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
;
; Archives: PVCS
; Filename: fifo.asm
; Version: 1.0
; Status : draft ( )
; proposal (X)
; accepted ( ) dd-mm-yy/?acceptor.
;
; AUTHOR    Padma P. Mallela
;
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
;
; IPR statements description (can be collected).
;
; (C) Copyright 1996. Texas Instruments. All rights reserved.
;
; Change history:
;
; VERSION      DATE     /     AUTHORS           COMMENT
; 1.0     July–25–96  /    P.Mallela      original created
;
;
1. ABSTRACT

1.1 Function Type
   a.Core Routine
   b.Subroutine

1.2 Functional Description
   This file contains one subroutines: fifo_host_transfer

1.3 Specification/Design Reference (optional)
   called by main.asm depending upon if K_HOST_FLAG is set

1.4 Module Test Document Reference
   Not done

1.5 Compilation Information
   Compiler: TMS320C54X ASSEMBLER
   Version: 1.02 (PC)
   Activation: asm500 -s fifo.asm

1.6 Notes and Special Considerations


Example 10–22. Data Transfer from FIFO (Continued)

};
}; 
2. VOCABULARY
};
}; 2.1 Definition of Special Words, Keywords (optional)
};
}; 2.2 Local Compiler Flags
};
}; 2.3 Local Constants
};
};
};
};
3. EXTERNAL RESOURCES
};
}; 3.1 Include Files
};
}; .mmregs
.include "target.inc"
};
}; 3.2 External Data
};
}; .ref d_command_reg
};
}; .ref d_fifo_count
};
}; .ref d_command_value
};
}; .ref d_fifo_ptr
};
}; .ref d_output_addr
};
}; 3.3 Import Functions
};
};
};
};
4. INTERNAL RESOURCES
};
};
}; 4.1 Local Static Data
};
};
}; 4.2 Global Static Data
};
};
}; 4.3 Dynamic Data
};
};
}; 4.4 Temporary Data
};
};
}; 4.5 Export Functions
};
}; .def fifo_host_transfer
};
}; 5. SUBROUTINE CODE
};
};
};
};
5.1 fifo_host_transfer
};
};
};
5.2 Functional Description
};
}; This routine transfers a FIFO(64) of data to host thru CH B.
};
}; In the process, after transferring data from DSP to FIFO sends a com-
};
}; mand to host thru CH A. The host acknowledges and sends a command to 
};
}; target (DSP) thru CH A. The host transfer can be disabled by setting 
};
}; the K_HOST_FLAG = 0

Example 10–22. Data Transfer from FIFO (Continued)

5.3 Activation
Activation example:
CALL fifo_host_transfer

Reentrancy: No
Recursive : No

5.4 Inputs
Data structure: d_output_addr
Data Format: 16-bit variable
Modified: NO
Description: holds the starting addr of either PING/PONG addr.

Data structure: d_fifo_count
Data Format: 16-bit var
Modified: Yes
Description: counter for # of transfers

Data structure: d_fifo_ptr
Data Format: 16-bit variable
Modified: Yes
Description: holds the output bffr addr. and incremented by 32 for every transfer

5.5 Outputs

Data structure: AR7
Data Format: 16-bit output buffer pointer
Modified: Yes
Description: either point to PING/PONG buffer

5.6 Global

Data structure: d_command_reg
Data Format: 16-bit variable
Modified: Yes
Description: command from host is read thru CH A

Data structure: d_command_value
Data Format: 16-bit variable
Modified: Yes
Description: holds the command value

5.7 Special considerations for data structure

5.8 Entry and Exit conditions

Note: UM – Used & Modified, U – Used, NU – Not Used
Example 10–22. Data Transfer from FIFO (Continued)

; 5.9 Execution
; Execution time: ?cycles
; Call rate: not applicable for this application
;
;==============================================================================
;HeaderEnd
; 5.10 Code
; fifo_host_transfer:
; LD  #FIFO_DP,DP
   .if K_HOST_FLAG =1
      PORTR  K_TRGCR_ADDR,d_command_reg ; while (port14 & BXST)
      BITF  d_command_reg,K_BXST
      MVK  fifo_discard,TC ; FIFO discard
      MVDK d_output_addr,OUTBUF_P ; load PING/PONG bffr address
      RPT #K_FIFO_SIZE–1 ; write first set of 64 data 
                     ; to FIFO
      PORTW *OUTBUF_P+,K_CHB ; Fill FIFO
      ST #K_FIFO_FULL,d_command_value
      PORTW d_command_value, K_CHA ; write command to comnd reg A
      ST #1,d_fifo_count ; start counting for tranfers
      MVKD OUTBUF_P,d_fifo_ptr ; save the fifo_ptr
   .endif
   RET
.end

*************************************************************************
* This file includes the TCR register configuration of EVM
*************************************************************************
K_AIC_RST .set 0b << 15 ; if AICRST=0, aic is reset
K_USR_BOT  .set 000b << 12 ; User discrete output bits
               0,1,2
K_RESRV    .set 0000b << 8  ; Reserved bits
K_USR_BIN  .set 00b << 6   ; User discrete input bits 0,1
K_RCV_BRST .set 00b << 4   ; Channel B receive status regs
               buffer half or more
K_XMT_BXST .set 11b << 2   ; Ch B trasnmit status register
               buffer half or more
K_RCV_ARST .set 0b << 1    ; Ch A receive register
K_XMT_AXST .set 0b << 1    ; Ch A transmit register
K_TCR_HIGH .set K_AIC_RST|K_USR_BOT|K_RESRV
K_TCR_LOW  .set K_USR_BIN|K_RCV_BRST|K_XMT_BXST|K_RCV_ARST|K_XMT_AXST
K_TCR      .set K_TCR_HIGH|K_TCR_LOW

*************************************************************************
* this includes I/O address of CH_A, CH_B and different commands that’s been
* passed between host and the target
*************************************************************************
K_0        .set 0h ; constant 0
K_FIFO_FULL .set 0xFF ; Full FIFO command written by 
                     ; target
K_FIFO_EMPTY .set 0xEE ; Empty FIFO command
                     ; written by host
K_AXST_CLEAR .set 0xAE ; Clear AXST empty command
                     ; written by the target
Example 10–22. Data Transfer from FIFO (Continued)

K_HANDSHAKE_CMD .set 0xAB ; handshake CMD written by host
K_CHB           .set  12h ; Use Channel B as I/O interface
                 ; to 54x EVM for sending data
K_CHA           .set  10h ; Use Channel A as I/O interface
                 ; to 54x EVM for send command
                 ; to host
K_TRGCR_ADDR   .set  14h ; Target status control register
                 ; I/O address location
K_AXST          .set  1h  ; 0h
K_ARST          .set  2h  ; used to check the control bits
K_BXST          .set  3h  ; check if K_FIFO_SIZE
                 ; its a 64 FIFO
K_FRAME_SIZE    .set  256 ; Frame size
K_HOST_FLAG     .set  1   ; if 0, then host interface
                 ; is disabled
Example 10–23. Interrupt 1 Service Routine

; TEXAS INSTRUMENTS INCORPORATED
; DSP Data Communication System Development / ASP
; Archives: PVCS
; Filename: hst_int1.asm
; Version: 1.0
; Status: draft ( )
; proposal (X)
; accepted ( ) dd-mm-yy/?acceptor.
; AUTHOR Padma P. Mallela
; Application Specific Products
; Data Communication System Development
; 12203 SW Freeway, MS 701
; Stafford, TX 77477
; IPR statements description (can be collected).
; (C) Copyright 1996. Texas Instruments. All rights reserved.
; Change history:
; VERSION DATE / AUTHORS COMMENT
; 1.0 July–25–96 / P.Mallela original created
;
1. ABSTRACT
1.1 Function Type
   a.Core Routine
   b.Subroutine
1.2 Functional Description
   This file contains interrupt service routine INT1:
   1) host_command_int1
1.3 Specification/Design Reference (optional)
   INT1 is serviced whenever host writes to CH A
1.4 Module Test Document Reference
   Not done
1.5 Compilation Information
   Compiler: TMS320C54X ASSEMBLER
   Version: 1.02 (PC)
   Activation: asm500 -s hst_int1.asm
1.6 Notes and Special Considerations
Example 10–23. Interrupt 1 Service Routine (Continued)

1. Application Code

2. VOCABULARY

2.1 Definition of Special Words, Keywords (optional)

2.2 Local Compiler Flags

2.3 Local Constants

3. EXTERNAL RESOURCES

3.1 Include Files

.include "target.inc"

3.2 External Data

.include FIFO_DP
.include d_command_reg
.include d_fifo_count
.include FIFO_DP
.include d_command_value
.include d_fifo_ptr
.include d_output_addr

3.3 Import Functions

4. INTERNAL RESOURCES

4.1 Local Static Data

4.2 Global Static Data

4.3 Dynamic Data

4.4 Temporary Data

4.5 Export Functions

.def host_command_int1

5. SUBROUTINE CODE

HeaderBegin

5.1 host_command_int1

5.2 Functional Description

The host generates INT1 DSP whenever it writes to CH A. In INT1
service routine, the command from host is read whether the FIFO
has been empty. Writes another 32 data from target to FIFO.
Sends a command to host. The host acknowledges the command and read
the 32 data from the FIFO and sends a command to the target for
Example 10–23. Interrupt 1 Service Routine (Continued)

; another set of 32 data. This process continues for 6 times till all
; 256 processed samples are transferred to host. Processing INT1 is
; done background, i.e., INT1 is globally enabled.

; 5.3 Activation
; Activation example:
; BD host_command_int1
; PSHM ST0
; PSHM ST1
; Reentrancy: No
; Recursive: No

; 5.4 Inputs
; Data structure: d_fifo_count
; Data Format: 16-bit var
; Modified: Yes
; Description: counter for # of transfers

; Data structure: d_fifo_ptr
; Data Format: 16-bit variable
; Modified: Yes
; Description: holds the output bfr addr. and incremented by
; 32 for every transfer

; 5.5 Outputs
; Data structure: AR7
; Data Format: 16-bit output buffer pointer
; Modified: Yes
; Description: either point to PING/PONG buffer

; 5.6 Global
; Data structure: d_command_reg
; Data Format: 16-bit variable
; Modified: Yes
; Description: command from host is read thru CH A

; Data structure: d_command_value
; Data Format: 16-bit variable
; Modified: Yes
; Description: holds the command value

; 5.7 Special considerations for data structure
;
Example 10–23. Interrupt 1 Service Routine (Continued)

; 5.8 Entry and Exit conditions
;
;    |DP|OVM|SXM|C16|FRCT|ASM|AR0|AR1|AR2|AR3|AR4|AR5|AR6|AR7|A |B |BK|BRC| T|TRN
; in |U | 1 | 1 |NU | 1  |NU |NU |NU |NU |NU |NU |NU |NU |U  |U  |NU|NU|NU|NU |NU|NU
; out|U | 1 | 1 |NU | 1  |NU |NU |NU |NU |NU |NU |NU |NU |U  |UM|NU|NU|NU |NU|NU

Note : UM – Used & Modified, U – Used, NU – Not Used

; 5.9 Execution
; Execution time: ?cycles
; Call rate: not applicable for this application
;
==============================================================================
; HeaderEnd
; 5.10 Code
; .asg AR7,OUTBUF_P ; output buffer pointer
; .asg AR7,SV_RSTRE_AR7
; .sect "fifo_fil"
host_command_int1:
  PSHM AL
  PSHM AH
  PSHM AG
  PSHM SV_RSTRE_AR7 ; AR7 is used as a pointer for
                   ; output buffer
  LD #FIFO_DP,DP ; restore the DP
  PORTR K_CHA,d_command_value ; read command from host
wait_host_receive_data
  PORTR K_TRGCR_ADDR,d_command_reg ; while (port14 & AXST)
  BITF d_command_reg,K_ARST ; check FIFO empty
  BC wait_host_receive_data,TC ; branch occurs
  LD #K_FIFO_EMPTY,A ; indicate of FIFO empty
  SUB d_command_value,A
bad_command
  BC bad_command,ANEQ ; read the command send by host
  LD #(K_FRAME_SIZE/(K_FIFO_SIZE/2))–1,A
  SUB d_fifo_count,A ; check for complete transfer of
                    ; 256 samples
  BC start_remain_fifo_transfer,AGT
  BD transfer_over
  ST #0,d_fifo_count ; reset the fifo count
                    ; start_remain_fifo_transfer
MVDK d_fifo_ptr,OUTBUF_P ; load PING/PONG bffr address
Example 10–23. Interrupt 1 Service Routine (Continued)

