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Preface

Read This First

About This Manual

The TMS320C54x Assembly Language Tools User’s Guide tells you how to use these assembly language tools:

- Assembler
- Archiver
- Linker
- Absolute lister
- Cross-reference lister
- Hex conversion utility

How to Use This Manual

The goal of this book is to help you learn how to use the Texas Instruments assembly language tools specifically designed for the TMS320C54x™ DSPs. This book is divided into four parts:

- **Introductory information** gives you an overview of the assembly language development tools and also discusses common object file format (COFF), which helps you to use the TMS320C54x tools more efficiently. Read Chapter 2, *Introduction to Common Object File Format*, before using the assembler and linker.

- **Assembler description** contains detailed information about using the assembler. This section explains how to invoke the assembler and discusses source statement format, valid constants and expressions, assembler output, and assembler directives. It also describes macro elements.

- **Additional assembly language tools** describes in detail each of the tools provided with the assembler to help you create assembly language source files. For example, Chapter 7 explains how to invoke the linker, how the linker operates, and how to use linker directives. Chapter 10 explains how to use the hex conversion utility.
Reference material provides supplementary information. This section contains technical data about the internal format and structure of COFF object files. It discusses symbolic debugging directives that the C/C++ compiler uses. Finally, it includes hex conversion utility examples, assembler and linker error messages, and a glossary.

Notational Conventions

This document uses the following conventions:

- Program listings, program examples, and interactive displays appear in a special typeface. Examples use a bold version of the special typeface for emphasis; interactive displays use a bold version of the special typeface to distinguish commands that you enter from items that the system displays (such as prompts, command output, error messages, etc.).

Here is a sample program listing:

2 0001 2f x .byte 47
3 0002 32 z .byte 50
4 0003 .text

- In syntax descriptions, the instruction, command, or directive is in a bold typeface font and parameters are in an italic typeface. Portions of a syntax that are in bold should be entered as shown; portions of a syntax that are in italics describe the type of information that should be entered. Here is an example of command line syntax:

abs500 filename

abs500 is a command. The command invokes the absolute lister and has one parameter, indicated by filename. When you invoke the absolute lister, you supply the name of the file that the absolute lister uses as input.

- Square brackets ([ and ]) identify an optional parameter. If you use an optional parameter, you specify the information within the brackets; you don’t enter the brackets themselves. This is an example of a command that has an optional parameter:

hex500 [–options] filename

The hex500 command has two parameters. The first parameter, –options, is optional. Since options is plural, you may select several options. The second parameter, filename, is required.
In assembler syntax statements, column 1 is reserved for the first character of a label or symbol. If the label or symbol is optional, it is usually not shown. If it is a required parameter, then it will be shown starting against the left margin of the shaded box, as in the example below. No instruction, command, directive, or parameter, other than a symbol or label, should begin in column 1.

\[
\text{symbol .usect } "\text{section name"}, \text{ size in words [, blocking flag] [, alignment flag]}
\]

The symbol is required for the .usect directive and must begin in column 1. The section name must be enclosed in quotes and the section size in words must be separated from the section name by a comma. The blocking flag and alignment flag are optional and, if used, must be separated by commas.

Some directives can have a varying number of parameters. For example, the .byte directive can have up to 100 parameters. The syntax for this directive is:

\[
.\text{byte } \text{value}_1 [\, \ldots \, , \text{value}_n]
\]

This syntax shows that .byte must have at least one value parameter, but you have the option of supplying additional value parameters, separated by commas.

Following are other symbols and abbreviations used throughout this document.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR0–AR7</td>
<td>Auxiliary Registers 0 through 7</td>
<td>PC</td>
<td>Program counter register</td>
</tr>
<tr>
<td>B,b</td>
<td>Suffix — binary integer</td>
<td>Q,q</td>
<td>Suffix — octal integer</td>
</tr>
<tr>
<td>H,h</td>
<td>Suffix — hexadecimal integer</td>
<td>SP</td>
<td>Stack pointer register</td>
</tr>
<tr>
<td>LSB</td>
<td>Least significant bit</td>
<td>ST</td>
<td>Status register</td>
</tr>
<tr>
<td>MSB</td>
<td>Most significant bit</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

C54x is used throughout this manual to collectively refer to all supported C54x devices.
Related Documentation From Texas Instruments

The following books describe the TMS320C54x devices 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 Optimizing C Compiler User’s Guide** (literature number SPRU103) describes the TMS320C54x™ C compiler. This C compiler accepts ANSI standard C source code and produces assembly language source code for the TMS320C54x generation of devices.

**TMS320C54x DSP Reference Set, Volume 1: CPU** (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, and the instruction pipeline. 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.

**Code Composer User’s Guide** (literature number SPRU328) explains how to use the Code Composer development environment to build and debug embedded real-time DSP applications.

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## Contents

1. **Introduction** .............................................................. 1-1
   Provides an overview of the software development tools.
   1.1 Software Development Tools Overview .............................. 1-2
   1.2 Tools Descriptions .................................................... 1-3

2. **Introduction to Common Object File Format** ...................... 2-1
   Discusses the basic COFF concept of sections and how they can help you use the assembler and linker more efficiently. Common object file format, or COFF, is the object file format used by the tools.
   2.1 COFF File Types ..................................................... 2-2
   2.2 Sections ............................................................. 2-3
   2.3 How the Assembler Handles Sections .............................. 2-5
      2.3.1 Uninitialized Sections ............................................ 2-5
      2.3.2 Initialized Sections .............................................. 2-7
      2.3.3 Named Sections .................................................. 2-8
      2.3.4 Subsections ...................................................... 2-9
      2.3.5 Section Program Counters ..................................... 2-9
      2.3.6 An Example That Uses Sections Directives .................. 2-10
   2.4 How the Linker Handles Sections .................................... 2-13
      2.4.1 Default Memory Allocation ..................................... 2-14
      2.4.2 Placing Sections in the Memory Map .......................... 2-15
   2.5 Relocation .......................................................... 2-16
      2.5.1 Relocation Issues ............................................... 2-17
   2.6 Runtime Relocation ................................................ 2-19
   2.7 Loading a Program .................................................. 2-20
   2.8 Symbols in a COFF File ............................................. 2-21
      2.8.1 External Symbols ................................................ 2-21
      2.8.2 The Symbol Table .............................................. 2-22

3. **Assembler Description** ................................................ 3-1
   Explains how to invoke the assembler and discusses source statement format, valid constants and expressions, and assembler output.
   3.1 Assembler Overview .................................................. 3-2
   3.2 Assembler Development Flow ....................................... 3-3
   3.3 Invoking the Assembler ............................................. 3-4
3.4 Naming Alternate Files and Directories for Assembler Input ................................. 3-8
  3.4.1 Using the –i Assembler Option ......................................................... 3-8
  3.4.2 Using Environment Variables (C54X_A_DIR and A_DIR) ............................. 3-9

3.5 Source Statement Format ...................................................................................... 3-11
  3.5.1 Source Statement Syntax ............................................................................ 3-11
  3.5.2 Label Field ................................................................................................. 3-12
  3.5.3 Mnemonic Instruction Fields ........................................................................ 3-12
  3.5.4 Algebraic Instruction Field ........................................................................... 3-14
  3.5.5 Comment Field ........................................................................................... 3-14

3.6 Constants ............................................................................................................ 3-15
  3.6.1 Binary Integers ............................................................................................ 3-15
  3.6.2 Octal Integers .............................................................................................. 3-15
  3.6.3 Decimal Integers .......................................................................................... 3-16
  3.6.4 Hexadecimal Integers .................................................................................. 3-16
  3.6.5 Character Constants ..................................................................................... 3-16
  3.6.6 Floating-Point Constants ............................................................................ 3-17

3.7 Character Strings ................................................................................................. 3-18

3.8 Symbols ............................................................................................................... 3-19
  3.8.1 Labels .......................................................................................................... 3-19
  3.8.2 Symbolic Constants ..................................................................................... 3-19
  3.8.3 Defining Symbolic Constants (~d Option) .................................................... 3-20
  3.8.4 Predefined Symbolic Constants ................................................................... 3-20
  3.8.5 Substitution Symbols ................................................................................... 3-21
  3.8.6 Local Labels ................................................................................................. 3-22

3.9 Expressions ......................................................................................................... 3-25
  3.9.1 Operators .................................................................................................... 3-26
  3.9.2 Expression Overflow and Underflow ........................................................... 3-26
  3.9.3 Well-Defined Expressions .......................................................................... 3-27
  3.9.4 Conditional Expressions ............................................................................. 3-27
  3.9.5 Relocatable Symbols and Legal Expressions .............................................. 3-28

3.10 Built-in Functions ............................................................................................... 3-30

3.11 Loading Values into Extended Program Memory ............................................... 3-32

3.12 Source Listings .................................................................................................. 3-33

3.13 Cross-Reference Listings ..................................................................................... 3-37

4 Assembler Directives .............................................................................................. 4-1
Describes the directives according to function, and presents the directives in alphabetical order.

4.1 Directives Summary .......................................................................................... 4-2
4.2 Compatibility With the TMS320C1x/C2x/C2xx/C5x Assembler Directives ......... 4-8
4.3 Directives That Define Sections ........................................................................ 4-9
4.4 Directives That Initialize Constants ................................................................ 4-11
4.5 Directives That Align the Section Program Counter ........................................ 4-15
4.6 Directives That Format the Output Listing ...................................................... 4-17
4.7 Directives That Reference Other Files ............................................................. 4-19
4.8 Conditional Assembly Directives ................................................................. 4-20
4.9 Assembly-Time Symbol Directives ............................................................. 4-21
4.10 Miscellaneous Directives ........................................................................... 4-23
4.11 Directives Reference .................................................................................. 4-25

5 Macro Language .............................................................................................. 5-1
 Describes macro directives, substitution symbols used as macro parameters, and how to create macros.

5.1 Using Macros ............................................................................................... 5-2
5.2 Defining Macros ........................................................................................... 5-3
5.3 Macro Parameters/Substitution Symbols ....................................................... 5-6
  5.3.1 Directives That Define Substitution Symbols ........................................... 5-7
  5.3.2 Built-In Substitution Symbol Functions .................................................. 5-8
  5.3.3 Recursive Substitution Symbols ............................................................... 5-10
  5.3.4 Forced Substitution ................................................................................ 5-11
  5.3.5 Accessing Individual Characters of Subscripted Substitution Symbols .... 5-12
  5.3.6 Substitution Symbols as Local Variables in Macros ............................... 5-13
5.4 Macro Libraries ............................................................................................ 5-14
5.5 Using Conditional Assembly in Macros ......................................................... 5-15
5.6 Using Labels in Macros ............................................................................... 5-17
5.7 Producing Messages in Macros .................................................................... 5-19
5.8 Formatting the Output Listing ...................................................................... 5-21
5.9 Using Recursive and Nested Macros ............................................................ 5-22
5.10 Macro Directives Summary ....................................................................... 5-25

6 Archiver Description ......................................................................................... 6-1
 Contains instructions for invoking the archiver, creating new archive libraries, and modifying existing libraries.