RPT    #(K_FIFO_SIZE/2)-1          ; write 32 data to FIFO
PORTW  *OUTBUF_P+,K_CHB            ; Fill FIFO half
ST     #K_FIFO_FULL,d_command_value
PORTW  d_command_value, K_CHA      ; write command to cmdnd reg A
       ; for FIFO half
ADDM   #1,d_fifo_count
MVKD   OUTBUF_P,d_fifo_ptr         ; save the fifo_ptr
transfer_over:
POPM   SV_RSTRE_AR7                 ; restore AR7
POPM   AG
POPM   AH
POPM   AL
POPM   ST1
POPM   ST0
RETE
.end
Example 10–24. Function Calls on Host Side

Host Action

This function initializes the data buffer and reads the FIFO so that FIFO is empty when the real data transfers start.

```c
void initialize_slave(void)
{
    int j;
    for (j=0; j < 64; j++)
        dataa[j] = inport(BDAT_REG); /* read data from data reg. */
    for (j=0; j < 256; j++)
        dataa[j] = 0;
    outport(CONT_REG, inport(CONT_REG) & 0xf7ff);
}
```

This function sends a command to the target for a new set of data from FIFO.

```c
void send_command_new_FIFO(command unsigned int command;
{
    command = 0xEE;
    outport (ADAT_REG,command);
    while(inport(CONT_REG) & AXST);
}
```

This initiates the handshake between the target and host. The host writes a command to target which sets the AXST flag to 1. The INT1 is generated whenever host writes to CH A. On the target side, INT1 is polled and reads the CH A. This clears ARST on target side. A command is written to Ch A on target after emptying the FIFO that sets AXSt = 1. Later sets XF to go low. On host XF is polled and then reads CH A that clears ARST to 0 and AXST to 0 on the target side.

```c
int receive_clear_AXST(void) /* RECEIVE COMMAND FROM EVM */
{
    /* This function sends a command to target for a new set of data from FIFO*/
    /* This initiates the handshake between the target and host. The host writes */
    /* a command to target which sets the AXST flag to 1. The INT1 is generated */
    /* whenever host writes to CH A. On the target side, INT1 is polled and reads */
    /* the CH A. This clears ARST on target side. A command is written to Ch A on */
    /* target after emptying the FIFO that sets AXSt = 1. Later sets XF to go low. */
    /* On host XF is polled and then reads CH A that clears ARST to 0 and AXST to 0 */
    /* on the target side */
}```
Example 10–24. Function Calls on Host Side (Continued)

```c
{
    command = 0xAB;
    outport (ADAT_REG,command);    /* write command to evm */
    while(inport(CONT_REG) & AXST);
    while((inport(CONT_REG) & XF));
    while(!(inport(CONT_REG) & ARST));  /* wait for evm to send command*/
    reply = inport(ADAT_REG);       /* read command into reply    */
    while ((reply & 0xAE) !=0xAE);
    return(reply);                 /* return command for process'g*/
}
/*-----------------------------------------------*/
Example 10–25. Main Function Call on Host Side

```c
#include <bios.h>
#include "view2.c"
int get_kbhit(void);
extern void send_command_new_FIFO(unsigned int);

int count=0, n, fifo_size;
int main_done =0;
int done = 0;
int hit;
initialize_slave();
/* a command is written to CH A to initiate handshake */
command_AXST = receive_clear_AXST();
while (!main_done)
{
    done =0;
    init_graphics();
    while(!done)
    {
        count =0;
        if(kbhit())
        {
            hit = get_kbhit();
            setviewport(120,433,290,445,0);
            clearviewport();
            switch(hit)
            {
            case    (F1):    amplitude = amplitude * 2 ; outtextxy(1,1,"Amplitude decreased")
            break;
                // case    (F2):    if (amplitude>=2) amplitude = amplitude / 2
                //                ; outtextxy(1,1,"Amplitude increased")
                //                ; break;
            case    (F2):    done =1
                        ; closegraph()
                        ;break;
            case    (F3):    done =1
                        ;main_done=1
                        ;closegraph()
                        ;break;
            }
        }
    }
else
```
Example 10–25. Main Function Call on Host Side (Continued)

```c
{  
    command_FIFO = receive_command_FIFO_FULL();
    for (fifo_size=0; fifo_size < 64; fifo_size++)
        dataa[fifo_size+count] = inport(BDAT_REG);
    send_command_new_FIFO(command);
    for (count=64; count< 256; count++)
    {
        command_FIFO = receive_command_FIFO_FULL();     /* command from target*/
        for (fifo_size=0; fifo_size < 32; fifo_size++)
            dataa[fifo_size+count] = inport(BDAT_REG);      /* read 32 word fifo*/
        count = count+31;
        send_command_new_FIFO(command);                /* send command to target*/
    }
    screen();
}
}

closegraph();
}
int get_kbhit(void)
{
    unsigned int key = bioskey(0);
    fflush(stdin);
    return(key);
}
```

FILE NAME: HOST.H C54x

HOST SIDE FLAGS, CONSTANTS, COMMAND NUMBERS, AND GLOBAL VARIABLES

The numbers I’ve picked for the file I/O constants, command numbers, and basic control constants are not important. These numbers could really be anything, as long as two of them are not the same. Please notice the pattern I used for file commands. Masks and pointers CANNOT be changed.

```c
#include <stdio.h>

#define  MAX_FRAME        256      /* size of data frame to be passed */

#define  STOP        99
#define  NO          98
#define  YES         97
#define  READY       96
#define  CLEAR       95
#define  ACKNOWLEDGE  0
```

FILE I/O CONSTANTS AND COMMAND

```c
#define MAX_FRAME 256
```

BASIC CONTROL CONSTANTS

```c
unsigned int ADAT_REG = (unsigned int)(0x240 + 0x800);
unsigned int BDAT_REG = (unsigned int)(0x240 + 0x804);
unsigned int CONT_REG = (unsigned int)(0x240 + 0x808);
```
Example 10–25. Main Function Call on Host Side (Continued)

/*----------------- MASKS FOR READING MESSAGE FLAGS OF CONTROL REGISTER ----------------*/
unsigned int XF = (unsigned int) 0x0020;
unsigned int ARST = (unsigned int) 0x0002;
unsigned int AXST = (unsigned int) 0x0001;
unsigned int BRST_MASK = (unsigned int) 0x0200;
unsigned int BXST_MASK = (unsigned int) 0x0008;

/*-------------------------- GLOBAL VARIABLES USED BY EVM.C AND MASTER.C -----------------------------*/
FILE*file[20]; /* stores ptrs to files in files.dat*/
int reply; /* integer for whatever */
int reply1[128];
int data[256];
int index;
unsigned int command;
unsigned int command1;
unsigned int command_new_data;
unsigned int command_FIFO;
unsigned int command_AXST;
unsigned int command_HANDSHAKE;
int amplitude = -10;
Example 10–26. Graphic Drivers Routine

```c
#include <graphics.h>
#include <stdlib.h>
#include <stdio.h>
#include <conio.h>

void init_graphics(void)
{
    int i;
    int gdriver = DETECT, gmode, errorcode; int left, top, right, bottom;
    initgraph(&gdriver, &gmode, ""); errorcode = graphresult();
    if (errorcode != grOk)
    {
        printf("Graphics error: %s\n", grapherrormsg(errorcode));
        printf("Press any key to halt.\n");
        getch();
    }

cleardevice();
setlinestyle(0,0,1);
setcolor(1);
setfillstyle(1,3);
rectangle(1,1,getmaxx()–1,getmaxy()–1);
setcolor(7);
left = 5;
top = getmaxy()/2 + – 123;
right = 108;
bottom = getmaxy()/2 + 163;
rectangle(left,top,right,bottom);
line(left,top + 30,right,top + 30);
line(left,bottom+29,right,bottom+29);
rectangle(left,top – 110,right+523,top – 5);
rectangle(right+4,bottom + 5, right + 523,bottom + 70);
rectangle(left,bottom +5,right,bottom+70);
setcolor(15);
settextstyle(0,0,1);
/*
outtextxy(left+25,top+12,"CONTROL");
outtextxy(right+16,bottom+32,"MESSAGES: ");
outtextxy(left+13,bottom+13,"AIC STATUS");*/
outtextxy(left+2,bottom+38,"Freq: 8kHz");
settextstyle(0,0,3);
outtextxy(left+10,top–72,"C54X EVM Spectrum Analyzer");
setfillstyle(0,0,3);
outtextxy(left+10,top–72,"C54X EVM Spectrum Analyzer");
settextstyle(0,0,1);
left = getmaxx() / 2 - 206;
top = getmaxy() / 2 - 123;
right = getmaxx() / 2 + 312;
bottom = getmaxy() / 2 + 163;
rectangle(left, top, right, bottom);
floodfill(left+10,top+10,15);
```
Example 10–26. Graphic Drivers Routine (Continued)

    setcolor(15);
    setlinestyle(0,0,3);
    left   = getmaxx()/2 – 311;
    top    = getmaxy()/2 + 57 – 40;
    right  = left + 25;
    bottom = top + 25; rectangle(left,top,right,bottom);
    setfillstyle(1,1); floodfill(left+5,top+5,15);
    settextstyle(0,0,1);
    outtextxy(left+5,top+10,“F3”);
    //
    outtextxy(left+30,top+10,”Quit”);
    setcolor(15); setlinestyle(0,0,3);
    left   = getmaxx()/2 – 311;
    top    = getmaxy()/2 – 23 – 40;
    right  = left + 25;
    bottom = top + 25; rectangle(left,top,right,bottom)
    setfillstyle(1,1); floodfill(left+5,top+5,15);
    settextstyle(0,0,1); outtextxy(left+6,top+10,”F1”);
    outtextxy(left+30,top+9,”Decrease”);
    outtextxy(left+30,top+16,”amplitude”);
    setcolor(15);
    setlinestyle(0,0,3);
    left   = getmaxx()/2 – 311;
    top    = getmaxy()/2 + 17 – 40;
    right  = left + 25;
    bottom = top + 25;
    rectangle(left,top,right,bottom);
    setfillstyle(1,1);
    floodfill(left+5,top+5,15);
    settextstyle(0,0,1); outtextxy(left+6,top+10,”F2”);
    outtextxy(left+30,top+9,”Increase”);
    outtextxy(left+30,top+16,”amplitude”);
Example 10–27. Display the Data on the Screen

/******************************************************************************/
/*                             FILE NAME: VIEW2.C                             */
/*                        DISPLAYS DATA ON THE SCREEN                         */
/******************************************************************************/
#include "host.c"
void screen(void)
{
    int x,y;
    int i,n;
    /* setup window (viewport) to display the AIC data */
    x = getmaxx()/2 – 203;
    y = getmaxy()/2;
    setviewport(x,y–120,x+512,y+160,1);
    /* move CP to left side of viewport */
    x = getx();
    y = gety() + 143;
    moveto(x,y);
    /* make waveform by drawing lines btwn 256 data points sent by EVM */
    setlinestyle(0,0,1);
    setcolor(14);
    for(i=0;i<256;i++) lineto(x+1+2*i,y+dataa[i]/amplitude);
    /* erase waveform just drawn by re-writing it in background color */
    moveto(x,y);
    setcolor(3);
    for(i=0;i<256;i++) lineto(x+1+2*i,y+dataa[i]/amplitude);
}
Example 10–28.  Linker Command File for the Application