6.1 Archiver Overview ....................................................................................... 6-2
6.2 Archiver Development Flow ....................................................................... 6-3
6.3 Invoking the Archiver ............................................................................... 6-4
6.4 Archiver Examples ....................................................................................... 6-6

7 Linker Description ............................................................................................. 7-1
 Explains how to invoke the linker, provides details about linker operation, discusses linker directives, and presents a detailed linking example.

7.1 Linker Overview ........................................................................................... 7-2
7.2 Linker Development Flow ........................................................................... 7-3
7.3 Invoking the Linker ..................................................................................... 7-4
7.4 Linker Options ............................................................................................. 7-6
  7.4.1 Relocation Capabilities (–a and –r Options) .............................................. 7-8
  7.4.2 Disable Merge of Symbolic Debugging Information (–b Option) ........... 7-10
  7.4.3 C Language Options (–c and –cr Options) .............................................. 7-10
  7.4.4 Define an Entry Point (–e global_symbol Option) .................................. 7-11
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.4.5 Set Default Fill Value (–f cc Option)</td>
<td>7-11</td>
</tr>
<tr>
<td>7.4.6 Make a Symbol Global (–g global_symbol Option)</td>
<td>7-12</td>
</tr>
<tr>
<td>7.4.7 Make All Global Symbols Static (–h Option)</td>
<td>7-12</td>
</tr>
<tr>
<td>7.4.8 Define Heap Size (–heap constant Option)</td>
<td>7-12</td>
</tr>
<tr>
<td>7.4.9 Alter the Library Search Algorithm (–l Option, –i Option, and C54X_C_DIR/C_DIR Environment Variables)</td>
<td>7-13</td>
</tr>
<tr>
<td>7.4.10 Disable Conditional Linking (–j Option)</td>
<td>7-16</td>
</tr>
<tr>
<td>7.4.11 Ignore Alignment Flags (–k Option)</td>
<td>7-16</td>
</tr>
<tr>
<td>7.4.12 Create a Map File (–m filename Option)</td>
<td>7-16</td>
</tr>
<tr>
<td>7.4.13 Name an Output Module (–o filename Option)</td>
<td>7-17</td>
</tr>
<tr>
<td>7.4.14 Specify a Quiet Run (–q Option)</td>
<td>7-17</td>
</tr>
<tr>
<td>7.4.15 Strip Symbolic Information (–s Option)</td>
<td>7-17</td>
</tr>
<tr>
<td>7.4.16 Define Stack Size (–stack constant Option)</td>
<td>7-18</td>
</tr>
<tr>
<td>7.4.17 Introduce an Unresolved Symbol (–u symbol Option)</td>
<td>7-18</td>
</tr>
<tr>
<td>7.4.18 Specify a COFF Format (–v Option)</td>
<td>7-19</td>
</tr>
<tr>
<td>7.4.19 Display a Message for Output Section Information (–w Option)</td>
<td>7-19</td>
</tr>
<tr>
<td>7.4.20 Exhaustively Read Libraries (–x Option)</td>
<td>7-20</td>
</tr>
<tr>
<td>7.5 Linker Command Files</td>
<td>7-21</td>
</tr>
<tr>
<td>7.5.1 Reserved Names in Linker Command Files</td>
<td>7-24</td>
</tr>
<tr>
<td>7.5.2 Constants in Command Files</td>
<td>7-24</td>
</tr>
<tr>
<td>7.6 Object Libraries</td>
<td>7-25</td>
</tr>
<tr>
<td>7.7 The MEMORY Directive</td>
<td>7-27</td>
</tr>
<tr>
<td>7.7.1 Default Memory Model</td>
<td>7-27</td>
</tr>
<tr>
<td>7.7.2 MEMORY Directive Syntax</td>
<td>7-27</td>
</tr>
<tr>
<td>7.8 The SECTIONS Directive</td>
<td>7-32</td>
</tr>
<tr>
<td>7.8.1 Default Configuration</td>
<td>7-32</td>
</tr>
<tr>
<td>7.8.2 SECTIONS Directive Syntax</td>
<td>7-32</td>
</tr>
<tr>
<td>7.8.3 Allocation</td>
<td>7-35</td>
</tr>
<tr>
<td>7.9 Specifying a Section’s Runtime Address</td>
<td>7-44</td>
</tr>
<tr>
<td>7.9.1 Specifying Load and Run Addresses</td>
<td>7-44</td>
</tr>
<tr>
<td>7.9.2 Uninitialized Sections</td>
<td>7-45</td>
</tr>
<tr>
<td>7.9.3 Referring to the Load Address by Using the .label Directive</td>
<td>7-45</td>
</tr>
<tr>
<td>7.10 Using UNION and GROUP Statements</td>
<td>7-48</td>
</tr>
<tr>
<td>7.10.1 Overlaying Sections With the UNION Statement</td>
<td>7-48</td>
</tr>
<tr>
<td>7.10.2 Grouping Output Sections Together</td>
<td>7-50</td>
</tr>
<tr>
<td>7.10.3 Nesting UNIONs and GROUPs</td>
<td>7-51</td>
</tr>
<tr>
<td>7.10.4 Checking the Consistency of Allocators</td>
<td>7-52</td>
</tr>
<tr>
<td>7.11 Overlay Pages</td>
<td>7-53</td>
</tr>
<tr>
<td>7.11.1 Using the MEMORY Directive to Define Overlay Pages</td>
<td>7-53</td>
</tr>
<tr>
<td>7.11.2 Using Overlay Pages With the SECTIONS Directive</td>
<td>7-55</td>
</tr>
<tr>
<td>7.11.3 Page Definition Syntax</td>
<td>7-56</td>
</tr>
<tr>
<td>7.12 Default Allocation Algorithm</td>
<td>7-58</td>
</tr>
<tr>
<td>7.12.1 Allocation Algorithm</td>
<td>7-58</td>
</tr>
<tr>
<td>7.12.2 General Rules for Output Sections</td>
<td>7-59</td>
</tr>
</tbody>
</table>
10.4.2 Data Width ........................................ 10-10
10.4.3 Memory Width .................................... 10-10
10.4.4 ROM Width ........................................ 10-11
10.4.5 A Memory Configuration Example ............ 10-14
10.4.6 Specifying Word Order for Output Words .... 10-14
10.5 The ROMS Directive .............................. 10-16
10.5.1 When to Use the ROMS Directive ............ 10-18
10.5.2 An Example of the ROMS Directive ........... 10-19
10.5.3 Creating a Map File of the ROMS Directive .. 10-21
10.6 The SECTIONS Directive ......................... 10-22
10.7 Output Filenames ................................. 10-24
10.7.1 Assigning Output Filenames ................... 10-24
10.8 Image Mode and the –fill Option ............... 10-26
10.8.1 The –image Option ............................... 10-26
10.8.2 Specifying a Fill Value ......................... 10-27
10.8.3 Steps to Follow in Image Mode ................. 10-27
10.9 Building a Table for an On-Chip Boot Loader .. 10-28
10.9.1 Description of the Boot Table ................. 10-28
10.9.2 The Boot Table Format ......................... 10-28
10.9.3 How to Build the Boot Table ................... 10-29
10.9.4 Booting From a Device Peripheral .......... 10-32
10.9.5 Setting the Entry Point for the Boot Table .. 10-32
10.9.6 Using the C54x Boot Loader ................... 10-33
10.10 Controlling the ROM Device Address .......... 10-35
10.10.1 Controlling the Starting Address ............. 10-35
10.10.2 Controlling the Address Increment Index .... 10-37
10.10.3 The –byte Option ............................... 10-37
10.10.4 Dealing With Address Holes ................. 10-37
10.11 Description of the Object Formats ............. 10-39
10.11.1 ASCII-Hex Object Format (–a Option) ...... 10-40
10.11.2 Intel MCS-86 Object Format (–i Option) ..... 10-41
10.11.3 Motorola Exorciser Object Format (–m1, –m2, –m3 Options) ........................................ 10-42
10.11.4 Texas Instruments SDSMAC Object Format (–t Option) ........................................ 10-43
10.11.5 Extended Tektronix Object Format (–x Option) ........................................ 10-44
10.12 Hex Conversion Utility Error Messages ....... 10-45

11 Mnemonic-to-Algebraic Translator Description ........................................ 11-1

Expects how to invoke the mnemonic-to-algebraic translator utility to convert a source file containing mnemonic instructions to a source file containing algebraic instructions.

11.1 Translator Overview ................................ 11-2
11.1.1 What the Translator Does ....................... 11-2
11.1.2 What the Translator Does Not Do ............... 11-2
11.2 Translator Development Flow ..................... 11-3
11.3 Invoking the Translator ......................... 11-4
11.4 Translation Modes ........................................... 11-5
  11.4.1 Literal Mode (–t Option) ................................. 11-5
  11.4.2 About Symbol Names in Literal Mode ............... 11-5
  11.4.3 Expansion Mode (–e Option) ......................... 11-6
11.5 How the Translator Works With Macros ................. 11-8
  11.5.1 Directives in Macros .................................. 11-8
  11.5.2 Macro Local Variables ................................. 11-9
  11.5.3 Defining Labels When Invoking A Macro .......... 11-10

A Common Object File Format ........................................  A-1
Contains supplemental technical data about the internal format and structure of COFF object files.
  A.1 COFF File Structure ........................................ A-2
      A.1.1 Impact of Switching Operating Systems ............ A-4
  A.2 File Header Structure ..................................... A-5
  A.3 Optional File Header Format .............................. A-6
  A.4 Section Header Structure ................................ A-7
  A.5 Structuring Relocation Information ...................... A-10
  A.6 Line-Number Table Structure ......................... A-12
  A.7 Symbol Table Structure and Content ..................... A-14
      A.7.1 Special Symbols .................................. A-16
      A.7.2 Symbol Name Format ............................. A-18
      A.7.3 String Table Structure ........................... A-18
      A.7.4 Storage Classes ................................ A-19
      A.7.5 Symbol Values ................................... A-20
      A.7.6 Section Number ................................ A-21
      A.7.7 Type Entry ........................................ A-21
      A.7.8 Auxiliary Entries ................................. A-23

B Symbolic Debugging Directives ..................................  B-1
Discusses symbolic debugging directives that the C compiler uses.

C Hex Conversion Utility Examples .................................  C-1
Illustrates command file development for a variety of memory systems and situations.
  C.1 Base Code for the Examples ............................. C-2
  C.2 Example 1: Building A Hex Command File for Two 8-Bit EPROMs  C-3
  C.3 Example 2: Avoiding Holes With Multiple Sections .......... C-5
  C.4 Example 3: Generating a Boot Table .................... C-10
  C.5 Example 4: Generating a Boot Table for LP Core Devices . C-17

D Assembler Error Messages ........................................ D-1
Lists the error messages that the assembler and linker issue, and gives a description of the condition(s) that caused each error.

E Linker Error Messages ........................................... E-1
Lists the error messages that the assembler and linker issue, and gives a description of the condition(s) that caused each error.

F Glossary ............................................................ F-1
Defines terms and acronyms used in this book.
Figures

1–1 TMS320C54x Software Development Flow ........................................... 1-2
2–1 Partitioning Memory Into Logical Blocks ........................................... 2-4
2–2 Object Code Generated by the File in Example 2–1 .............................. 2-12
2–3 Combining Input Sections to Form an Executable Object Module .......... 2-14
3–1 Assembler Development Flow ............................................................... 3-3
4–1 The .space and .bes Directives ............................................................ 4-11
4–2 The .field Directive .............................................................................. 4-12
4–3 Initialization Directives ........................................................................ 4-14
4–4 The .align Directive ............................................................................ 4-16
4–5 Allocating .bss Blocks Within a Page ................................................... 4-31
4–6 The .field Directive .............................................................................. 4-49
4–7 The .usect Directive ............................................................................ 4-97
6–1 Archiver Development Flow ................................................................. 6-3
7–1 Linker Development Flow ..................................................................... 7-3
7–2 Memory Map Defined in Example 7–3 .................................................. 7-31
7–3 Section Allocation Defined by Example 7–4 ......................................... 7-34
7–4 Runtime Execution of Example 7–6 ...................................................... 7-47
7–5 Memory Allocation Shown in Example 7–7 and Example 7–8 ............... 7-49
7–6 Overlay Pages Defined by Example 7–11 and Example 7–12 ................. 7-54
7–7 RAM Model of Autoinitialization ......................................................... 7-74
7–8 ROM Model of Autoinitialization ......................................................... 7-74
8–1 Absolute Lister Development Flow ....................................................... 8-2
8–2 module1.lst ......................................................................................... 8-9
8–3 module2.lst ......................................................................................... 8-9
9–1 Cross-Reference Lister Development Flow ........................................... 9-2
10–1 Hex Conversion Utility Development Flow ........................................ 10-2
10–2 Hex Conversion Utility Process Flow ................................................ 10-9
10–3 Data and Memory Widths ................................................................... 10-11
10–4 Data, Memory, and ROM Widths ....................................................... 10-13
10–5 C54x Memory Configuration Example ............................................... 10-14
10–6 Varying the Word Order .................................................................... 10-15
10–7 The infile.out File From Example 10–1 Partitioned Into Four Output Files .................................................. 10-20
10–8 Sample Command File for Booting From a C54x EPROM ..................... 10-34
10–9 Hex Command File for Avoiding a Hole at the Beginning of a Section 10-38
10–10 ASCII-Hex Object Format ................................................................. 10-40
10–11 Intel Hex Object Format ................................................................. 10-41
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>10–12</td>
<td>Motorola-S Format</td>
<td>10-42</td>
</tr>
<tr>
<td>10–13</td>
<td>TI-Tagged Object Format</td>
<td>10-43</td>
</tr>
<tr>
<td>10–14</td>
<td>Extended Tektronix Object Format</td>
<td>10-44</td>
</tr>
<tr>
<td>11–1</td>
<td>Translator Development Flow</td>
<td>11-3</td>
</tr>
<tr>
<td>11–2</td>
<td>Literal Mode Process</td>
<td>11-5</td>
</tr>
<tr>
<td>11–3</td>
<td>Expansion Mode Process</td>
<td>11-6</td>
</tr>
<tr>
<td>11–4</td>
<td>Defining Labels</td>
<td>11-10</td>
</tr>
<tr>
<td>11–5</td>
<td>Rewritten Source Code</td>
<td>11-10</td>
</tr>
<tr>
<td>A–1</td>
<td>COFF File Structure</td>
<td>A-2</td>
</tr>
<tr>
<td>A–2</td>
<td>COFF Object File</td>
<td>A-3</td>
</tr>
<tr>
<td>A–3</td>
<td>Section Header Pointers for the .text Section</td>
<td>A-9</td>
</tr>
<tr>
<td>A–4</td>
<td>Line-Number Blocks</td>
<td>A-12</td>
</tr>
<tr>
<td>A–5</td>
<td>Line-Number Entries</td>
<td>A-13</td>
</tr>
<tr>
<td>A–6</td>
<td>Symbol Table Contents</td>
<td>A-14</td>
</tr>
<tr>
<td>A–7</td>
<td>Symbols for Blocks</td>
<td>A-17</td>
</tr>
<tr>
<td>A–8</td>
<td>Symbols for Functions</td>
<td>A-17</td>
</tr>
<tr>
<td>A–9</td>
<td>String Table</td>
<td>A-18</td>
</tr>
<tr>
<td>C–1</td>
<td>A Two 8-Bit EPROM System</td>
<td>C-3</td>
</tr>
<tr>
<td>C–2</td>
<td>Data From Output File</td>
<td>C-6</td>
</tr>
<tr>
<td>C–3</td>
<td>EPROM System for a C54x</td>
<td>C-10</td>
</tr>
<tr>
<td>C–4</td>
<td>EPROM System for a C54xLP</td>
<td>C-17</td>
</tr>
</tbody>
</table>
### Tables

<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>3–1</td>
<td>Operators Used in Expressions (Precedence)</td>
</tr>
<tr>
<td>3–2</td>
<td>Expressions With Absolute and Relocatable Symbols</td>
</tr>
<tr>
<td>3–3</td>
<td>Assembler Built-In Math Functions</td>
</tr>
<tr>
<td>3–4</td>
<td>Symbol Attributes</td>
</tr>
<tr>
<td>4–1</td>
<td>Assembler Directives Summary</td>
</tr>
<tr>
<td>4–2</td>
<td>Memory-Mapped Registers</td>
</tr>
<tr>
<td>5–1</td>
<td>Functions and Return Values</td>
</tr>
<tr>
<td>5–2</td>
<td>Creating Macros</td>
</tr>
<tr>
<td>5–3</td>
<td>Manipulating Substitution Symbols</td>
</tr>
<tr>
<td>5–4</td>
<td>Conditional Assembly</td>
</tr>
<tr>
<td>5–5</td>
<td>Producing Assembly-Time Messages</td>
</tr>
<tr>
<td>5–6</td>
<td>Formatting the Listing</td>
</tr>
<tr>
<td>7–1</td>
<td>Operators Used in Expressions (Precedence)</td>
</tr>
<tr>
<td>9–1</td>
<td>Symbol Attributes</td>
</tr>
<tr>
<td>10–1</td>
<td>Hex Conversion Utility Options</td>
</tr>
<tr>
<td>10–2</td>
<td>Boot-Loader Options</td>
</tr>
<tr>
<td>10–3</td>
<td>Options for Specifying Hex Conversion Formats</td>
</tr>
<tr>
<td>A–1</td>
<td>File Header Contents</td>
</tr>
<tr>
<td>A–2</td>
<td>File Header Flags (Bytes 18 and 19)</td>
</tr>
<tr>
<td>A–3</td>
<td>Optional File Header Contents</td>
</tr>
<tr>
<td>A–4</td>
<td>Section Header Contents</td>
</tr>
<tr>
<td>A–5</td>
<td>Section Header Contents for COFF1 Files</td>
</tr>
<tr>
<td>A–6</td>
<td>Section Header Flags</td>
</tr>
<tr>
<td>A–7</td>
<td>Relocation Entry Contents</td>
</tr>
<tr>
<td>A–8</td>
<td>Relocation Types (Bytes 8 and 9)</td>
</tr>
<tr>
<td>A–9</td>
<td>Line-Number Entry Format</td>
</tr>
<tr>
<td>A–10</td>
<td>Symbol Table Entry Contents</td>
</tr>
<tr>
<td>A–11</td>
<td>Special Symbols in the Symbol Table</td>
</tr>
<tr>
<td>A–12</td>
<td>Symbol Storage Classes</td>
</tr>
<tr>
<td>A–13</td>
<td>Special Symbols and Their Storage Classes</td>
</tr>
<tr>
<td>A–14</td>
<td>Symbol Values and Storage Classes</td>
</tr>
<tr>
<td>A–15</td>
<td>Section Numbers</td>
</tr>
<tr>
<td>A–16</td>
<td>Basic Types</td>
</tr>
<tr>
<td>A–17</td>
<td>Derived Types</td>
</tr>
<tr>
<td>A–18</td>
<td>Auxiliary Symbol Table Entries Format</td>
</tr>
<tr>
<td>A–19</td>
<td>Filename Format for Auxiliary Table Entries</td>
</tr>
</tbody>
</table>

xvi
A–20  Section Format for Auxiliary Table Entries     A-24
A–21  Tag Name Format for Auxiliary Table Entries     A-24
A–22  End-of-Structure Format for Auxiliary Table Entries     A-25
A–23  Function Format for Auxiliary Table Entries     A-25
A–24  Array Format for Auxiliary Table Entries     A-26
A–25  End-of-Blocks/Functions Format for Auxiliary Table Entries     A-26
A–26  Beginning-of-Blocks/Functions Format for Auxiliary Table Entries     A-27
A–27  Structure, Union, and Enumeration Names Format for Auxiliary Table Entries     A-27
Examples