/******************************************************************************
* This linker command file is assigns the memory allocation for the application  *
* based on the EVM54x specifically 541.                                     *
*******************************************************************************/
vectors.obj
init_54x.obj
init_ser.obj
init_aic.obj
aic_cfg.obj
memory.obj
main.obj
prcs_int.obj
rcv_int1.obj
task.obj
fir.obj
iir.obj
sym_fir.obj
adapt.obj
echo.obj
rfft.obj
bit_rev.obj
fft.obj
unpack.obj
power.obj
hand_shk.obj
hst_int1.obj
fifo.obj
-o main.out
-m main.map
MEMORY
{
    PAGE 0:
        PROG : origin = 0x7000, length = 0x1000
        VECS : origin = 0xff80, length = 0x7f
        COFF_SYM: origin = 0x1400, length = 0x40
        COFF_FIR: origin = 0x1440, length = 0x40
        AIC_TBLE: origin = 0x1480, length = 0x10
        TASK_TBL: origin = 0x1490, length = 0x10
        TASK_INT: origin = 0x14a0, length = 0x10
        IIR_COFF: origin = 0x14b0, length = 0x10
        COEFFH : origin = 0x1500, length = 0x100
        TWID_SIN: origin = 0x1000, length = 0x80
        TWID_COS: origin = 0x1200, length = 0x80
    PAGE 1: /* Data space */
        ALL_VARS: origin = 0x0080, length = 0x0080
        DRAM : origin = 0x0100, length = 0x1300
        EXT_DAT : origin = 0x1400, length = 0xE000
        REGS : origin = 0x0000, length = 0x0060
}
Example 10–28. Linker Command File for the Application (Continued)

SECTIONS
{
  .text : {} > PROG PAGE 0 /* code */
  vectors : {} > VECS PAGE 0 /* Vector table */
  main_prg : {} > PROG PAGE 0
  zeropad : {} > PROG PAGE 0
  aic_cnfg : {} > PROG PAGE 0
  ser_cnfg : {} > PROG PAGE 0
  fifo_fil : {} > PROG PAGE 0
  task_hnd : {} > PROG PAGE 0
  handshake: {} > PROG PAGE 0
  fir_prg : {} > PROG PAGE 0
  iir : {} > PROG PAGE 0
  filter : {} > PROG PAGE 0
  rfft_prg : {} > PROG PAGE 0
  aic_reg : {} > AIC_TABLE PAGE 0
  task_int : {} > TASK_INT PAGE 0
  task_tbl : {} > TASK_TBL PAGE 0
  coff_fir : {} > COFF_FIR PAGE 0
  sym_fir : {} > COFF_SYM PAGE 0
  iir_coff : {} > IIR_COFF PAGE 0
  coeffh : {} > COEFFH PAGE 0
  sin_tbl : {} > TWID_SIN PAGE 0
  cos_tbl : {} > TWID_COS PAGE 0
  inpt_buf : {} > DRAM,align(1024) PAGE 1
  outdata : {} > DRAM,align(1024) PAGE 1

UNION:
  fft_bffr
  adpt_sct:
  *(bufferw) /* This is needed for alignment of 128 words */
  .+=80h;
  *(bufferp)
}
}
)
)\nUNION: > DRAM align(256) PAGE 1
{
  fir_bfr
  cir_bfr
  coff_iir
  bufferh
  twid_sin
}
)
)
UNION: > DRAM align(256) PAGE 1
{
  fir_coff
  cir_bfr1
  bufferx
  twid_cos
}
Example 10–28. Linker Command File for the Application (Continued)

GROUP: > ALL_VARS PAGE 1
{
    aic_vars
    rcv_vars
    fifo_var
    tsk_vars
    fir_vars
    iir_vars
    adpt_var
    fft_vars
}
stack : {} > DRAM PAGE 1
}
Example 10–29. Memory Map of TMS320C541

;TMS320C541 MEMORY MAP
MR
;
MA 0x0000, 1, 0x002A, RAM ; MMRs
MA 0x0030, 1, 0x0003, RAM ;
MA 0x0060, 1, 0x0020, RAM ; SCRATCH PAD
MA 0x0080, 1, 0x1380, RAM ; INTERNAL DATA RAM
MA 0x0080, 0, 0x1380, RAM ; INTERNAL PROGRAM RAM
MA 0x9000, 0, 0x7000, ROM ; INTERNAL ROM
ma 0x1400, 0, 0xec00, ram ; external ram
ma 0x1400, 1, 0xec00, ram ; external ram
ma 0x0000, 2, 0x15, iport ; i/o space
map on
;
;Define reset alias to set PMST for MC mode
;
;alias myreset, ”e pmst = 0xff80; reset ”
;e pmst = 0xffe0 ; MP mode, OVLY, DROM off CLKOUT on
;e hbpenbl = 0x0000
e *0x28 = 0x2000 ; two wait states on i/o, none for memory
e *0x29 = 0x0000 ; no bank switching necessary
dasm pc
echo Loaded TMS320C54x evmint.cmd
This appendix assists you in meeting the design requirements of the Texas Instruments XDS510 emulator with respect to IEEE-1149.1 designs and discusses the XDS510 cable (manufacturing part number 2617698-0001). This cable is identified by a label on the cable pod marked JTAG 3/5V and supports both standard 3-V and 5-V target system power inputs.

The term JTAG, as used in this book, refers to TI scan-based emulation, which is based on the IEEE 1149.1 standard.

For more information concerning the IEEE 1149.1 standard, contact IEEE Customer Service:

Address:  IEEE Customer Service  
445 Hoes Lane, PO Box 1331  
Piscataway, NJ 08855-1331

Phone:  (800) 678–IEEE in the US and Canada  
(908) 981–1393 outside the US and Canada

FAX:  (908) 981–9667       Telex:  833233

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.1 Designing Your Target System's Emulator Connector (14-Pin Header)</td>
<td>A-2</td>
</tr>
<tr>
<td>A.2 Bus Protocol</td>
<td>A-4</td>
</tr>
<tr>
<td>A.3 Emulator Cable Pod</td>
<td>A-5</td>
</tr>
<tr>
<td>A.4 Emulator Cable Pod Signal Timing</td>
<td>A-6</td>
</tr>
<tr>
<td>A.5 Emulation Timing Calculations</td>
<td>A-7</td>
</tr>
<tr>
<td>A.6 Connections Between the Emulator and the Target System</td>
<td>A-10</td>
</tr>
<tr>
<td>A.7 Physical Dimensions for the 14-Pin Emulator Connector</td>
<td>A-14</td>
</tr>
<tr>
<td>A.8 Emulation Design Considerations</td>
<td>A-16</td>
</tr>
</tbody>
</table>
A.1 Designing Your Target System’s Emulator Connector (14-Pin Header)

JTAG target devices support emulation through a dedicated emulation port. This port is accessed directly by the emulator and provides emulation functions that are a superset of those specified by IEEE 1149.1. To communicate with the emulator, your target system must have a 14-pin header (two rows of seven pins) with the connections that are shown in Figure A–1. Table A–1 describes the emulation signals.

Although you can use other headers, the recommended unshrouded, straight header has these DuPont connector systems part numbers:

- 65610–114
- 65611–114
- 67996–114
- 67997–114

Figure A–1. 14-Pin Header Signals and Header Dimensions

<table>
<thead>
<tr>
<th>Signal</th>
<th>Pin 1</th>
<th>Pin 2</th>
<th>Pin 3</th>
<th>Pin 4</th>
<th>Pin 5</th>
<th>Pin 6</th>
<th>Pin 7</th>
<th>Pin 8</th>
<th>Pin 9</th>
<th>Pin 10</th>
<th>Pin 11</th>
<th>Pin 12</th>
<th>Pin 13</th>
<th>Pin 14</th>
</tr>
</thead>
<tbody>
<tr>
<td>TMS</td>
<td>1</td>
<td>2</td>
<td>TRST</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDI</td>
<td>3</td>
<td>4</td>
<td>GND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PD (VCC)</td>
<td>5</td>
<td>6</td>
<td>no pin (key)†</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDO</td>
<td>7</td>
<td>8</td>
<td>GND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCK_RET</td>
<td>9</td>
<td>10</td>
<td>GND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCK</td>
<td>11</td>
<td>12</td>
<td>GND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EMU0</td>
<td>13</td>
<td>14</td>
<td>EMU1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† While the corresponding female position on the cable connector is plugged to prevent improper connection, the cable lead for pin 6 is present in the cable and is grounded, as shown in the schematics and wiring diagrams in this appendix.
**Table A–1. 14-Pin Header Signal Descriptions**

<table>
<thead>
<tr>
<th>Signal</th>
<th>Description</th>
<th>Emulator† State</th>
<th>Target† State</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMU0</td>
<td>Emulation pin 0</td>
<td>I</td>
<td>I/O</td>
</tr>
<tr>
<td>EMU1</td>
<td>Emulation pin 1</td>
<td>I</td>
<td>I/O</td>
</tr>
<tr>
<td>GND</td>
<td>Ground</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PD(VCC)</td>
<td>Presence detect. Indicates that the emulation</td>
<td>I</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>cable is connected and that the target is</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>powered up. PD should be tied to VCC in the</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>target system.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCK</td>
<td>Test clock. TCK is a 10.368-MHz clock source</td>
<td>O</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>from the emulation cable pod. This signal can</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>be used to drive the system test clock.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCK_RET</td>
<td>Test clock return. Test clock input to the</td>
<td>I</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>emulator. May be a buffered or unbuffered</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>version of TCK.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDI</td>
<td>Test data input</td>
<td>O</td>
<td>I</td>
</tr>
<tr>
<td>TDO</td>
<td>Test data output</td>
<td>I</td>
<td>O</td>
</tr>
<tr>
<td>TMS</td>
<td>Test mode select</td>
<td>O</td>
<td>I</td>
</tr>
<tr>
<td>TRST†‡</td>
<td>Test reset</td>
<td>O</td>
<td>I</td>
</tr>
</tbody>
</table>

† I = input; O = output
‡ Do not use pullup resistors on TRST: it has an internal pulldown device. In a low-noise environment, TRST can be left floating. In a high-noise environment, an additional pulldown resistor may be needed. (The size of this resistor should be based on electrical current considerations.)
A.2 Bus Protocol

The IEEE 1149.1 specification covers the requirements for the test access port (TAP) bus slave devices and provides certain rules, summarized as follows:

- The TMS and TDI inputs are sampled on the rising edge of the TCK signal of the device.
- The TDO output is clocked from the falling edge of the TCK signal of the device.

When these devices are daisy-chained together, the TDO of one device has approximately a half TCK cycle setup time before the next device’s TDI signal. This timing scheme minimizes race conditions that would occur if both TDO and TDI were timed from the same TCK edge. The penalty for this timing scheme is a reduced TCK frequency.

The IEEE 1149.1 specification does not provide rules for bus master (emulator) devices. Instead, it states that the device expects a bus master to provide bus slave compatible timings. The XDS510 provides timings that meet the bus slave rules.
A.3 Emulator Cable Pod

Figure A–2 shows a portion of the emulator cable pod. The functional features of the pod are:

- TDO and TCK_RET can be parallel-terminated inside the pod if required by the application. By default, these signals are not terminated.
- TCK is driven with a 74LVT240 device. Because of the high-current drive (32-mA $I_{OL}/I_{OH}$), this signal can be parallel-terminated. If TCK is tied to TCK_RET, you can use the parallel terminator in the pod.
- TMS and TDI can be generated from the falling edge of TCK_RET, according to the IEEE 1149.1 bus slave device timing rules.
- TMS and TDI are series-terminated to reduce signal reflections.
- A 10.368-MHz test clock source is provided. You can also provide your own test clock for greater flexibility.

Figure A–2. Emulator Cable Pod Interface

† The emulator pod uses TCK_RET as its clock source for internal synchronization. TCK is provided as an optional target system test clock source.
A.4 Emulator Cable Pod Signal Timing

Figure A–3 shows the signal timings for the emulator cable pod. Table A–2 defines the timing parameters illustrated in the figure. These timing parameters are calculated from values specified in the standard data sheets for the emulator and cable pod and are for reference only. Texas Instruments does not test or guarantee these timings.