2–1 Using Sections Directives ................................................................. 2–11
2–2 Code That Generates Relocation Entries ........................................ 2–16
3–1 $n Local Labels ............................................................................. 3–22
3–2 name? Local Labels ....................................................................... 3–24
3–3 Well-Defined Expressions ............................................................... 3–27
3–4 Assembler Listing .......................................................................... 3–35
3–5 Sample Cross-Reference Listing ..................................................... 3–37
4–1 Sections Directives ....................................................................... 4–10
5–1 Macro Definition, Call, and Expansion .......................................... 5–4
5–2 Calling a Macro With Varying Numbers of Arguments ................. 5–7
5–3 The .asg Directive ......................................................................... 5–8
5–4 The .eval Directive ....................................................................... 5–8
5–5 Using Built-In Substitution Symbol Functions ............................... 5–9
5–6 Recursive Substitution ................................................................... 5–10
5–7 Using the Forced Substitution Operator ......................................... 5–11
5–8 Using Subscripted Substitution Symbols to Redefine an Instruction 5–12
5–9 Using Subscripted Substitution Symbols to Find Substrings .......... 5–13
5–10 The .loop/.break/.endloop Directives .......................................... 5–16
5–11 Nested Conditional Assembly Directives ..................................... 5–16
5–12 Built-In Substitution Symbol Functions Used in a Conditional Assembly Code Block ............................................................. 5–16
5–13 Unique Labels in a Macro ............................................................. 5–17
5–14 Producing Messages in a Macro ................................................... 5–20
5–15 Using Nested Macros .................................................................. 5–22
5–16 Using Recursive Macros ............................................................... 5–23
7–1 Linker Command File ................................................................... 7–22
7–2 Command File With Linker Directives ......................................... 7–23
7–3 The MEMORY Directive ............................................................... 7–28
7–4 The SECTIONS Directive ............................................................. 7–34
7–5 The Most Common Method of Specifying Section Contents .......... 7–38
7–6 Copying a Section From ROM to RAM ......................................... 7–46
7–7 The UNION Statement .................................................................. 7–48
7–8 Separate Load Addresses for UNION Sections ............................... 7–48
7–9 Allocate Sections Together ............................................................ 7–50
7–10 Nesting GROUP and UNION statements ...................................... 7–51
7–11 Memory Directive With Overlay Pages ......................................... 7–53
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7–12</td>
<td>SECTIONS Directive Definition for Overlays in Figure 7–6</td>
<td>7-55</td>
</tr>
<tr>
<td>7–13</td>
<td>Default Allocation for TMS320C54x Devices</td>
<td>7-58</td>
</tr>
<tr>
<td>7–14</td>
<td>Linker Command File, demo.cmd</td>
<td>7-77</td>
</tr>
<tr>
<td>7–15</td>
<td>Output Map File, demo.map</td>
<td>7-78</td>
</tr>
<tr>
<td>10–1</td>
<td>A ROMS Directive Example</td>
<td>10-19</td>
</tr>
<tr>
<td>10–2</td>
<td>Map File Output From Example 10–1 Showing Memory Ranges</td>
<td>10-21</td>
</tr>
<tr>
<td>11–1</td>
<td>Treatment of Symbol Names in Literal Mode</td>
<td>11-5</td>
</tr>
<tr>
<td>11–2</td>
<td>Expansion Mode</td>
<td>11-7</td>
</tr>
<tr>
<td>11–3</td>
<td>Directives in Macros</td>
<td>11-8</td>
</tr>
<tr>
<td>11–4</td>
<td>Macro Local Variables</td>
<td>11-9</td>
</tr>
<tr>
<td>C–1</td>
<td>Assembly Code for Hex Conversion Utility Examples</td>
<td>C-2</td>
</tr>
<tr>
<td>C–2</td>
<td>A Linker Command File for Two 8-Bit EPROMs</td>
<td>C-4</td>
</tr>
<tr>
<td>C–3</td>
<td>A Hex Command File for Two 8-Bit EPROMs</td>
<td>C-5</td>
</tr>
<tr>
<td>C–4</td>
<td>Map File Resulting From Hex Command File in Example C–3 on page C-5</td>
<td>C-7</td>
</tr>
<tr>
<td>C–5</td>
<td>Method One for Avoiding Holes</td>
<td>C-8</td>
</tr>
<tr>
<td>C–6</td>
<td>Method Two for Avoiding Holes</td>
<td>C-9</td>
</tr>
<tr>
<td>C–7</td>
<td>C Code for Example 3</td>
<td>C-10</td>
</tr>
<tr>
<td>C–8</td>
<td>Linker Command File to Form a Single Boot Section</td>
<td>C-12</td>
</tr>
<tr>
<td>C–9</td>
<td>Section Allocation Portion of Map File Resulting From the Command File</td>
<td>C-13</td>
</tr>
<tr>
<td>C–10</td>
<td>Hex Command File for Converting a COFF File</td>
<td>C-15</td>
</tr>
<tr>
<td>C–11</td>
<td>Map File Resulting From the Command File in Example C–10</td>
<td>C-16</td>
</tr>
<tr>
<td>C–12</td>
<td>Hex Conversion Utility Output File Resulting From the Command File in C–10</td>
<td>C-16</td>
</tr>
<tr>
<td>C–13</td>
<td>C Code for a C54xLP</td>
<td>C-17</td>
</tr>
<tr>
<td>C–14</td>
<td>Linker Command File for a C54xLP</td>
<td>C-19</td>
</tr>
<tr>
<td>C–15</td>
<td>Section Allocation Portion of Map File Resulting From the Command File in Example C–14</td>
<td>C-19</td>
</tr>
<tr>
<td>C–16</td>
<td>Hex Command File for Converting a COFF File</td>
<td>C-22</td>
</tr>
<tr>
<td>C–17</td>
<td>Map File Resulting From the Command File in Example C–16</td>
<td>C-23</td>
</tr>
<tr>
<td>C–18</td>
<td>Hex Conversion Utility Output File Resulting From the Command File in C–16</td>
<td>C-23</td>
</tr>
</tbody>
</table>
Introduction

The TMS320C54x™ DSPs are supported by the following assembly language tools:

- Assembler
- Archiver
- Linker
- Absolute lister
- Cross-reference utility
- Hex conversion utility
- Mnemonic-to-algebraic translator utility

This chapter shows how these tools fit into the general software tools development flow and gives a brief description of each tool. For convenience, it also summarizes the C compiler and debugging tools. For detailed information on the compiler and debugger and for complete descriptions of the TMS320C54x devices, refer to the books listed in Related Documentation From Texas Instruments on page vi.

The assembly language tools create and use object files in common object file format (COFF) to facilitate modular programming. Object files contain separate blocks (called sections) of code and data that you can load into C54x™ memory spaces. You can program the C54x more efficiently if you have a basic understanding of COFF. Chapter 2, Introduction to Common Object File Format, discusses this object format in detail.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Software Development Tools Overview</td>
<td>1-2</td>
</tr>
<tr>
<td>1.2 Tools Descriptions</td>
<td>1-3</td>
</tr>
</tbody>
</table>
1.1 Software Development Tools Overview

Figure 1–1 illustrates the C54x software development flow. The shaded portion of the figure highlights the most common path of software development; the other portions are optional.

Figure 1–1. TMS320C54x Software Development Flow
1.2 Tools Descriptions

The following list describes the tools that are shown in Figure 1–1:

- The **C/C++ compiler** translates C/C++ source code into C54x assembly language source code. The compiler package includes the **library-build utility**, with which you can build your own runtime libraries.

- The **assembler** translates assembly language source files into machine language COFF object files. Source files can contain instructions, assembler directives, and macro directives. You can use assembler directives to control various aspects of the assembly process, such as the source listing format, data alignment, and section content.

- The **linker** combines relocatable COFF object files (created by the assembler) into a single executable COFF object module. As it creates the executable module, it binds symbols to memory locations and resolves all references to those symbols. It also accepts archiver library members and output modules created by a previous linker run. Linker directives allow you to combine object file sections, bind sections or symbols to addresses or within memory ranges, and define or redefine global symbols.

- The **archiver** collects a group of files into a single archive file. For example, you can collect several macros into a macro library. The assembler searches the library and uses the members that are called as macros by the source file. You can also use the archiver to collect a group of object files into an object library. The linker includes in the library the members that resolve external references during the link.

- The **mnemonic-to-algebraic assembly translator utility** converts an assembly language source file containing mnemonic instructions to an assembly language source file containing algebraic instructions.

- The **library-build utility** builds your own customized C/C++ runtime-support library. Standard runtime-support library functions are provided as source code in rts.src and as object code in rts.lib.

- The TMS320C54x DSP accepts COFF files as input, but most EPROM programmers do not. The **hex conversion utility** converts a COFF object file into TI-tagged, Intel, Motorola, or Tektronix object format. The converted file can be downloaded to an EPROM programmer.
The **absolute lister** accepts linked object files as input and creates .abs files as output. You assemble .abs files to produce a listing that contains absolute rather than relative addresses. Without the absolute lister, producing such a listing would be tedious and require many manual operations.

The **cross-reference lister** uses object files to produce a cross-reference listing showing symbols, their definitions, and their references in the linked source files.

The purpose of this development process is to produce a module that can be executed in a C54x target system. You can use one of several debugging tools to refine and correct your code. Available products include:

- An instruction-accurate software simulator
- An evaluation module (EVM)
- An XDS emulator

These debugging tools are accessed within Code Composer Studio. For more information, see the *Code Composer Studio User’s Guide*. 
The assembler and linker create object files that can be executed by a TMS320C54x™ device. The format for these object files is called common object file format (COFF).

COFF makes modular programming easier, because it encourages you to think in terms of blocks of code and data when you write an assembly language program. These blocks are known as sections. Both the assembler and the linker provide directives that allow you to create and manipulate sections.

This chapter provides an overview of COFF sections. For additional information, see Appendix A, Common Object File Format, which explains the COFF structure.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 COFF File Types</td>
<td>2-2</td>
</tr>
<tr>
<td>2.2 Sections</td>
<td>2-3</td>
</tr>
<tr>
<td>2.3 How the Assembler Handles Sections</td>
<td>2-5</td>
</tr>
<tr>
<td>2.4 How the Linker Handles Sections</td>
<td>2-13</td>
</tr>
<tr>
<td>2.5 Relocation</td>
<td>2-16</td>
</tr>
<tr>
<td>2.6 Runtime Relocation</td>
<td>2-19</td>
</tr>
<tr>
<td>2.7 Loading a Program</td>
<td>2-20</td>
</tr>
<tr>
<td>2.8 Symbols in a COFF File</td>
<td>2-21</td>
</tr>
</tbody>
</table>
2.1 COFF File Types

The following types of COFF files exist:

- COFF0
- COFF1
- COFF2

Each COFF file type has a different header format. The data portions of the COFF files are identical. For details about the COFF file structure, see Appendix A, Common Object File Format.

The TMS320C54x assembler and C compiler create COFF2 files. The linker can read and write all types of COFF files. By default, the linker creates COFF2 files. Use the –v linker option to specify a different format. The linker supports COFF0 and COFF1 files for older versions of the assembler and C compiler only.
2.2 Sections

The smallest unit of an object file is called a section. A section is a block of code or data that will ultimately occupy contiguous space in the memory map. Each section of an object file is separate and distinct. COFF object files always contain three default sections:

- **.text section** usually contains executable code
- **.data section** usually contains initialized data
- **.bss section** usually reserves space for uninitialized variables

In addition, the assembler and linker allow you to create, name, and link named sections that are used like the .data, .text, and .bss sections.

There are two basic types of sections:

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>initialized sections</td>
<td>contain data or code. The .text and .data sections are initialized; named sections created with the .sect assembler directive are also initialized.</td>
</tr>
<tr>
<td>uninitialized sections</td>
<td>reserve space for uninitialized data. The .bss section is uninitialized; named sections created with the .usect assembler directive are also uninitialized.</td>
</tr>
</tbody>
</table>

Several assembler directives allow you to associate various portions of code and data with the appropriate sections. The assembler builds these sections during the assembly process, creating an object file organized as shown in Figure 2–1.

One of the linker’s functions is to relocate sections into the target memory map; this function is called allocation. Because most systems contain several types of memory, using sections can help you use target memory more efficiently. All sections are independently relocatable; you can place any section into any allocated block of target memory. For example, you can define a section that contains an initialization routine and then allocate the routine into a portion of the memory map that contains ROM.
Figure 2–1 shows the relationship between sections in an object file and a hypothetical target memory.

Figure 2–1. Partitioning Memory Into Logical Blocks
2.3 How the Assembler Handles Sections

The assembler identifies the portions of an assembly language program that belong in a section. The assembler has several directives that support this function:

- `.bss`
- `.usect`
- `.text`
- `.data`
- `.sect`

The `.bss` and `.usect` directives create uninitialized sections; the other directives create initialized sections.