The emulator pod uses TCK_RET as its clock source for internal synchronization. TCK is provided as an optional target system test clock source.

**Figure A–3. Emulator Cable Pod Timings**

![Diagram of emulator cable pod signal timings](image)

**Table A–2. Emulator Cable Pod Timing Parameters**

<table>
<thead>
<tr>
<th>No.</th>
<th>Parameter</th>
<th>Description</th>
<th>Min</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>t_c(TCK)</td>
<td>Cycle time, TCK_RET</td>
<td>35</td>
<td>200</td>
<td>ns</td>
</tr>
<tr>
<td>2</td>
<td>t_w(TCKH)</td>
<td>Pulse duration, TCK_RET high</td>
<td>15</td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>3</td>
<td>t_w(TCKL)</td>
<td>Pulse duration, TCK_RET low</td>
<td>15</td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>4</td>
<td>t_d(TMS)</td>
<td>Delay time, TMS or TDI valid for TCK_RET low</td>
<td>6</td>
<td>20</td>
<td>ns</td>
</tr>
<tr>
<td>5</td>
<td>t_su(TDO)</td>
<td>Setup time, TDO to TCK_RET high</td>
<td>3</td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>6</td>
<td>t_h(TDO)</td>
<td>Hold time, TDO from TCK_RET high</td>
<td>12</td>
<td></td>
<td>ns</td>
</tr>
</tbody>
</table>
A.5 Emulation Timing Calculations

Example A–1 and Example A–2 help you calculate emulation timings in your system. For actual target timing parameters, see the appropriate data sheet for the device you are emulating.

The examples use the following assumptions:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t_{su(TTMS)} )</td>
<td>Setup time, target TMS or TDI to TCK high</td>
<td>10 ns</td>
</tr>
<tr>
<td>( t_{d(TTDO)} )</td>
<td>Delay time, target TDO from TCK low</td>
<td>15 ns</td>
</tr>
<tr>
<td>( t_{d(bufmax)} )</td>
<td>Delay time, target buffer maximum</td>
<td>10 ns</td>
</tr>
<tr>
<td>( t_{d(bufmin)} )</td>
<td>Delay time, target buffer minimum</td>
<td>1 ns</td>
</tr>
<tr>
<td>( t_{bufskew} )</td>
<td>Skew time, target buffer between two devices in the same package: [ t_{d(bufmax)} - t_{d(bufmin)} ] \times 0.15</td>
<td>1.35 ns</td>
</tr>
<tr>
<td>( t_{TCKfactor} )</td>
<td>Duty cycle, assume a 40/60% duty cycle clock</td>
<td>0.4 (40%)</td>
</tr>
</tbody>
</table>

Also, the examples use the following values from Table A–2 on page A-6:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t_{d(TMSmax)} )</td>
<td>Delay time, emulator TMS or TDI from TCK_RET low, maximum</td>
<td>20 ns</td>
</tr>
<tr>
<td>( t_{su(TDOmin)} )</td>
<td>Setup time, TDO to emulator TCK_RET high, minimum</td>
<td>3 ns</td>
</tr>
</tbody>
</table>

There are two key timing paths to consider in the emulation design:

- The TCK_RET-to-TMS or TDI path, called \( t_{pd(TCK_RET-TMS/TDI)} \) (propagation delay time)
- The TCK_RET-to-TDO path, called \( t_{pd(TCK_RET-TDO)} \)

In the examples, the worst-case path delay is calculated to determine the maximum system test clock frequency.
Example A–1. Key Timing for a Single-Processor System Without Buffers

\[
\begin{align*}
t_{pd}(TCK_{RET}-TMS/TDI) &= \frac{t_{d}(TMS_{max}) + t_{su}(TTMS)}{t_{TCKfactor}} \\
&= \frac{(20 \text{ ns} + 10 \text{ ns})}{0.4} \\
&= 75 \text{ ns}, \text{ or } 13.3 \text{ MHz}
\end{align*}
\]

\[
\begin{align*}
t_{pd}(TCK_{RET}-TDO) &= \frac{t_{d}(TDO) + t_{su}(TDO_{min})}{t_{TCKfactor}} \\
&= \frac{(15 \text{ ns} + 3 \text{ ns})}{0.4} \\
&= 45 \text{ ns}, \text{ or } 22.2 \text{ MHz}
\end{align*}
\]

In this case, because the TCK_RET-to-TMS/TDI path requires more time to complete, it is the limiting factor.

Example A–2. Key Timing for a Single- or Multiple-Processor System With Buffered Input and Output

\[
\begin{align*}
t_{pd}(TCK_{RET}-TMS/TDI) &= \frac{t_{d}(TMS_{max}) + t_{su}(TTMS) + t_{bufskew}}{t_{TCKfactor}} \\
&= \frac{(20 \text{ ns} + 10 \text{ ns} + 1.35 \text{ ns})}{0.4} \\
&= 78.4 \text{ ns}, \text{ or } 12.7 \text{ MHz}
\end{align*}
\]

\[
\begin{align*}
t_{pd}(TCK_{RET}-TDO) &= \frac{t_{d}(TDO) + t_{su}(TDO_{min}) + t_{d}(bufmax)}{t_{TCKfactor}} \\
&= \frac{(15 \text{ ns} + 3 \text{ ns} + 10 \text{ ns})}{0.4} \\
&= 70 \text{ ns}, \text{ or } 14.3 \text{ MHz}
\end{align*}
\]

In this case also, because the TCK_RET-to-TMS/TDI path requires more time to complete, it is the limiting factor.
In a multiprocessor application, it is necessary to ensure that the EMU0 and EMU1 lines can go from a logic low level to a logic high level in less than 10 µs, this parameter is called rise time, \( t_r \). This can be calculated as follows:

\[
\begin{align*}
\tau_r &= 5 \left( R_{\text{pullup}} \times N_{\text{devices}} \times C_{\text{load per device}} \right) \\
&= 5 \left( 4.7 \, \text{kΩ} \times 16 \times 15 \, \text{pF} \right) \\
&= 5 \left( 4.7 \times 10^3 \, \text{Ω} \times 16 \times 15 = 1128 \times 10^{-9} \right) \\
&= 5.64 \, \mu\text{s}
\end{align*}
\]
A.6 Connections Between the Emulator and the Target System

It is extremely important to provide high-quality signals between the emulator and the JTAG target system. You must supply the correct signal buffering, test clock inputs, and multiple processor interconnections to ensure proper emulator and target system operation.

Signals applied to the EMU0 and EMU1 pins on the JTAG target device can be either input or output. In general, these two pins are used as both input and output in multiprocessor systems to handle global run/stop operations. EMU0 and EMU1 signals are applied only as inputs to the XDS510 emulator header.

A.6.1 Buffering Signals

If the distance between the emulation header and the JTAG target device is greater than 6 inches, the emulation signals must be buffered. If the distance is less than 6 inches, no buffering is necessary. Figure A–4 shows the simpler, no-buffering situation.

The distance between the header and the JTAG target device must be no more than 6 inches. The EMU0 and EMU1 signals must have pullup resistors connected to VCC to provide a signal rise time of less than 10 µs. A 4.7-kΩ resistor is suggested for most applications.

![Figure A–4. Emulator Connections Without Signal Buffering](image)

Figure A–5 shows the connections necessary for buffered transmission signals. The distance between the emulation header and the processor is greater than 6 inches. Emulation signals TMS, TDI, TDO, and TCK_RET are buffered through the same device package.
Figure A–5. Emulator Connections With Signal Buffering

The EMU0 and EMU1 signals must have pullup resistors connected to V\textsubscript{CC} to provide a signal rise time of less than 10 µs. A 4.7-kΩ resistor is suggested for most applications.

The input buffers for TMS and TDI should have pullup resistors connected to V\textsubscript{CC} to hold these signals at a known value when the emulator is not connected. A resistor value of 4.7 kΩ or greater is suggested.

To have high-quality signals (especially the processor TCK and the emulator TCK\_RET signals), you may have to employ special care when routing the printed wiring board trace. You also may have to use termination resistors to match the trace impedance. The emulator pod provides optional internal parallel terminators on the TCK\_RET and TDO. TMS and TDI provide fixed series termination.

Because TRST is an asynchronous signal, it should be buffered as needed to ensure sufficient current to all target devices.
A.6.2 Using a Target-System Clock

Figure A–6 shows an application with the system test clock generated in the target system. In this application, the emulator’s TCK signal is left unconnected.

**Figure A–6. Target-System-Generated Test Clock**

There are two benefits in generating the test clock in the target system:

- The emulator provides only a single 10.368-MHz test clock. If you allow the target system to generate your test clock, you can set the frequency to match your system requirements.

- In some cases, you may have other devices in your system that require a test clock when the emulator is not connected. The system test clock also serves this purpose.

**Note:** When the TMS and TDI lines are buffered, pullup resistors must be used to hold the buffer inputs at a known level when the emulator cable is not connected.
A.6.3 Configuring Multiple Processors

Figure A–7 shows a typical daisy-chained multiprocessor configuration that meets the minimum requirements of the IEEE 1149.1 specification. The emulation signals are buffered to isolate the processors from the emulator and provide adequate signal drive for the target system. One of the benefits of this interface is that you can slow down the test clock to eliminate timing problems. Follow these guidelines for multiprocessor support:

- The processor TMS, TDI, TDO, and TCK signals must be buffered through the same physical device package for better control of timing skew.
- The input buffers for TMS, TDI, and TCK should have pullup resistors connected to VCC to hold these signals at a known value when the emulator is not connected. A resistor value of 4.7 k\(\Omega\) or greater is suggested.
- Buffering EMU0 and EMU1 is optional but highly recommended to provide isolation. These are not critical signals and do not have to be buffered through the same physical package as TMS, TCK, TDI, and TDO.

Figure A–7. Multiprocessor Connections
A.7 Physical Dimensions for the 14-Pin Emulator Connector

The JTAG emulator target cable consists of a 3-foot section of jacketed cable that connects to the emulator, an active cable pod, and a short section of jacketed cable that connects to the target system. The overall cable length is approximately 3 feet 10 inches. Figure A–8 and Figure A–9 (page A-15) show the physical dimensions for the target cable pod and short cable. The cable pod box is nonconductive plastic with four recessed metal screws.

Figure A–8. Pod/Connector Dimensions

Note: All dimensions are in inches and are nominal dimensions, unless otherwise specified. Pin-to-pin spacing on the connector is 0.100 inches in both the X and Y planes.
Figure A–9. 14-Pin Connector Dimensions

- Cable
- Connector, side view
- Connector, front view
- 2 rows of pins
- Key, pin 6
- 0.20 inch, nominal
- 0.66 inch, nominal
- 0.100 inch, nominal (pin spacing)
- 0.87 inch, nominal
- 0.100 inch, nominal (pin spacing)
A.8 Emulation Design Considerations

This section describes the use and application of the scan path linker (SPL), which can simultaneously add all four secondary JTAG scan paths to the main scan path. It also describes the use of the emulation pins and the configuration of multiple processors.

A.8.1 Using Scan Path Linkers

You can use the TI ACT8997 scan path linker (SPL) to divide the JTAG emulation scan path into smaller, logically connected groups of 4 to 16 devices. As described in the Advanced Logic and Bus Interface Logic Data Book, the SPL is compatible with the JTAG emulation scanning. The SPL is capable of adding any combination of its four secondary scan paths into the main scan path.

A system of multiple, secondary JTAG scan paths has better fault tolerance and isolation than a single scan path. Since an SPL has the capability of adding all secondary scan paths to the main scan path simultaneously, it can support global emulation operations, such as starting or stopping a selected group of processors.

TI emulators do not support the nesting of SPLs (for example, an SPL connected to the secondary scan path of another SPL). However, you can have multiple SPLs on the main scan path.

Scan path selectors are not supported by this emulation system. The TI ACT8999 scan path selector is similar to the SPL, but it can add only one of its secondary scan paths at a time to the main JTAG scan path. Thus, global emulation operations are not assured with the scan path selector.