You can create subsections of any section to give you tighter control of the memory map. Subsections are created using the `.sect` and `.usect` directives. Subsections are identified with the base section name and a subsection name separated by a colon. See subsection 2.3.4, Subsections, page 2-9, for more information.

**Note: Default Section Directive**

If you don’t use any of the sections directives, the assembler assembles everything into the `.text` section.

2.3.1 Uninitialized Sections

Uninitialized sections reserve space in processor memory; they are usually allocated into RAM. These sections have no actual contents in the object file; they simply reserve memory. A program can use this space at runtime for creating and storing variables.

Uninitialized data areas are built by using the `.bss` and `.usect` assembler directives.

- The `.bss` directive reserves space in the `.bss` section.
- The `.usect` directive reserves space in a specific, uninitialized named section.

Each time you invoke the `.bss` directive, the assembler reserves more space in the appropriate section. Each time you invoke the `.usect` directive, the assembler reserves more space in the specified named section.
The syntax for these directives is:

```
.bss symbol, size in words [, [blocking flag] [, alignment flag]]
symbol .usect "section name", size in words [, [blocking flag] [, alignment flag]]
```

- **symbol** points to the first word reserved by this invocation of the .bss or .usect directive. The symbol corresponds to the name of the variable that you’re reserving space for. It can be referenced by any other section and can also be declared as a global symbol (with the .global assembler directive).
- **size in words** is an absolute expression.
  - The .bss directive reserves size words in the .bss section.
  - The .usect directive reserves size words in section name.
- **blocking flag** is an optional parameter. If you specify a value other than 0 for this parameter, the assembler associates size words contiguously; the allocated space will not cross a page boundary, unless size is greater than a page, in which case the object will start on a page boundary.
- **alignment flag** is an optional parameter. If you specify a value other than 0 for this parameter, the section is aligned to a long word boundary.
- **section name** tells the assembler which named section to reserve space in. For more information about named sections, see subsection 2.3.3, Named Sections, on page 2-8.

The .text, .data, and .sect directives tell the assembler to stop assembling into the current section and begin assembling into the indicated section. The .bss and .usect directives, however, do not end the current section and begin a new one; they simply escape temporarily from the current section. The .bss and .usect directives can appear anywhere in an initialized section without affecting its contents.

Uninitialized subsections can be created with the .usect directive. The assembler treats uninitialized subsections in the same manner as uninitialized sections. See subsection 2.3.4, Subsections, on page 2-9 for more information on creating subsections.
2.3.2 Initialized Sections

Initialized sections contain executable code or initialized data. The contents of these sections are stored in the object file and placed in processor memory when the program is loaded. Each initialized section is independently relocatable and may reference symbols that are defined in other sections. The linker automatically resolves these section-relative references.

Three directives tell the assembler to place code or data into a section. The syntaxes for these directives are:

```
.text [value]
data [value]
sect "section name" [, value]
```

When the assembler encounters one of these directives, it stops assembling into the current section (acting as an implied end-current-section command). It then assembles subsequent code into the designated section until it encounters another .text, .data, or .sect directive. The value, if present, specifies the starting value of the section program counter. The starting value of the section program counter can be specified only once; it must be done the first time the directive for that section is encountered. By default, the SPC starts at 0.

Sections are built through an iterative process. For example, when the assembler first encounters a .data directive, the .data section is empty. The statements following this first .data directive are assembled into the .data section (until the assembler encounters a .text or .sect directive). If the assembler encounters subsequent .data directives, it adds the statements following these .data directives to the statements already in the .data section. This creates a single .data section that can be allocated contiguously into memory.

Initialized subsections can be created with the .sect directive. The assembler treats initialized subsections in the same manner as initialized sections. See subsection 2.3.4, Subsections, on page 2-9 for more information on creating subsections.
2.3.3 Named Sections

Named sections are sections that you create. You can use them like the default .text, .data, and .bss sections, but they are assembled separately.

For example, repeated use of the .text directive builds up a single .text section in the object file. When linked, this .text section is allocated into memory as a single unit. Suppose there is a portion of executable code (perhaps an initialization routine) that you don’t want allocated with .text. If you assemble this segment of code into a named section, it is assembled separately from .text, and you can allocate it into memory separately. You can also assemble initialized data that is separate from the .data section, and you can reserve space for uninitialized variables that is separate from the .bss section.

The following directives let you create named sections:

- The .usect directive creates sections that are used like the .bss section. These sections reserve space in RAM for variables.

- The .sect directive creates sections, like the default .text and .data sections, that can contain code or data. The .sect directive creates named sections with relocatable addresses.

The syntax for these directives is shown below:

```
symbol .usect "section name", size in words [, [blocking flag] [, alignment flag]]
.sect "section name"
```

The `section name` parameter is the name of the section. You can create up to 32 767 separate named sections. A section name can be up to 200 characters. For the .sect and .usect directives, a section name can refer to a subsection (see subsection 2.3.4, Subsections, for details).

Each time you invoke one of these directives with a new name, you create a new named section. Each time you invoke one of these directives with a name that was already used, the assembler assembles code or data (or reserves space) into the section with that name. *You cannot use the same names with different directives.* That is, you cannot create a section with the .usect directive and then try to use the same section with .sect.
2.3.4 Subsections

Subsections are smaller sections within larger sections. Like sections, subsections can be manipulated by the linker. Subsections give you tighter control of the memory map. You can create subsections by using the .sect or .usect directive. The syntax for a subsection name is:

```
section name:subsection name
```

A subsection is identified by the base section name followed by a colon, then the name of the subsection. A subsection can be allocated separately or grouped with other sections using the same base name. For example, to create a subsection called `_func` within the .text section, enter the following:

```
.sect ".text:_func"
```

You can allocate `_func` separately or with other .text sections.

You can create two types of subsections:

- Initialized subsections are created using the .sect directive. See subsection 2.3.2, Initialized Sections, on page 2-7.
- Uninitialized subsections are created using the .usect directive. See subsection 2.3.1, Uninitialized Sections, on page 2-5.

Subsections are allocated in the same manner as sections. See Section 7.8, The SECTIONS Directive, on page 7-32 for more information.

2.3.5 Section Program Counters

The assembler maintains a separate program counter for each section. These program counters are known as section program counters, or SPCs.

An SPC represents the current address within a section of code or data. Initially, the assembler sets each SPC to 0. As the assembler fills a section with code or data, it increments the appropriate SPC. If you resume assembling into a section, the assembler remembers the appropriate SPC’s previous value and continues incrementing the SPC at that point.

The assembler treats each section as if it began at address 0; the linker relocates each section according to its final location in the memory map. For more information, see Section 2.5, Relocation, on page 2-16.
2.3.6 An Example That Uses Sections Directives

Example 2–1 shows how you can build COFF sections incrementally, using the sections directives to swap back and forth between the different sections. You can use sections directives to begin assembling into a section for the first time, or to continue assembling into a section that already contains code. In the latter case, the assembler simply appends the new code to the code that is already in the section.

The format in Example 2–1 is a listing file. Example 2–1 shows how the SPCs are modified during assembly. A line in a listing file has four fields:

Field 1 contains the source code line counter.
Field 2 contains the section program counter.
Field 3 contains the object code.
Field 4 contains the original source statement.
Example 2–1. Using Sections Directives

2  ************************************************
3  ** Assemble an initialized table into .data. **
4  ************************************************
5 000000 .data
6 000000 0011 coeff .word 011h,022h,033h
7 000001 0022
8 000002 0033
9 ************************************************
10 ** Reserve space in .bss for a variable. **
11 ************************************************
12 000000 .bss buffer,10
13 ************************************************
14 000003 0123 ptr .word 0123h
15 ************************************************
16 ** Assemble code into the .text section. **
17 ************************************************
18 000000 .text
19 000000 100f add: LD 0Fh,A
20 000001 f010 aloop: SUB #1,A
21 000003 f842 BC aloop,AGEQ
22 ************************************************
23 ** Another initialized table into .data. **
24 ************************************************
25 000004 .data
26 000004 00aa ivals .word 0AAh, 0BBh, 0CCh
27 000005 00bb
28 000006 00cc
29 ************************************************
30 ** Define another section for more variables. **
31 ************************************************
32 000000 var2 .usect "newvars", 1
33 000001 inbuf .usect "newvars", 7
34 ************************************************
35 ** Assemble more code into .text. **
36 ************************************************
37 000000 .text
38 000005 110a mpy: LD 0Ah,B
39 000006 f166 mloop: MPY #0Ah,B
40 000007 00a
41 000008 f868 BC mloop,BNOV
42 000009 0006'
43 ************************************************
44 ** Define a named section for int. vectors. **
45 ************************************************
46 000000 .sect "vectors"
47 000000 0011 .word 011h, 033h
48 000001 0033
49 000002 0033
50
How the Assembler Handles Sections

As Figure 2–2 shows, the file in Example 2–1 creates five sections:

- **.text** contains ten 16-bit words of object code.
- **.data** contains seven words of object code.
- **vectors** is a named section created with the .sect directive; it contains two words of initialized data.
- **.bss** reserves 10 words in memory.
- **newvars** is a named section created with the .usect directive; it reserves eight words in memory.

The second column shows the object code that is assembled into these sections; the first column shows the line numbers of the source statements that generated the object code.

**Figure 2–2. Object Code Generated by the File in Example 2–1**

<table>
<thead>
<tr>
<th>Line Numbers</th>
<th>Object Code</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>100f</td>
<td>.text</td>
</tr>
<tr>
<td>20</td>
<td>0010</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0001</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>842</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>0001</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>110a</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>f166</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>000a</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>868</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>0006</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0011</td>
<td>.data</td>
</tr>
<tr>
<td>6</td>
<td>0022</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0033</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0123</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>00aa</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>00bb</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>00cc</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>0011</td>
<td>vectors</td>
</tr>
<tr>
<td>44</td>
<td>0033</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>No data—10 words reserved</td>
<td>.bss</td>
</tr>
<tr>
<td>30</td>
<td>No data—eight words reserved</td>
<td>newvars</td>
</tr>
<tr>
<td>31</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.4 How the Linker Handles Sections

The linker has two main functions related to sections. First, the linker uses the sections in COFF object files as building blocks; it combines input sections (when more than one file is being linked) to create output sections in an executable COFF output module. Second, the linker chooses memory addresses for the output sections.

Two linker directives support these functions:

- The MEMORY directive allows you to define the memory map of a target system. You can name portions of memory and specify their starting addresses and their lengths.

- The SECTIONS directive tells the linker how to combine input sections into output sections and where to place these output sections in memory.

Subsections allow you to manipulate sections with greater precision. You can specify subsections with the linker’s SECTIONS directive. If you do not specify a subsection explicitly, then the subsection is combined with the other sections with the same base section name.

It is not always necessary to use linker directives. If you don’t use them, the linker uses the target processor’s default allocation algorithm described in Section 7.12, Default Allocation Algorithm, on page 7-58. When you do use linker directives, you must specify them in a linker command file.

Refer to the following sections for more information about linker command files and linker directives:

<table>
<thead>
<tr>
<th>Section Number</th>
<th>Section Name</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5</td>
<td>Linker Command Files</td>
<td>7-21</td>
</tr>
<tr>
<td>7.7</td>
<td>The MEMORY Directive</td>
<td>7-27</td>
</tr>
<tr>
<td>7.8</td>
<td>The SECTIONS Directive</td>
<td>7-32</td>
</tr>
<tr>
<td>7.12</td>
<td>Default Allocation Algorithm</td>
<td>7-58</td>
</tr>
</tbody>
</table>
2.4.1 Default Memory Allocation

Figure 2–3 illustrates the process of linking two files.

Figure 2–3. Combining Input Sections to Form an Executable Object Module

In Figure 2–3, file1.obj and file2.obj have been assembled to be used as linker input. Each contains the .text, .data, and .bss default sections; in addition, each contains named sections. The executable output module shows the combined sections. The linker combines file1.text with file2.text to form one .text section, then combines the .data sections, then the .bss sections, and finally places the named sections at the end. The memory map shows how the sections are put into memory; by default, the linker begins at address 080h and places the sections one after the other as shown.
2.4.2 Placing Sections in the Memory Map

Figure 2–3 illustrates the linker’s default methods for combining sections. Sometimes you may not want to use the default setup. For example, you may not want all of the .text sections to be combined into a single .text section. Or you may want a named section placed where the .data section would normally be allocated. Most memory maps contain various types of memory (RAM, ROM, EPROM, etc.) in varying amounts; you may want to place a section in a specific type of memory.

For further explanation of section placement within the memory map, see Section 7.7, The MEMORY Directive, on page 7-27 and Section 7.8, The SECTIONS Directive, on page 7-32.
2.5 Relocation

The assembler treats each section as if it began at address 0. All relocatable symbols (labels) are relative to address 0 in their sections. Of course, all sections can’t actually begin at address 0 in memory, so the linker relocates sections by:

- Allocating them into the memory map so that they begin at the appropriate address
- Adjusting symbol values to correspond to the new section addresses
- Adjusting references to relocated symbols to reflect the adjusted symbol values

The linker uses relocation entries to adjust references to symbol values. The assembler creates a relocation entry each time a relocatable symbol is referenced. The linker then uses these entries to patch the references after the symbols are relocated. Example 2–2 contains a code segment for the C54x that generates relocation entries.

Example 2–2. Code That Generates Relocation Entries

(a) Mnemonic example

```
1 .ref X
2 .ref Z
3 000000 .text
4 000000 F073 B Y ; Generates a Relocation Entry
   000001 0006'
5 000002 F073 B Z ; Generates a Relocation Entry
   000003 0000!
6 000004 F020 LD #X, A ; Generates a Relocation Entry
   000005 0000!
5 000006 F7E0 Y: RESET
```

(b) Algebraic example

```
1 .ref X
2 .ref Z
3 000000 .text
4 000000 F073 goto Y ; Generates a Relocation Entry
   000001 0006'
5 000002 F073 B Z ; Generates a Relocation Entry
   000003 0000!
6 000004 F020 A = #X ; Generates a Relocation Entry
   000005 0000!
7 000006 F7E0 Y: reset
```
In Example 2–2, both symbols X, Y, and Z are relocatable. Y is defined in the .text section of this module; X and Z are defined in another module. When the code is assembled, X and Z have a value of 0 (the assembler assumes all undefined external symbols have values of 0), and Y has a value of 6 (relative to address 0 in the .text section). The assembler generates relocation entries for X, Y, and Z. The references to X and Z are external references (indicated by the ! character in the listing). The reference to Y is to an internally defined relocatable symbol (indicated by the ' character in the listing).

After the code is linked, suppose that X is relocated to address 7100h. Suppose also that the .text section is relocated to begin at address 7200h; Y now has a relocated value of 7204h. The linker uses the two relocation entries to patch the two references in the object code:

\[
\begin{align*}
\text{f073 B Y becomes f073 0004'} & \text{7204'} \\
\text{f020 LD #X, A becomes f020 0000!} & \text{7100!}
\end{align*}
\]

Each section in a COFF object file has a table of relocation entries. The table contains one relocation entry for each relocatable reference in the section. The linker usually removes relocation entries after it uses them. This prevents the output file from being relocated again (if it is relinked or when it is loaded). A file that contains no relocation entries is an absolute file (all its addresses are absolute addresses). If you want the linker to retain relocation entries, invoke the linker with the \texttt{–r} option.

### 2.5.1 Relocation Issues

The linker may warn you about certain relocation issues.

In an assembly program, if an instruction with a PC-relative field contains a reference to a symbol, label, or address, the relative displacement is expected to fit in the instruction’s field. If the displacement doesn’t fit into the field (because the referenced item’s location is too far away), the linker issues an error. For example, the linker will issue an error message when an instruction with an 8-bit, unsigned, PC-relative field references a symbol located 256 or more bytes away from the instruction.
Similarly, if an instruction with an absolute address field contains a reference to a symbol, label, or address, the referenced item is expected to be located at an address that will fit in the instruction’s field. For example, if a function is linked at 0x10000, its address cannot be encoded into a 16-bit instruction field.

In both cases, the linker truncates the high bits of the value.

To deal with these issues, examine your link map and linker command file. You may be able to rearrange output sections to put referenced symbols closer to the referencing instruction.

Alternatively, consider using a different assembly instruction with a wider field. Or, if you only need the lower bits of a symbol, use a mask expression to mask off the lower bits.
2.6 Runtime Relocation

At times, you may want to load code into one area of memory and run it in another. For example, you may have performance-critical code in a ROM-based system. The code must be loaded into ROM, but it would run faster in RAM.

The linker provides a simple way to handle this. Using the SECTIONS directive, you can optionally direct the linker to allocate a section twice: first to set its load address, and again to set its run address. Use the *load* keyword for the load address and the *run* keyword for the run address.

The load address determines where a loader will place the raw data for the section. Any references to the section (such as labels in it) refer to its run address. The application must copy the section from its load address to its run address; this does *not* happen automatically simply because you specify a separate run address. For an example that illustrates how to move a block of code at runtime, see Example 7–6 on page 7-46.

If you provide only one allocation (either load or run) for a section, the section is allocated only once and will load and run at the same address. If you provide both allocations, the section is actually allocated as if it were two different sections of the same size.

Uninitialized sections (such as .bss) are not loaded, so the only significant address is the run address. The linker allocates uninitialized sections only once: if you specify both run and load addresses, the linker warns you and ignores the load address.

For a complete description of runtime relocation, see Section 7.9, *Specifying a Section’s Runtime Address*, on page 7-44.
2.7 Loading a Program

The linker produces executable COFF object modules. An executable object file has the same COFF format as object files that are used as linker input; the sections in an executable object file, however, are combined and relocated so that they can be loaded directly into target memory.

Several methods can be used for loading a program, depending on the execution environment. Two common situations are described below.

- The TMS320C54x debugging tools, including the software simulator, XDS51x emulator, and software development system, have built-in loaders. Each of these tools contains a LOAD command that invokes a loader; the loader reads the executable file and copies the program into target memory.

- You can use the hex conversion utility (hex500, which is shipped as part of the assembly language package) to convert the executable COFF object module into one of several object file formats. You can then use the converted file with an EPROM programmer to burn the program into an EPROM.
2.8 Symbols in a COFF File

A COFF file contains a symbol table that stores information about symbols in the program. The linker uses this table when it performs relocation. Debugging tools can also use the symbol table to provide symbolic debugging.

2.8.1 External Symbols

External symbols are symbols that are defined in one module and referenced in another module. You can use the .def, .ref, or .global directives to identify symbols as external:

- **.def**: Defined in the current module and used in another module
- **.ref**: Referenced in the current module, but defined in another module
- **.global**: May be either of the above

The following code segment illustrates these definitions.

```assembly
x: ADD #56h, A ; Define x
   B y ; Reference y
   .def x ; DEF of x
   .ref y ; REF of y
```

The .def definition of x says that it is an external symbol defined in this module and that other modules can reference x. The .ref definition of y says that it is an undefined symbol that is defined in another module.

The assembler places both x and y in the object file’s symbol table. When the file is linked with other object files, the entry for x defines unresolved references to x from other files. The entry for y causes the linker to look through the symbol tables of other files for y’s definition.

The linker must match all references with corresponding definitions. If the linker cannot find a symbol’s definition, it prints an error message about the unresolved reference. This type of error prevents the linker from creating an executable object module.
2.8.2 The Symbol Table

The assembler always generates an entry in the symbol table when it encounters an external symbol (both definitions and references). The assembler also creates special symbols that point to the beginning of each section; the linker uses these symbols to resolve the address of and references symbols that are defined in the section.

The assembler does not usually create symbol table entries for any symbols other than those described above, because the linker does not use them. For example, labels are not included in the symbol table unless they are declared with .global. For symbolic debugging purposes, it is sometimes useful to have entries in the symbol table for each symbol in a program. To accomplish this, invoke the assembler with the –s option.
The assembler translates assembly language source files into machine language object files. These files are in common object file format (COFF), which is discussed in Chapter 2, *Introduction to Common Object File Format*, and Appendix A, *Common Object File Format*. Source files can contain the following assembly language elements:

- Assembler directives described in Chapter 4
- Macro directives described in Chapter 5
- Assembly language instructions described in the TMS320C54x Instruction Set Reference Guides

### Topic Page

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 Assembler Overview</td>
<td>3-2</td>
</tr>
<tr>
<td>3.2 Assembler Development Flow</td>
<td>3-3</td>
</tr>
<tr>
<td>3.3 Invoking the Assembler</td>
<td>3-4</td>
</tr>
<tr>
<td>3.4 Naming Alternate Files and Directories for Assembler Input</td>
<td>3-8</td>
</tr>
<tr>
<td>3.5 Source Statement Format</td>
<td>3-11</td>
</tr>
<tr>
<td>3.6 Constants</td>
<td>3-15</td>
</tr>
<tr>
<td>3.7 Character Strings</td>
<td>3-18</td>
</tr>
<tr>
<td>3.8 Symbols</td>
<td>3-19</td>
</tr>
<tr>
<td>3.9 Expressions</td>
<td>3-25</td>
</tr>
<tr>
<td>3.10 Built-In Functions</td>
<td>3-30</td>
</tr>
<tr>
<td>3.11 Loading Values into Extended Program Memory</td>
<td>3-32</td>
</tr>
<tr>
<td>3.12 Source Listings</td>
<td>3-33</td>
</tr>
<tr>
<td>3.13 Cross-Reference Listing</td>
<td>3-37</td>
</tr>
</tbody>
</table>
3.1 Assembler Overview

This two-pass assembler does the following:

- Processes the source statements in a text file to produce a relocatable C64x object file
- Produces a source listing (if requested) and provides you with control over this listing
- Allows you to segment your code into sections and maintain an SPC (section program counter) for each section of object code
- Defines and references global symbols and appends a cross-reference listing to the source listing (if requested)
- Assembles conditional blocks
- Supports macros, allowing you to define macros inline or in a library
3.2 Assembler Development Flow

Figure 3–1 illustrates the assembler’s role in the assembly language development flow. The assembler accepts assembly language source files as input, whether created by the assembler itself or by the C/C++ compiler.