You can insert an SPL on a backplane so that you can add up to four device boards to the system without the jumper wiring required with nonbackplane devices. You connect an SPL to the main JTAG scan path in the same way you connect any other device. Figure A–10 shows how to connect a secondary scan path to an SPL.
Figure A–10. Connecting a Secondary JTAG Scan Path to a Scan Path Linker

The TRST signal from the main scan path drives all devices, even those on the secondary scan paths of the SPL. The TCK signal on each target device on the secondary scan path of an SPL is driven by the SPL's DTCK signal. The TMS signal on each device on the secondary scan path is driven by the respective DTMS signals on the SPL.

DTDO0 on the SPL is connected to the TDI signal of the first device on the secondary scan path. DTDI0 on the SPL is connected to the TDO signal of the last device in the secondary scan path. Within each secondary scan path, the TDI signal of a device is connected to the TDO signal of the device before it. If the SPL is on a backplane, its secondary JTAG scan paths are on add-on boards; if signal degradation is a problem, you may need to buffer both the TRST and DTCK signals. Although degradation is less likely for DTMS signals, you may also need to buffer them for the same reasons.
A.8.2 Emulation Timing Calculations for a Scan Path Linker (SPL)

Example A–3 and Example A–4 help you to calculate the key emulation timings in the SPL secondary scan path of your system. For actual target timing parameters, see the appropriate device data sheet for your target device.

The examples use the following assumptions:

- $t_{su}(TTMS)$: Setup time, target TMS/TDI to TCK high, 10 ns
- $t_d(TTDO)$: Delay time, target TDO from TCK low, 15 ns
- $t_d(buf_{max})$: Delay time, target buffer, maximum, 10 ns
- $t_d(buf_{min})$: Delay time, target buffer, minimum, 1 ns
- $t_{bufskew}$: Skew time, target buffer, between two devices in the same package: $[t_d(buf_{max}) - t_d(buf_{min})] \times 0.15 = 1.35$ ns
- $t(TCKfactor)$: Duty cycle, TCK assume a 40/60% clock, 0.4 (40%)

Also, the examples use the following values from the SPL data sheet:

- $t_d(DTMS_{max})$: Delay time, SPL DTMS/DTDO from TCK low, maximum, 31 ns
- $t_{su}(DTDL_{min})$: Setup time, DTDI to SPL TCK high, minimum, 7 ns
- $t_d(DTCKH_{min})$: Delay time, SPL DTCK from TCK high, minimum, 2 ns
- $t_d(DTCKL_{max})$: Delay time, SPL DTCK from TCK low, maximum, 16 ns

There are two key timing paths to consider in the emulation design:

- The TCK-to-DTMS/DTDO path, called $t_{pd}(TCK-DTMS)$
- The TCK-to-DTDI path, called $t_{pd}(TCK-DTDI)$
Of the following two cases, the worst-case path delay is calculated to determine the maximum system test clock frequency.


\[
\begin{align*}
\tau_{pd(TCK-DTMS)} &= \left( \frac{t_{d(DTMS_{max})} + t_{d(DTCK_{Hmin})} + t_{su(TTMS)}}{t_{TCKfactor}} \right) \\
&= \left( \frac{31 \text{ ns} + 2 \text{ ns} + 10 \text{ ns}}{0.4} \right) \\
&= 107.5 \text{ ns}, \text{ or } 9.3 \text{ MHz} \\

\tau_{pd(TCK-DTDI)} &= \left( \frac{t_{d(TTDO)} + t_{d(DTCKL_{max})} + t_{su(DTDL_{min})}}{t_{TCKfactor}} \right) \\
&= \left( \frac{15 \text{ ns} + 16 \text{ ns} + 7 \text{ ns}}{0.4} \right) \\
&= 9.5 \text{ ns}, \text{ or } 10.5 \text{ MHz}
\end{align*}
\]

In this case, the TCK-to-DTMS/DTDL path is the limiting factor.

**Example A–4. Key Timing for a Single- or Multiprocessor-System With Buffered Input and Output (SPL)**

\[
\begin{align*}
\tau_{pd(TCK-TDMS)} &= \left( \frac{t_{d(DTMS_{max})} + \tau_{DTCK_{Hmin}} + t_{su(TTMS)} + \tau_{bufskew}}{t_{TCKfactor}} \right) \\
&= \left( \frac{31 \text{ ns} + 2 \text{ ns} + 10 \text{ ns} + 1.35 \text{ ns}}{0.4} \right) \\
&= 110.9 \text{ ns}, \text{ or } 9.0 \text{ MHz} \\

\tau_{pd(TCK-DTDI)} &= \left( \frac{t_{d(TTDO)} + t_{d(DTCKL_{max})} + t_{su(DTDL_{min})} + \tau_{bufskew}}{t_{TCKfactor}} \right) \\
&= \left( \frac{15 \text{ ns} + 15 \text{ ns} + 7 \text{ ns} + 10 \text{ ns}}{0.4} \right) \\
&= 120 \text{ ns}, \text{ or } 8.3 \text{ MHz}
\end{align*}
\]

In this case, the TCK-to-DTDI path is the limiting factor.
A.8.3 Using Emulation Pins

The EMU0/1 pins of TI devices are bidirectional, 3-state output pins. When in
an inactive state, these pins are at high impedance. When the pins are active,
they provide one of two types of output:

- **Signal Event.** The EMU0/1 pins can be configured via software to signal
  internal events. In this mode, driving one of these pins low can cause
devices to signal such events. To enable this operation, the EMU0/1 pins
function as open-collector sources. External devices such as logic analyz-
ers can also be connected to the EMU0/1 signals in this manner. If such
an external source is used, it must also be connected via an open-collector
source.

- **External Count.** The EMU0/1 pins can be configured via software as
totem-pole outputs for driving an external counter. If the output of more
than one device is configured for totem-pole operation, then these devices
can be damaged. The emulation software detects and prevents this condi-
tion. However, the emulation software has no control over external
sources on the EMU0/1 signal. Therefore, all external sources must be
inactive when any device is in the external count mode.

TI devices can be configured by software to halt processing if their EMU0/1
pins are driven low. This feature combined with the signal event output, allows
one TI device to halt all other TI devices on a given event for system-level de-
bugging.

If you route the EMU0/1 signals between multiple boards, they require special
handling because they are more complex than normal emulation signals.
Figure A–11 shows an example configuration that allows any processor in the
system to stop any other processor in the system. Do not tie the EMU0/1 pins
of more than 16 processors together in a single group without using buffers.
Buffers provide the crisp signals that are required during a RUNB (run bench-
mark) debugger command or when the external analysis counter feature is
used.
Figure A–11. EMU0/1 Configuration to Meet Timing Requirements of Less Than 25 ns

Notes: 1) The low time on EMU0/1-IN should be at least one TCK cycle and less than 10 μs. Software sets the EMU0/1-OUT pin to a high state.
2) To enable the open-collector driver and pullup resistor on EMU1 to provide rise/fall times of less than 25 ns, the modification shown in this figure is suggested. Rise times of more than 25 ns can cause the emulator to detect false edges during the RUNB command or when the external counter selected from the debugger analysis menu is used.

These seven important points apply to the circuitry shown in Figure A–11 and the timing shown in Figure A–12:

- Open-collector drivers isolate each board. The EMU0/1 pins are tied together on each board.

- At the board edge, the EMU0/1 signals are split to provide both input and output connections. This is required to prevent the open-collector drivers from acting as latches that can be set only once.

- The EMU0/1 signals are bused down the backplane. Pullup resistors must be installed as required.
The bused EMU0/1 signals go into a programmable logic array device PAL® whose function is to generate a low pulse on the EMU0/1-IN signal when a low level is detected on the EMU0/1-OUT signal. This pulse must be longer than one TCK period to affect the devices but less than 10 µs to avoid possible conflicts or retriggering once the emulation software clears the device’s pins.

During a RUNB debugger command or other external analysis count, the EMU0/1 pins on the target device become totem-pole outputs. The EMU1 pin is a ripple carry-out of the internal counter. EMU0 becomes a processor-halted signal. During a RUNB or other external analysis count, the EMU0/1-IN signal to all boards must remain in the high (disabled) state. You must provide some type of external input (XCNT_ENABLE) to the PAL® to disable the PAL® from driving EMU0/1-IN to a low state.

If you use sources other than TI processors (such as logic analyzers) to drive EMU0/1, their signal lines must be isolated by open-collector drivers and be inactive during RUNB and other external analysis counts.

You must connect the EMU0/1-OUT signals to the emulation header or directly to a test bus controller.

Figure A–12. Suggested Timings for the EMU0 and EMU1 Signals
Figure A–13. EMU0/1 Configuration With Additional AND Gate to Meet Timing Requirements of Greater Than 25 ns

Notes:
1) The low time on EMU0/1-IN should be at least one TCK cycle and less than \(10\mu s\). Software will set the EMU0/1-OUT port to a high state.
2) To enable the open-collector driver and pullup resistor on EMU1 to provide rise/fall time of greater than 25 ns, the modification shown in this figure is suggested. Rise times of more than 25 ns can cause the emulator to detect false edges during the RUNB command or when the external counter selected from the debugger analysis menu is used.
You do not need to have devices on one target board stop devices on another target board using the EMU0/1 signals (see the circuit in Figure A–14). In this configuration, the global-stop capability is lost. It is important not to overload EMU0/1 with more than 16 devices.

**Figure A–14. EMU0/1 Configuration Without Global Stop**

![EMU0/1 Configuration Without Global Stop](image)

**Note:** The open-collector driver and pullup resistor on EMU1 must be able to provide rise/fall times of less than 25 ns. Rise times of more than 25 ns can cause the emulator to detect false edges during the RUNB command or when the external counter selected from the debugger analysis menu is used. If this condition cannot be met, then the EMU0/1 signals from the individual boards must be ANDed together (as shown in Figure A–14) to produce an EMU0/1 signal for the emulator.

**A.8.4 Performing Diagnostic Applications**

For systems that require built-in diagnostics, it is possible to connect the emulation scan path directly to a TI ACT8990 test bus controller (TBC) instead of the emulation header. The TBC is described in the Texas Instruments *Advanced Logic and Bus Interface Logic Data Book*. Figure A–15 shows the scan path connections of \( n \) devices to the TBC.
In the system design shown in Figure A–15, the TBC emulation signals TCKI, TDO, TMS0, TMS2/EVNT0, TMS3/EVNT1, TMS5/EVNT3, TCKO, and TDI0 are used, and TMS1, TMS4/EVNT2, and TDI1 are not connected. The target devices’ EMU0 and EMU1 signals are connected to VCC through pullup resistors and tied to the TBC’s TMS2/EVNT0 and TMS3/EVNT1 pins, respectively. The TBC’s TCKI pin is connected to a clock generator. The TCK signal for the main JTAG scan path is driven by the TBC’s TCKO pin.

On the TBC, the TMS0 pin drives the TMS pins on each device on the main JTAG scan path. TDO on the TBC connects to TDI on the first device on the main JTAG scan path. TDI0 on the TBC is connected to the TDO signal of the last device on the main JTAG scan path. Within the main JTAG scan path, the TDI signal of a device is connected to the TDO signal of the device before it. TRST for the devices can be generated either by inverting the TBC’s TMS5/EVNT3 signal for software control or by logic on the board itself.
Appendix B

Development Support and Part Order Information

This appendix provides development support information, device part numbers, and support tool ordering information for the '54x.

Each '54x support product is described in the TMS320 DSP Development Support Reference Guide. In addition, more than 100 third-party developers offer products that support the TI TMS320 family. For more information, refer to the TMS320 Third-Party Support Reference Guide.

For information on pricing and availability, contact the nearest TI Field Sales Office or authorized distributor. See the list at the back of this book.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>B.1 Development Support</td>
<td>B-2</td>
</tr>
<tr>
<td>B.2 Part Order Information</td>
<td>B-5</td>
</tr>
</tbody>
</table>
B.1 Development Support

This section describes the development support provided by Texas Instruments.

B.1.1 Development Tools

TI offers an extensive line of development tools for the '54x generation of DSPs, including tools to evaluate the performance of the processors, generate code, develop algorithm implementations, and fully integrate and debug software and hardware modules.