Figure 3–1. Assembler Development Flow
3.3 Invoking the Assembler

To invoke the assembler, enter the following:

```
```

**asm500** is the command that invokes the assembler.

**input file** names the assembly language source file. If you do not supply an extension, the assembler uses the default extension `.asm`, unless the –f assembler option is used. If you do not supply an input filename, the assembler prompts you for one.

The source file can contain mnemonic or algebraic instructions, but not both. The default instruction set is mnemonic. To specify the algebraic instruction set, use the –mg option.

**object file** names the C54x object file that the assembler creates. If you do not supply an extension, the assembler uses `.obj` as a default. If you do not supply an object file, the assembler creates a file that uses the input filename with the `.obj` extension.

**listing file** names the optional listing file that the assembler can create.

- If you do not supply a listing file, the assembler does not create one unless you use the –l (lowercase L) option or the –x option. In this case, the assembler uses the input filename with a .lst extension and places the listing file in the input file directory.

- If you supply a listing file but do not supply an extension, the assembler uses .lst as the default extension.

**options** identifies the assembler options that you want to use. Options are not case-sensitive and can appear anywhere on the command line, following the assembler name. Precede each option with a hyphen. Single-letter options without parameters can be combined: for example, –ic is equivalent to –i –c. Options that have parameters, such as –i, must be specified separately.

**–@** `–@filename` appends the contents of `filename` to the command line. You can use this option to avoid the limitations on command line length imposed by the host operating system. Within a command file, filenames or option parameters containing embedded spaces or hyphens must be surrounded with quotation marks.

For example: “this-file.asm”
Invoking the Assembler

- **a** creates an absolute listing. When you use `–a`, the assembler does not produce an object file. The `–a` option is used in conjunction with the absolute lister.

- **c** makes case insignificant in the assembly language files. For example, `–c` will make the symbols ABC and abc equivalent. If you do not use this option, case is significant (default). Case significance is enforced primarily with symbol names, not with mnemonics and register names.

- **d** `–d name [=value]` sets the name symbol. This is equivalent to inserting `name .set value` at the beginning of the assembly file. If `value` is omitted, the symbol is set to 1. For more information, see subsection 3.8.3, *Defining Symbolic Constants (–d Option)*, on page 3-20.

- **f** suppresses the assembler’s default behavior of adding a .asm extension to a source file name that does not already include an extension.

- **g** enables assembler source debugging in the source debugger. Line information is output to the COFF file for every line of source in the assembly language source file. Note that you cannot use the `–g` option on assembly code that already contains .line directives (i.e., code that was generated by the C/C++ compiler run with `–g`).

- **h** `–h help` any of these options displays a listing of the available assembler options.

- **?** `–h help` any of these options displays a listing of the available assembler options.

- **hc** `–hc filename` tells the assembler to copy the specified file for the assembly module. The file is inserted before source file statements. The copied file appears in the assembly listing files.

- **hi** `–hi filename` tells the assembler to include the specified file for the assembly module. The file is included before source file statements. The included file does not appear in the assembly listing files.
-i specifies a directory where the assembler can find files named by the .copy, .include, or .mlib directives. The format of the -i option is -i pathname. For more information, see subsection 3.4.1, -i Assembler Option, on page 3-8.

-l (lowercase L) produces a listing file.

-mf specifies that assembly calls use extended addressing.

-mg specifies that the source file contains algebraic instructions.

-q (quiet) suppresses the banner and all progress information.

-r -r[num] suppresses the assembler remark identified by num. A remark is an informational assembler message that is less severe than a warning. If you do not specify a value for num, all remarks will be suppressed.

-pw generates warnings for some assembly code pipeline conflicts. The assembler cannot detect all pipeline conflicts. Pipeline conflicts are detected in straight-line code only. Upon detection of a pipeline conflict, the assembler will print a warning, and report the latency slots (words) that need to be filled (by NOPs or other instructions) in order to resolve the conflict.

-s puts all defined symbols in the object file’s symbol table. The assembler usually puts only global symbols into the symbol table. When you use -s, symbols defined as labels or as assembly-time constants are also placed in the table.

-u -uname undefines the predefined constant name, which overrides any -d options for the specified constant.
-v  vvalue determines the processor for which instructions are built. Use one of the following for value: 541, 542, 543, 545, 545lp, 546lp, 548, 549.

-x  produces a cross-reference table and appends it to the end of the listing file; also adds cross-reference information to the object file for use by the cross-reference utility. If you do not request a listing file, the assembler creates one anyway.
3.4 Naming Alternate Files and Directories for Assembler Input

The .copy, .include, and .mlib directives tell the assembler to use code from external files. The .copy and .include directives tell the assembler to read source statements from another file, and the .mlib directive names a library that contains macro functions. Chapter 4, Assembler Directives, contains examples of the .copy, .include, and .mlib directives. The syntax for these directives is:

```
.copy "filename"
.include "filename"
.mlib "filename"
```

The filename names a copy/include file that the assembler reads statements from or a macro library that contains macro definitions. The filename may be a complete pathname, a partial pathname, or a filename with no path information. The assembler searches for the file in the following order:

1) The directory that contains the current source file. The current source file is the file being assembled when the .copy, .include, or .mlib directive is encountered.

2) Any directories named with the –i assembler option

3) Any directories set with the environment variables C54X_A_DIR and A_DIR

4) Any directories set with the environment variables C54X_C_DIR and C_DIR

You can augment the assembler’s directory search algorithm by using the –i assembler option or the C54X_A_DIR and A_DIR environment variables.

3.4.1 Using the –i Assembler Option

The –i assembler option names an alternate directory that contains copy/include files or macro libraries. The format of the –i option is as follows:

```
asm500 –ipathname source filename
```

Each –i option names one pathname. There is no limit to the number of paths that you can specify. In assembly source, you can use the .copy, .include, or .mlib directive without specifying path information. If the assembler doesn’t
find the file in the directory that contains the current source file, it searches the paths designated by the –i options.

For example, assume that a file called source.asm is in the current directory; source.asm contains the following directive statement:

```
.copy "copy.asm"
```

Assume that the file is stored in the following directory:

Windows™ c:\tools\files\copy.asm
UNIX               /tools/files/copy.asm

<table>
<thead>
<tr>
<th>Operating System</th>
<th>Enter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windows</td>
<td>asm500 –ic:\tools\files source.asm</td>
</tr>
<tr>
<td>UNIX</td>
<td>asm500 –i/tools/files source.asm</td>
</tr>
</tbody>
</table>

The assembler first searches for copy.asm in the current directory because source.asm is in the current directory. Then the assembler searches in the directory named with the –i option.

3.4.2 Using Environment Variables (C54X_A_DIR and A_DIR)

An environment variable is a system symbol that you define and assign a string to. The assembler uses the environment variables C54X_A_DIR and A_DIR to name alternate directories that contain copy/include files or macro libraries.

The assembler looks for the C54X_A_DIR environment variable first and then reads and processes it. If it does not find this variable, it reads the A_DIR environment variable and processes it. If both variables are set, the settings of the processor-specific variable are used. The processor-specific variable is useful when you are using Texas Instruments tools for different processors at the same time.

If the assembler doesn’t find C54X_A_DIR and/or A_DIR, it will then search for C54X_C_DIR and C_DIR.

The command for assigning the environment variable is as follows:

<table>
<thead>
<tr>
<th>Operating System</th>
<th>Enter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windows</td>
<td>set A_DIR= pathname;another pathname ...</td>
</tr>
<tr>
<td>UNIX</td>
<td>setenv A_DIR “pathname;another pathname ...”</td>
</tr>
</tbody>
</table>
Naming Alternate Files and Directories for Assembler Input

The *pathnames* are directories that contain copy/include files or macro libraries. You can separate the pathnames with a semicolon or with blanks. In assembly source, you can use the .copy, .include, or .mlib directive without specifying path information. If the assembler doesn’t find the file in the directory that contains the current source file or in directories named by –i, it searches the paths named by the environment variable.

For example, assume that a file called source.asm contains these statements:

```asciidoc
.copy "copy1.asm"
.copy "copy2.asm"
```

Assume that the files are stored in the following directories:

Windows        c:\tools\files\copy1.asm  
c:\dsys\copy2.asm

UNIX             /tools/files/copy1.asm  
/dsys/copy2.asm

You could set up the search path with the commands shown in the following table:

<table>
<thead>
<tr>
<th>Operating System</th>
<th>Enter</th>
</tr>
</thead>
</table>
| Windows          | set A_DIR=c:\dsys   
asm500 –ic:\tools\files source.asm                            |
| UNIX             | setenv A_DIR "/dsys"   
asm500 -i/tools/files source.asm                                |

The assembler first searches for copy1.asm and copy2.asm in the current directory because source.asm is in the current directory. Then the assembler searches in the directory named with the –i option and finds copy1.asm. Finally, the assembler searches the directory named with A_DIR and finds copy2.asm.

Note that the environment variable remains set until you reboot the system or reset the variable by entering one of these commands:

<table>
<thead>
<tr>
<th>Operating System</th>
<th>Enter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windows</td>
<td>set A_DIR=</td>
</tr>
<tr>
<td>UNIX</td>
<td>unsetenv A_DIR</td>
</tr>
</tbody>
</table>
3.5 Source Statement Format

TMS320C54x assembly language source programs consist of source statements that can contain assembler directives, assembly language instructions, macro directives, and comments. Source statement lines can be as long as the source file format allows.

Example source statements are shown below.

(a) Mnemonic instructions

```
SYM1 .set 2 ; Symbol SYM1 = 2.
Begin: LD #SYM1, AR1 ; Load AR1 with 2.
       .word 016h ; Initialize word (016h)
```

(b) Algebraic instructions

```
SYM1 .set 2 ; Symbol SYM1 = 2.
Begin: AR1 = #SYM1 ; Load AR1 with 2.
       .data
       .byte 016h ; Initialize word (016h)
```

3.5.1 Source Statement Syntax

A source statement can contain four ordered fields. The general syntax for source statements is as follows:

<table>
<thead>
<tr>
<th>Mnemonic syntax:</th>
<th>Algebraic syntax:</th>
</tr>
</thead>
<tbody>
<tr>
<td>[label] [:] mnemonic [operand list] [:comment]</td>
<td>[label] [:] instruction [:comment]</td>
</tr>
</tbody>
</table>

Follow these guidelines:

- All statements must begin with a label, a blank, an asterisk, or a semicolon.
- A statement containing an assembler directive must be specified entirely on one line.
- Labels are optional; if used, they must begin in column 1.
- One or more blanks must separate each field. Tab characters are equivalent to blanks.
- Comments are optional. Comments that begin in column 1 can begin with an asterisk or a semicolon (* or ;), but comments that begin in any other column must begin with a semicolon.
3.5.2 Label Field

Labels are optional for all assembly language instructions and for most (but not all) assembler directives. When used, a label must begin in column 1 of a source statement. A label can contain up to 32 alphanumeric characters (A–Z, a–z, 0–9, _, and $). Labels are case sensitive, and the first character cannot be a number. A label can be followed by a colon (:); the colon is not treated as part of the label name. If you don’t use a label, the first character position must contain a blank, a semicolon, or an asterisk.