**Code Generation Tools**

- The optimizing ANSI C compiler translates ANSI C language directly into highly optimized assembly code. You can then assemble and link this code with the TI assembler/linker, which is shipped with the compiler. This product is currently available for PCs (DOS, DOS extended memory, OS/2), HP workstations, and SPARC workstations. See the *TMS320C54x Optimizing C Compiler User’s Guide* for detailed information about this tool.

- The assembler/linker converts source mnemonics to executable object code. This product is currently available for PCs (DOS, DOS extended memory, OS/2). The '54x assembler for HP and SPARC workstations is available only as part of the optimizing '54x compiler. See the *TMS320C54x Assembly Language Tools User’s Guide* for detailed information about available assembly-language tools.

**System Integration and Debug Tools**

- The simulator simulates (via software) the operation of the '54x and can be used in C and assembly software development. This product is currently available for PCs (DOS, Windows), HP workstations, and SPARC workstations. See the *TMS320C54x C Source Debugger User’s Guide* for detailed information about the debugger.

- The XDS510 emulator performs full-speed in-circuit emulation with the '54x, providing access to all registers as well as to internal and external memory of the device. It can be used in C and assembly software development and has the capability to debug multiple processors. This product is currently available for PCs (DOS, Windows, OS/2), HP workstations, and SPARC workstations. This product includes the emulator board (emulator box, power supply, and SCSI connector cables in the HP and SPARC versions), the '54x C source debugger and the JTAG cable.
Because the 'C2xx, 'C3x, 'C4x, and 'C5x XDS510 emulators also come with the same emulator board (or box) as the '54x, you can buy the '54x C Source Debugger Software as a separate product called the '54x C Source Debugger Conversion Software. This enables you to debug '54x applications with a previously purchased emulator board. The emulator cable that comes with the 'C3x XDS510 emulator cannot be used with the '54x. You need the JTAG emulation conversion cable (see Section B.2) instead. The emulator cable that comes with the 'C5x XDS510 emulator can be used with the '54x without any restriction. See the TMS320C54x C Source Debugger User’s Guide for detailed information about the '54x emulator.

The TMS320C54x evaluation module (EVM) is a PC/AT plug-in card that lets you evaluate certain characteristics of the '54x digital signal processor to see if it meets your application requirements. The '54x EVM carries a '541 DSP on board to allow full-speed verification of '54x code. The EVM has 5K bytes of on-chip program/data RAM, 28K bytes of on-chip ROM, two serial ports, a timer, access to 64K bytes each of external program and data RAM, and an external analog interface for evaluation of the '54x family of devices for applications. See the TMS320C54x Evaluation Module Technical Reference for detailed information about the '54x EVM.

B.1.2 Third-Party Support

The TMS320 family is supported by products and services from more than 100 independent third-party vendors and consultants. These support products take various forms (both as software and hardware), from cross-assemblers, simulators, and DSP utility packages to logic analyzers and emulators. The expertise of those involved in support services ranges from speech encoding and vector quantization to software/hardware design and system analysis.

To ask about third-party services, products, applications, and algorithm development packages, contact the third party directly. Refer to the TMS320 Third-Party Support Reference Guide for addresses and phone numbers.
B.1.3 Technical Training Organization (TTO) TMS320 Workshops

'54x DSP Design Workshop. This workshop is tailored for hardware and software design engineers and decision-makers who will be designing and utilizing the '54x generation of DSP devices. Hands-on exercises throughout the course give participants a rapid start in developing '54x design skills. Microprocessor/assembly language experience is required. Experience with digital design techniques and C language programming experience is desirable.

These topics are covered in the '54x workshop:

- '54x architecture/instruction set
- Use of the PC-based software simulator
- Use of the '54x assembler/linker
- C programming environment
- System architecture considerations
- Memory and I/O interfacing
- Development support

For registration information, pricing, or to enroll, call (800)336–5236, ext. 3904.

B.1.4 Assistance

For assistance to TMS320 questions on device problems, development tools, documentation, software upgrades, and new products, you can contact TI. See If You Need Assistance in Preface for information.
B.2 Part Order Information

This section describes the part numbers of '54x devices, development support hardware, and software tools.

B.2.1 Device and Development Support Tool Nomenclature Prefixes

To designate the stages in the product development cycle, TI assigns prefixes to the part numbers of all TMS320 devices and support tools. Each TMS320 device has one of three prefix designators: TMX, TMP, or TMS. Each support tool has one of two possible prefix designators: TMDX or TMDS. These prefixes represent evolutionary stages of product development from engineering prototypes (TMX/TMDX) through fully qualified production devices and tools (TMS/TMDS). This development flow is defined below.

Device Development Evolutionary Flow:

**TMX**  The part is an experimental device that is not necessarily representative of the final device’s electrical specifications.

**TMP**  The part is a device from a final silicon die that conforms to the device’s electrical specifications but has not completed quality and reliability verification.

**TMS**  The part is a fully qualified production device.

Support Tool Development Evolutionary Flow:

**TMDX**  The development-support product that has not yet completed Texas Instruments internal qualification testing.

**TMDS**  The development-support product is a fully qualified development support product.

TMX and TMP devices and TMDX development support tools are shipped with the following disclaimer:

“Developmental product is intended for internal evaluation purposes.”

TMS devices and TMDS development support tools have been fully characterized, and the quality and reliability of the device has been fully demonstrated. Texas Instruments standard warranty applies to these products.

Note:

It is expected that prototype devices (TMX or TMP) have a greater failure rate than standard production devices. Texas Instruments recommends that these devices not be used in any production system, because their expected end-use failure rate is still undefined. Only qualified production devices should be used.
B.2.2 Device Nomenclature

TI device nomenclature includes the device family name and a suffix. Figure B–1 provides a legend for reading the complete device name for any ’54x device family member.

Figure B–1. TMS320C54x Device Nomenclature

- **Device Family**: TMS320 = DSP Family
- **Technology**:
  - C = 5 V ±10% CMOS
  - LC = 3.3 V ±10% CMOS
  - VC = 3 V ±10% CMOS
- **Device**: ’54x: 541 542 543 545 546 548
- **PLL Option**:
  - 1 = 1, 1.5, 2, 3
  - 2 = 1, 4, 4.5, 5
  - No number = Software-programmable PLL
- **Package Type**:
  - PBK = 128-pin TQFP
  - PGE = 144-pin TQFP
  - PN = 80-pin TQFP
  - PZ = 100-pin TQFP
  - PJ = 100-pin QFP

- **MIPS**
- **PGE 1 – 50**
### B.2.3 Development Support Tools

Table B–1 lists the development support tools available for the ‘54x, the platform on which they run, and their part numbers.

<table>
<thead>
<tr>
<th>Development Tool</th>
<th>Platform</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembler/Linker</td>
<td>PC (DOS™)</td>
<td>TMDS324L850-02</td>
</tr>
<tr>
<td>C Compiler/Assembler/Linker</td>
<td>PC (DOS™, Windows™, OS/2™)</td>
<td>TMDS324L855-02</td>
</tr>
<tr>
<td>C Compiler/Assembler/Linker</td>
<td>HP (HP-UX™) / SPARC™ (Sun OS™)</td>
<td>TMDS324L555-08</td>
</tr>
<tr>
<td>C Source Debugger Conversion Software</td>
<td>PC (DOS™, Windows™, OS/2™)</td>
<td>TMDS32401L0</td>
</tr>
<tr>
<td>C Source Debugger Conversion Software</td>
<td>HP (HP-UX™) / SPARC™ (Sun OS™) (XDS510™)</td>
<td>TMDS32406L0</td>
</tr>
<tr>
<td>Evaluation Module (EVM)</td>
<td>PC (DOS™, Windows™, OS/2™)</td>
<td>TMDX3260051</td>
</tr>
<tr>
<td>Simulator (C language)</td>
<td>PC (DOS™, Windows™)</td>
<td>TMDS324L851-02</td>
</tr>
<tr>
<td>Simulator (C language)</td>
<td>HP (HP-UX™) / SPARC™ (Sun OS™)</td>
<td>TMDS324L551-09</td>
</tr>
<tr>
<td>XDS510 Emulator†</td>
<td>PC (DOS™, Windows™, OS/2™)</td>
<td>TMDS00510</td>
</tr>
<tr>
<td>XDS510WS Emulator‡</td>
<td>HP (HP-UX™) / SPARC™ (Sun OS™) (SCSI)</td>
<td>TMDS00510WS</td>
</tr>
<tr>
<td>3 V/5 V PC/SPARC JTAG Emulation Cable</td>
<td>XDS510™ / XDS510WS™</td>
<td>TMDS3080002</td>
</tr>
</tbody>
</table>

† Includes XDS510 board and JTAG cable; TMDS32401L0 C-source debugger conversion software not included
‡ Includes XDS510WS box, SCSI cable, power supply, and JTAG cable; TMDS32406L0 C-source debugger conversion software not included
A: See accumulator A.

accumulator: A register that stores the results of an operation and provides an input for subsequent arithmetic logic unit (ALU) operations.

accumulator A: 40-bit register that stores the result of an operation and provides an input for subsequent arithmetic logic unit (ALU) operations.

accumulator B: 40-bit registers that stores the result of an operation and provides an input for subsequent arithmetic logic unit (ALU) operations.

adder: A unit that adds or subtracts two numbers.

address: The location of a word in memory.

address bus: A group of connections used to route addresses. The ’54x has four 16-bit address busses: CAB, DAB, EAB, and PAB.

addressing mode: The method by which an instruction calculates the location of an object in memory.

address visibility mode bit (AVIS): A bit in processor mode status register (PMST) that determines whether or not the internal program address appears on the device’s external address bus pins.

ALU: arithmetic logic unit. The part of the CPU that performs arithmetic and logic operations.

analog-to-digital (A/D) converter: Circuitry that translates an analog signal to a digital signal.

AR0–AR7: auxiliary registers 0–7. Eight 16-bit registers that can be accessed by the CPU and modified by the auxiliary register arithmetic units (ARAU) and are used primarily for data memory addressing.

ARAU: See auxiliary register arithmetic unit.
ARP: See auxiliary register pointer.

ASM: See accumulator shift mode field.

auxiliary register arithmetic unit: An unsigned, 16-bit arithmetic logic unit (ALU) used to calculate indirect addresses using auxiliary registers.

auxiliary register file: The area in data memory containing the eight 16-bit auxiliary registers. See also auxiliary registers.

auxiliary register pointer (ARP): A 3-bit field in status register 0 (ST0) used as a pointer to the currently-selected auxiliary register, when the device is operating in ‘C5x’/C2xx compatibility mode.

auxiliary registers: Eight 16-bit registers (AR7 – AR0) that are used as pointers to an address within data space. These registers are operated on by the auxiliary register arithmetic units (ARAUs) and are selected by the auxiliary register pointer (ARP). See also auxiliary register arithmetic unit.

AVIS: See address visibility mode bit.

B: See accumulator B.

bank-switching control register (BSCR): A 16-bit register that defines the external memory bank size and enables or disables automatic insertion of extra cycles when accesses cross memory bank boundaries.

barrel shifter: A unit that rotates bits in a word.

BK: See circular buffer size register.

block-repeat active flag (BRAF): A bit in status register 1 (ST1) that indicates whether or not a block repeat is currently active.

block-repeat counter (BRC): A 16-bit register that specifies the number of times a block of code is to be repeated when a block repeat is performed.

block-repeat end address register (REA): A 16-bit memory-mapped register containing the end address of a code segment being repeated.

block-repeat start address register (RSA): A 16-bit memory-mapped register containing the start address of a code segment being repeated.

boot: The process of loading a program into program memory.

boot loader: A built-in segment of code that transfers code from an external source to program memory at power-up.
Glossary

BRC: See block-repeat counter.

BSCR: See bank-switching control register.

BSP: buffered serial port. An enhanced synchronous serial port that includes
an autobuffering unit (ABU) that reduces CPU overhead in performing
serial operations.

BSPCE: BSP control extension register. A 16-bit memory-mapped register
that contains status and control bits for the buffered serial port (BSP) in-
terface. The 10 LSBs of the SPCE are dedicated to serial port interface
control, whereas the 6 MSBs are used for autobuffering unit (ABU) con-
trol.

butterfly: A kernel function for computing an N-point fast Fourier transform
(FFT), where N is a power of 2. The combinational pattern of inputs
resembles butterfly wings.

C: See carry bit.

C16: A bit in status register 1 (ST1) that determines whether the ALU oper-
ates in dual 16-bit mode or in double-precision mode.

carry bit: A bit in status register 0 (ST0) used by the ALU in extended arith-
metic operations and accumulator shifts and rotates. The carry bit can
be tested by conditional instructions.

circular buffer size register (BK): A 16-bit register used by the auxiliary reg-
ister arithmetic units (ARAU) to specify the data-block size in circular ad-
dressing.

code: A set of instructions written to perform a task; a computer program or
part of a program.

cold boot: The process of loading a program into program memory at
power-up.

compare, select, and store unit (CSSU): An application-specific hardware
unit dedicated to add/compare/select operations of the Viterbi operator.

CSSU: See compare, select, and store unit
DAGEN: See data-address generation logic (DAGEN).

DARAM: dual-access RAM. Memory that can be read from and written to in the same clock cycle.

data address bus: A group of connections used to route data memory addresses. The '54x has three 16-bit buses that carry data memory addresses: CAB, DAB, and EAB.

data-address generation logic (DAGEN): Logic circuitry that generates the addresses for data memory reads and writes. See also program-address generation logic (PAGEN).

data bus: A group of connections used to route data. The '54x has three 16-bit data buses: CB, DB, and EB.

data memory: A memory region used for storing and manipulating data. Addresses 00h–1Fh of data memory contain CPU registers. Addresses 20h–5Fh of data memory contain peripheral registers.

data page pointer (DP): A 9-bit field in status register 0 (ST0) that specifies which of 512, 128 × 16 word pages is currently selected for direct address generation. DP provides the nine MSBs of the data-memory address; the dma provides the lower seven. See also dma.

data ROM bit (DROM): A bit in PMST that determines whether or not part of the on-chip ROM is mapped into data space.

digital-to-analog (D/A) converter: Circuitry that translates a digital signal to an analog signal.

direct data-memory address bus: A 16-bit bus that carries the direct address for data memory.

direct memory address (dma, DMA): The seven LSBs of a direct-addressed instruction that are concatenated with the data page pointer (DP) to generate the entire data memory address. See also data page pointer.

dma: See direct memory address.

DP: See data page pointer.

DRB: direct data-memory address bus. A 16-bit bus that carries the direct address for data memory.

DROM: See data ROM bit.
**exponent encoder (EXP):** An application-specific hardware device that computes the exponent value of the accumulator.

**external interrupt:** A hardware interrupt triggered by a pin (INT0–INT3).

**fast Fourier transform (FFT):** An efficient method of computing the discrete Fourier transform, which transforms functions between the time domain and frequency domain. The time-to-frequency domain is called the forward transform, and the frequency-to-time domain is called the inverse transformation. See also butterfly.

**fast return register (RTN):** A 16-bit register used to hold the return address for the fast return from interrupt (RETF[D]) instruction.

**general-purpose input/output pins:** Pins that can be used to supply input signals from an external device or output signals to an external device. These pins are not linked to specific uses; rather, they provide input or output signals for a variety of purposes. These pins include the general-purpose BIO input pin and XF output pin.

**hardware interrupt:** An interrupt triggered through physical connections with on-chip peripherals or external devices.

**host port interface (HPI):** An 8-bit parallel interface that the CPU uses to communicate with a host processor.

**HPI control register (HPIC):** A 16-bit register that contains status and control bits for the host port interface (HPI).

**IFR:** See interrupt flag register.

**IMR:** See interrupt mask register.
**interrupt:** A condition caused either by an event external to the CPU or by a previously executed instruction that forces the current program to be suspended and causes the processor to execute an interrupt service routine corresponding to the interrupt.

**interrupt flag register (IFR):** A 16-bit memory-mapped register that flags pending interrupts.

**interrupt mask register (IMR):** A 16-bit memory-mapped register that masks external and internal interrupts.

**interrupt mode bit (INTM):** A bit in status register 1 (ST1) that globally masks or enables all interrupts.

**interrupt service routine (ISR):** A module of code that is executed in response to a hardware or software interrupt.

**IPTR:** *interrupt vector pointer.* A 9-bit field in the processor mode status register (PMST) that points to the 128-word page where interrupt vectors reside.

**IR:** *instruction register.* A 16-bit register used to hold a fetched instruction.

**latency:** The delay between when a condition occurs and when the device reacts to the condition. Also, in a pipeline, the necessary delay between the execution of two instructions to ensure that the values used by the second instruction are correct.

**LSB:** *least significant bit.* The lowest order bit in a word.

**maskable interrupts:** A hardware interrupt that can be enabled or disabled through software.

**memory map:** A map of the addressable memory space accessed by the ‘54x processor partitioned according to functionality (memory, registers, etc.).

**memory-mapped registers:** The ‘54x processor registers mapped into page 0 of the data memory space.

**microcomputer mode:** A mode in which the on-chip ROM is enabled and addressable for program accesses.
microprocessor/microcomputer (MP/MC) bit: A bit in the processor mode status register (PMST) that indicates whether the processor is operating in microprocessor or microcomputer mode. See also microcomputer mode; microprocessor mode.

microprocessor mode: A mode in which the on-chip ROM is disabled for program accesses.

micro stack: A stack that provides temporary storage for the address of the next instruction to be fetched when the program address generation logic is used to generate sequential addresses in data space.

MSB: most significant bit. The highest order bit in a word.

multiplier: A 17-bit × 17-bit multiplier that generates a 32-bit product. The multiplier executes multiple operations in a single cycle and operates using either signed or unsigned 2s-complement arithmetic.

nested interrupt: A higher-priority interrupt that must be serviced before completion of the current interrupt service routine (ISR). An executing ISR can set the interrupt mask register (IMR) bits to prevent being suspended by another interrupt.

nonmaskable interrupt: An interrupt that can be neither masked by the interrupt mask register (IMR) nor disabled by the INTM bit of status register 1 (ST1).

overflow: A condition in which the result of an arithmetic operation exceeds the capacity of the register used to hold that result.

overflow flag: A flag that indicates whether or not an arithmetic operation has exceeded the capacity of the corresponding register.
PAGEN: See program-address generation logic (PAGEN).

PAR: program address register. A 16-bit register used to address the program-memory operands in FIRS, MACD, MACP, MVDP, MVPD, READA, and WRITA instructions.

PC: program counter. A 16-bit register that indicates the location of the next instruction to be executed.


pma: program memory address. A register that provides the address of a multiplier operand that is contained in program memory.

PMST: processor mode status register. A 16-bit status register that controls the memory configuration of the device. See also ST0, ST1.

pop: Action of removing a word from a stack.

program-address generation logic (PAGEN): Logic circuitry that generates the address for program memory reads and writes, and the address for data memory in instructions that require two data operands. This circuitry can generate one address per machine. See also data-address generation logic (DAGEN).

program counter (PC): A 16-bit register that indicates the location of the next instruction to be executed.

program controller: Logic circuitry that decodes instructions, manages the pipeline, stores status of operations, and decodes conditional operations.

program memory: A memory region used for storing and executing programs.

push: Action of placing a word onto a stack.

RC: repeat counter. A 16-bit register used to specify the number of times a single instruction is executed.

register: A group of bits used for temporarily holding data or for controlling or specifying the status of a device.

repeat counter (RC): A 16-bit register used to specify the number of times a single instruction is executed.
**reset:** A means of bringing the CPU to a known state by setting the registers and control bits to predetermined values and signaling execution to start at a specified address.

**REA:** *block-repeat end address.* A 16-bit register that specifies the end address of a code segment to be repeated in repeat mode.

**RSA:** *block-repeat start address.* A 16-bit register that specifies the start address of a code segment to be repeated in repeat mode.

**RTN:** *fast return register.* A 16-bit register used to hold the return address for the fast return from interrupt (RETF[D]) instruction.

**SARAM:** *single-access RAM.* Memory that can be read written once during one clock cycle.

**serial port interface:** An on-chip full-duplex serial port interface that provides direct serial communication to serial devices with a minimum of external hardware, such as codecs and serial analog-to-digital (A/D) and digital-to-analog (D/A) converters. Status and control of the serial port is specified in the serial port control register (SPC).

**shifter:** A hardware unit that shifts bits in a word to the left or to the right.

**sign-control logic:** Circuitry used to extend data bits (signed/unsigned) to match the input data format of the multiplier, ALU, and shifter.

**sign extension:** An operation that fills the high order bits of a number with the sign bit.

**software interrupt (SINT):** An interrupt caused by the execution of an INTR or TRAP instruction.

**software wait-state register (SWWSR):** *software wait-state register.* A 16-bit register that selects the number of wait states for the program, data, and I/O spaces of off-chip memory.

**SP:** *stack pointer.* A register that always points to the last element pushed onto the stack.

**ST0:** A 16-bit register that contains '54x status and control bits. See also PMST; ST1.

**ST1:** A 16-bit register that contains '54x status and control bits. See also PMST, ST0.
stack: A block of memory used for storing return addresses for subroutines and interrupt service routines and for storing data.

stack pointer (SP): A register that always points to the last element pushed onto the stack.

temporary register (T): A 16-bit register that holds one of the operands for multiply operations, the dynamic shift count for the LACT, ADDT, and SUBT instructions, or the dynamic bit position for the BITT instruction.

time-division multiplexing (TDM): The process by which a single serial bus is shared by up to eight '54x devices with each device taking turns to communicate on the bus. There are a total of eight time slots (channels) available. During a time slot, a given device may talk to any combination of devices on the bus.

transition register (TRN): A 16-bit register that holds the transition decision for the path to new metrics to perform the Viterbi algorithm.

TSPC: *TDM serial port control register.* A 16-bit memory-mapped register that contains status and control bits for the TDM serial port.

wait state: A period of time that the CPU must wait for external program, data, or I/O memory to respond when reading from or writing to that external memory. The CPU waits one extra cycle (one CLKOUT1 cycle) for every wait state.

warm boot: The process by which the processor transfers control to the entry address of a previously-loaded program.

XF: *XF status flag.* A bit in status register ST1 that indicates the status of the XF pin.

XPC: *program counter extension.* A register that contains the upper 7 bits of the current program memory address.

zero fill: A method of filling the low or high order bits with zeros when loading a 16-bit number into a 32-bit field.
### Index

<table>
<thead>
<tr>
<th>A/D converter, definition</th>
<th>C-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>accumulator, definition</td>
<td>C-1</td>
</tr>
<tr>
<td>accumulator A, definition</td>
<td>C-1</td>
</tr>
<tr>
<td>accumulator B, definition</td>
<td>C-1</td>
</tr>
<tr>
<td>adaptive filtering using LMS instruction, example</td>
<td>10-74 to 10-83</td>
</tr>
<tr>
<td>add two floating-point numbers, example</td>
<td>6-25 to 6-31</td>
</tr>
<tr>
<td>adder, definition</td>
<td>C-1</td>
</tr>
<tr>
<td>addition</td>
<td>6-18</td>
</tr>
<tr>
<td>address, definition</td>
<td>C-1</td>
</tr>
<tr>
<td>address visibility, definition</td>
<td>C-1</td>
</tr>
<tr>
<td>addressing mode, definition</td>
<td>C-1</td>
</tr>
<tr>
<td>analog-to-digital converter, definition</td>
<td>C-1</td>
</tr>
<tr>
<td>applications</td>
<td></td>
</tr>
<tr>
<td>adaptive filtering, implementing adaptive FIR filter</td>
<td>4-12</td>
</tr>
<tr>
<td>channel decoding</td>
<td>7-5</td>
</tr>
<tr>
<td>branch metric equation</td>
<td>7-6</td>
</tr>
<tr>
<td>codebook search</td>
<td>7-2</td>
</tr>
<tr>
<td>convolutional encoding</td>
<td>7-3</td>
</tr>
<tr>
<td>block repeat active flag, definition</td>
<td>C-2</td>
</tr>
<tr>
<td>pointer and storage scheme trellis diagram</td>
<td>7-5</td>
</tr>
<tr>
<td>using the Viterbi algorithm</td>
<td>7-5</td>
</tr>
<tr>
<td>speech coder</td>
<td>7-2</td>
</tr>
<tr>
<td>CELP-based</td>
<td>7-2</td>
</tr>
<tr>
<td>code vector localization (equation)</td>
<td>7-4</td>
</tr>
<tr>
<td>code-excited linear predictive (CELP)</td>
<td>7-3</td>
</tr>
<tr>
<td>linear predictive coding (LPC) synthesis using codebook search</td>
<td>7-4</td>
</tr>
<tr>
<td>AR0-AR7, definition</td>
<td>C-1</td>
</tr>
<tr>
<td>ARAU. See auxiliary register arithmetic unit</td>
<td></td>
</tr>
<tr>
<td>ARAUs, definition</td>
<td>C-2</td>
</tr>
<tr>
<td>arithmetic logic unit (ALU), definition</td>
<td>C-1</td>
</tr>
<tr>
<td>ARP. See auxiliary register pointer</td>
<td></td>
</tr>
<tr>
<td>ASM. See accumulator shift mode field assistance</td>
<td>B-4</td>
</tr>
<tr>
<td>auxiliary register file, definition</td>
<td>C-2</td>
</tr>
<tr>
<td>auxiliary register pointer, definition</td>
<td>C-2</td>
</tr>
<tr>
<td>auxiliary registers, definition</td>
<td>C-2</td>
</tr>
<tr>
<td>AVIS</td>
<td></td>
</tr>
<tr>
<td>See also address visibility mode bit definition</td>
<td>C-1</td>
</tr>
<tr>
<td>B</td>
<td></td>
</tr>
<tr>
<td>B. See accumulator B</td>
<td></td>
</tr>
<tr>
<td>bank-switching control register, definition</td>
<td>C-2</td>
</tr>
<tr>
<td>barrel shifter</td>
<td>C-2</td>
</tr>
<tr>
<td>BIO pin</td>
<td>C-5</td>
</tr>
<tr>
<td>bit reversal routine, example</td>
<td>10-87 to 10-90</td>
</tr>
<tr>
<td>BK. See circular buffer size register</td>
<td></td>
</tr>
<tr>
<td>block diagrams</td>
<td></td>
</tr>
<tr>
<td>external interfaces, '541</td>
<td>1-5</td>
</tr>
<tr>
<td>implementing an adaptive FIR filter</td>
<td>4-12</td>
</tr>
<tr>
<td>pointer management storage scheme</td>
<td>7-7</td>
</tr>
<tr>
<td>speech coder</td>
<td>7-2</td>
</tr>
<tr>
<td>block repeat active flag, definition</td>
<td>C-2</td>
</tr>
</tbody>
</table>
block repeat active flag (BRAF) bit C-2
block repeat counter, definition C-2
block repeat end address (REA), definition C-9
block repeat start address (RSA), definition C-9
block repeat start address register, definition C-2
boot, definition C-2
boot loader, definition C-2
boot mode selection 8-2
process 8-3
BRC. See block repeat counter
BRE bit 3-29
BSP serial port control extension register (BSPCE) C-3
bit summary 3-29
BRE bit 3-29
BXE bit 3-30
CLKDV bits 3-31
CLKP bit 3-30
diagram 3-28
FE bit 3-30
FIG bit 3-30
FSP bit 3-30
HALTR bit 3-29
HALTX bit 3-29
PCM bit 3-30
RH bit 3-29
XH bit 3-29
buffered serial port (BSP), definition C-3
buffered signals, JTAG A-10
buffering A-10
bus devices A-4
bus protocol A-4
butterfly, definition C-3
BXE bit 3-30

C
C bit C-3
C compiler B-2
C16, definition C-3
cable, target system to emulator A-1 to A-25
cable pod A-5 A-6
carry bit, definition C-3
CELP-based speech coding 7-2
central processing unit (CPU), memory-mapped registers C-6
circular buffer size register, definition C-3
CLDV bits 3-31
CLKP bit 3-30
code, definition C-3
code generation tools B-2
codebook search example 7-4
cold boot, definition C-3
cold start, defini- tion C-3
compare, select and store unit (CSSU), definition C-3
compiler B-2
compute power spectrum of complex 256-point real FFT output, example 10-103 to 10-105
configuration, multiprocessor A-13
carrier A-2
dimensions, mechanical A-14
DuPont A-2
covolutional encoding, trellis diagram 7-5 to 7-7

D
data address bus, definition C-4
data bus, definition C-4
data memory, definition C-4
data page pointer, definition C-4
data page pointer (DP), definition C-4
data ROM bit, definition C-4
data ROM bit (DROM), definition C-4
data transfer — host action, example 9-13 to 9-14
data transfer — target action, example 9-12
data transfer from FIFO, exam- ple 10-106 to 10-110
data-address generation logic, definition C-4
debug tools B-2
debugger. See emulation development tools B-2
device nomenclature B-6
diagram B-6
prefixes B-5
diagnostic applications A-24
dimensions
12-pin header A-20
14-pin header A-14
mechanical, 14-pin header A-14

direct data-memory address bus, definition C-4
direct data-memory address bus (DRB), definition C-4

direct memory address, definition C-4
display data on screen, example 10-123
divide a floating-point number by another, example 6-37 to 6-42
division and modulus algorithm 6-2
dual-access RAM (DARAM), definition C-4
DuPont connector A-2

E
echo the input signal, example 10-56 to 10-58
EMU0/1
configuration A-21, A-23, A-24
emulation pins A-20
IN signals A-20
rising edge modification A-22
everal Emulation
JTAG cable A-1
timing calculations A-7 to A-9, A-18 to A-26
emulator connection to target system, JTAG mechanical
dimensions A-14 to A-25
designing the JTAG cable A-1
everal pins A-20
pod interface A-5
signal buffering A-10 to A-13
target cable, header design A-2 to A-3
emulator pod, timings A-6
exponent encoder, definition C-5
extended-precision arithmetic addition/subtraction 6-18
32-bit addition 6-18
32-bit subtraction 6-20
64-bit addition 6-13
64-bit subtraction 6-21
multiplication 6-21
32-bit fractional multiplication 6-23
32-bit integer multiplication 6-23
32-bit multiplication 6-23

external interface, ‘541 1-5

F
fast Fourier transform (FFT) C-5
fast return register, definition C-5
fast return register (RTN), definition C-9
FE bit 3-30
FIG bit 3-30
floating-point arithmetic 6-24
FSP bit 3-30
function calls on host side, example 10-116 to 10-117

generation of cosine wave, example 6-12 to 6-13
generation of sine wave, example 6-10 to 6-11
graphic drivers routine, example 10-121 to 10-122

H
HALTR bit 3-29
HALTX bit 3-29
handshake — host action, example 9-10 to 9-11
handshake — target action, example 9-8 to 9-9
handshake between host and target, example 10-25 to 10-28
header 14-pin A-2
dimensions 14-pin A-2
host control register (HCR) bit summary 9-3
diagram 9-2
host port interface, definition C-5
host port interface boot loading sequence 8-4
HPI control register (HPIC) C-5

I
I/O boot 8-8
IEEE 1149.1 specification, bus slave device rules A-4
initialization of serial port 1, example 10-33 to 10-37
initialization of variables, pointers, and buffers, example 10-29 to 10-32
instruction register (IR), definition C-6
interrupt, definition C-6
interrupt 1 service routine, example 10-111 to 10-115
interrupt flag register (IFR) definition C-6
interrupt mask register (IMR) definition C-6
interrupt mode (INTM) bit C-6
interrupt service routine, definition C-6
interrupt vector pointer (IPTR), definition C-6
interrupts
hardware C-5
nested C-7
nonmaskable C-7
user-maskable (external) C-5
memory allocation, example 10-10 to 10-15
memory map C-6
memory map of TMS320C541, example 10-127 to 10-128
memory-mapped registers, defined C-6
micro stack, definition C-7
microcomputer mode, definition C-6
microprocessor mode, definition C-7
microprocessor/microcomputer (MP/MC) bit C-7
most significant bit (MSB), definition C-7
multiply two floating-point numbers, example 6-32 to 6-36
nested interrupt C-7
nomenclature prefixes B-6
output modes
external count A-20
signal event A-20
overflow, definition C-7
overflow flag, definition C-7
PAL A-21, A-22, A-24
part numbers, tools B-7
part-order information B-5
PCM bit 3-30
pipeline, definition C-8
pop, definition C-8
processor initialization, example 10-22 to 10-24
processor mode status register (PMST) definition C-8
MP/MC bit C-7
program address register (PAR), definition C-8
program controller, definition C-8
program counter, definition C-8
program counter (PC), definition C-8
program counter extension (XPC), definition C-10

Index-4
program memory, definition C-8
program memory address (PMA), definition C-8
program-address generation logic, definition C-8
program-address generation logic (PAGEN), definition C-8
protocol, bus A-4
push, definition C-8
receive interrupt service routine, example 10-46 to 10-50
regional technology centers B-4
register
BSP control extension (BSPCE) C-3
definition C-8
host port interface control (HPIC) C-5
definition C-8
interrupt flag (IFR) C-6
definition C-8
interrupt mask (IMR) C-6
definition C-8
repeat counter, definition C-8
repeat counter (RC), definition C-8
reset, definition C-9
RH bit 3-29
RTCs B-4
run/stop operation A-10
RUNB_ENABLE, input A-22
scan path linkers A-16
secondary JTAG scan chain to an SPL A-17
suggested timings A-22
usage A-16
scan paths, TBC emulation connections for JTAG A-25
seminars B-4
serial port interface C-9
shifter, definition C-9
sign control logic, definition C-9
definition C-9
sign extension, definition C-9
signal descriptions 14-pin header A-3
signals
buffered A-10
description 14-pin header A-3
buffering for emulator connections A-10 to A-13
timing A-6
sines and cosines 6-9
single-access RAM (SARAM), definition C-9
single-instruction repeat loops, memory-to-memory block moves 5-6
SINT. See software interrupt
slave devices A-4
software development tools
assembler/linker B-2
c compiler B-2
general B-7
linker B-2
simulator B-2
software interrupt, definition C-9
software wait state register (SWWSR), definition C-9
square root computation, example 6-14 to 6-16
square roots 6-14
stack, definition C-10
stack pointer, definition C-10
stack pointer (SP), definition C-9
standard serial boot B-10
status register 0 (ST0), INTM bit C-6
straight, unshrouded 14-pin A-2
subtraction 6-18
support tools
development device B-7
support tools nomenclature, prefixes B-5
system interface, ’541 external interface B-2
system-integration tools 1-5
T
target cable A-14
target control register (TCR)
bit summary 9-5
diagram 9-4
target system, connection to emulator A-1 to A-25
target-system clock A-12
task scheduling, example 10-51 to 10-55
Index

TDM serial port control register (TSPC), definition C-10
TDO output A-4
temporary register (T), definition C-10
test bus controller A-22 A-24
test clock A-12 diagram A-12
third-party support B-3
time-division multiplexing (TDM), defined C-10
timing calculations A-7 to A-9 A-18 to A-26
TMS, signal A-4
TMS/TDI inputs A-4
TMS20C541, interface, external 1-5
tools, part numbers B-7
tools nomenclature, prefixes B-5
transition register, definition C-10

U
unpack 256-point real FFT output, example 10-97 to 10-102
unsigned/signed integer division, example 5-3 to 5-8

V
vector table initialization, example 10-6 to 10-9
Viterbi algorithm (channel decoding) 7-5
Viterbi operator for channel coding, example 7-8

W
warm boot 8-12
warm boot definition C-10
example 8-12 to 8-22
workshops 3-4

X
XDS510 emulator, JTAG cable. See emulation
XF pin C-5
XF status flag (XF), definition C-10
XH bit 3-29

Z
zero fill, definition C-10