When you use a label, its value is the current value of the section program counter (the label points to the statement it’s associated with). If, for example, you use the .word directive to initialize several words, a label would point to the first word. In the following example, the label Start has the value 40h.

```
.      .           .            .
.      .           .            .
.      .           .            .
9  000000  ; Assume some other code was assembled.
10  000040 000A  Start:  .word 0Ah,3,7
   000041 0003
   000042 0007
```

A label on a line by itself is a valid statement. The label assigns the current value of the section program counter to the label; this is equivalent to the following directive statement:

```
label .set $  ; $ provides the current value of the SPC.
```

When a label appears on a line by itself, it is assigned to the address of the instruction on the next line (the SPC is not incremented):

```
3  000043            Here:
4  000043 0003        .word 3
```

3.5.3 Mnemonic Instruction Fields

In mnemonic assembly, the label field is followed by the mnemonic and operand fields. These fields are described in the next two sections.

3.5.3.1 Mnemonic Field

The mnemonic field follows the label field. The mnemonic field must not start in column 1; if it does, it will be interpreted as a label. The mnemonic field can contain one of the following opcodes:

- Machine-instruction mnemonic (such as ABS, MPYU, STH)
- Assembler directive (such as .data, .list, .set)
- Macro directive (such as .macro, .var, .mexit)
- Macro call
3.5.3.2 Operand Field

The operand field is a list of operands that follow the mnemonic field. An operand can be a constant (see Section 3.6, Constants, on page 3-15), a symbol (see Section 3.8, Symbols, on page 3-19), or a combination of constants and symbols in an expression (see Section 3.9, Expressions, on page 3-25). You must separate operands with commas.

Operand Prefixes for Instructions

The assembler allows you to specify that a constant, symbol, or expression should be used as an address, an immediate value, or an indirect value. The following rules apply to the operands of instructions.

# prefix — the operand is an immediate value. If you use the # sign as a prefix, the assembler treats the operand as an immediate value. This is true even when the operand is a register or an address; the assembler treats the address as a value instead of using the contents of the address. This is an example of an instruction that uses an operand with the # prefix:

```
Label:  ADD #123, B
```

The operand #123 is an immediate value. The assembler adds 123 (decimal) to the contents of the specified accumulator.

* prefix — the operand is an indirect address. If you use the * sign as a prefix, the assembler treats the operand as an indirect address; that is, it uses the contents of the operand as an address. This is an example of an instruction that uses an operand with the * prefix:

```
Label:  LD *AR4, A
```

The operand *AR4 specifies an indirect address. The assembler goes to the address specified by the contents of register AR4 and then moves the contents of that location to the specified accumulator.

Immediate Value for Directives

The immediate value mode is primarily used with instructions. In some cases, it can also be used with the operands of directives.

It is not usually necessary to use the immediate value mode for directives. Compare the following statements:

```
ADD #10, A
.byte 10
```

In the first statement, the immediate value mode is necessary to tell the assembler to add the value 10 to accumulator A. In the second statement, however, immediate value is not used; the assembler expects the operand to be a value and initializes a byte with the value 10.
3.5.4 Algebraic Instruction Field

In algebraic assembly, the instruction field is a combination of the mnemonic and operand fields used in mnemonic syntax. You generally do not have a mnemonic followed by operands. Rather, the operands are part of the overall statement. The following items describe how to use the instruction field for algebraic syntax:

- Generally, operands are not separated by commas. Some algebraic instructions, however, consist of a mnemonic and operands. For algebraic statements of this type, commas are used to separate operands. For example, lms(Xmem, Ymem).

- Expressions that have more than one term that is used as a single operand must be delimited with parentheses. This rule does not apply to statements using a function call format, since they are already set off with parentheses. For example, consider \( A = B \ & \ #(1 \ll \text{sym}) \ll 5 \). The expression \( 1 \ll \text{sym} \) is used as a single operand and is therefore set off with parentheses.

- All register names are reserved.

- For algebraic instructions that consist of a mnemonic and operands, the mnemonic word is reserved.

3.5.5 Comment Field

A comment can begin in any column and extends to the end of the source line. A comment can contain any ASCII character, including blanks. Comments are printed in the assembly source listing, but they do not affect the assembly.

A source statement that contains only a comment is valid. If it begins in column 1, it can start with a semicolon (;) or asterisk (*). Comments that begin anywhere else on the line must begin with a semicolon. The asterisk identifies a comment only if it appears in column 1.
3.6 Constants

The assembler supports six types of constants:

- Binary integer
- Octal integer
- Decimal integer
- Hexadecimal integer
- Character
- Assembly time
- Floating-point

The assembler maintains each constant internally as a 32-bit quantity. Constants are not sign-extended. For example, the constant 0FFH is equal to 00FF (base 16) or 255 (base 10); it does not equal –1.

### 3.6.1 Binary Integers

A binary integer constant is a string of up to 16 binary digits (0s and 1s) followed by the suffix B (or \textit{b}). If fewer than 16 digits are specified, the assembler right justify the value and zero fills the unspecified bits. These are examples of valid binary constants:

- \texttt{00000000B} Constant equal to $0_{10}$ or $0_{16}$
- \texttt{0100000b} Constant equal to $32_{10}$ or $20_{16}$
- \texttt{01b} Constant equal to $1_{10}$ or $1_{16}$
- \texttt{1111	ext{1}000B} Constant equal to $248_{10}$ or $0F8_{16}$

### 3.6.2 Octal Integers

An octal integer constant is a string of up to 6 octal digits (0 through 7) prefixed with a 0 (zero) or suffixed with \textit{Q} or \textit{q}. These are examples of valid octal constants:

- \texttt{10Q} Constant equal to $8_{10}$ or $8_{16}$
- \texttt{100000Q} Constant equal to $32\ 768_{10}$ or $8\ 000_{16}$
- \texttt{226q} Constant equal to $150_{10}$ or $96_{16}$

Or, you can use C notation for octal constants:

- \texttt{010} Constant equal to $8_{10}$ or $8_{16}$
- \texttt{0100000} Constant equal to $32\ 768_{10}$ or $8\ 000_{16}$
- \texttt{0226} Constant equal to $150_{10}$ or $96_{16}$
3.6.3 Decimal Integers

A decimal integer constant is a string of decimal digits, ranging from \(-32\,768\) to \(65\,535\). These are examples of valid decimal constants:

- **1000** Constant equal to \(1000_{10}\) or \(3E8_{16}\)
- **\(-32768\)** Constant equal to \(-32\,768_{10}\) or \(8\,000_{16}\)
- **25** Constant equal to \(25_{10}\) or \(19_{16}\)

3.6.4 Hexadecimal Integers

A hexadecimal integer constant is a string of up to four hexadecimal digits followed by the suffix \(H\) (or \(h\)). Hexadecimal digits include the decimal values \(0–9\) and the letters \(A–F\) and \(a–f\). A hexadecimal constant must begin with a decimal value (0–9). If fewer than four hexadecimal digits are specified, the assembler right-justifies the bits. These are examples of valid hexadecimal constants:

- **78h** Constant equal to \(120_{10}\) or \(0078_{16}\)
- **0FH** Constant equal to \(15_{10}\) or \(000F_{16}\)
- **37AC\(h\)** Constant equal to \(14\,252_{10}\) or \(37AC_{16}\)

Or, you can use C notation for hexadecimal constants:

- **0x78** Constant equal to \(120_{10}\) or \(0078_{16}\)
- **0x0F** Constant equal to \(15_{10}\) or \(000F_{16}\)
- **0x37AC** Constant equal to \(14\,252_{10}\) or \(37AC_{16}\)

3.6.5 Character Constants

A character constant is a string of one or two characters enclosed in *single* quotes. The characters are represented internally as 8-bit ASCII characters. Two consecutive single quotes are required to represent each single quote that is part of a character constant. A character constant consisting only of two single quotes is valid and is assigned the value 0. If only one character is specified, the assembler right-justifies the bits. These are examples of valid character constants:

- **'a'** Represented internally as \(61_{16}\)
- **'C'** Represented internally as \(43_{16}\)
- **'''D'** Represented internally as \(2\,744_{16}\)
Note the difference between character constants and character strings (Section 3.7, Character Strings, on page 3-18, discusses character strings). A character constant represents a single integer value; a string is a list of characters.

3.6.6 Floating-Point Constants

A floating-point constant is a string of decimal digits, followed by an optional decimal point, fractional portion, and exponent portion. The syntax for a floating-point number is:

\[
[\ +\ |\ -\ ]\ [\ nnn\ ]\ .\ [\ nnn\ [\ E\ |\ e\ [\ +\ |\ -\ ]\ nnn\ ]\ ]
\]

Replace \( nnn \) with a string of decimal digits. You can precede \( nnn \) with a + or a -. You must specify a decimal point. For example, 3.e5 is valid, but 3e5 is not valid. The exponent indicates a power of 10. These are examples of valid constants:

- 3.0
- 3.14
- .3
- –0.314e13
- +314.59e–2
3.7 Character Strings

A character string is a string of characters enclosed in double quotes. Double quotes that are part of character strings are represented by two consecutive double quotes. The maximum length of a string varies and is defined for each directive that requires a character string. Characters are represented internally as 8-bit ASCII characters.

These are examples of valid character strings:

"sample program" defines the 14-character string sample program.
"PLAN ""C"" defines the 8-character string PLAN "C".

Character strings are used for the following:

- Filenames, as in .copy "filename"
- Section names, as in .sect "section name"
- Data initialization directives, as in .byte "charstring"
- Operands of .string directives
3.8 Symbols

Symbols are used as labels, constants, and substitution symbols. A symbol name is a string of up to 200 alphanumeric characters (A–Z, a–z, 0–9, $, and _). The first character in a symbol cannot be a number, and symbols cannot contain embedded blanks. The symbols you define are case sensitive; for example, the assembler recognizes ABC, Abc, and abc as three unique symbols. You can override case sensitivity with the –c assembler option. A symbol is valid only during the assembly in which it is defined, unless you use the .global directive to declare it as an external symbol.

3.8.1 Labels

Symbols used as labels become symbolic addresses associated with locations in the program. Labels used locally within a file must be unique. Mnemonic opcodes and assembler directive names (without the "." prefix) are valid label names.

Labels can also be used as the operands of .global, .ref, .def, or .bss directives; for example:

```
.global label1
label2  NOP
ADD     label1,B
B       label2
```

3.8.2 Symbolic Constants

Symbols can be set to constant values. By using constants, you can equate meaningful names with constant values. The .set and .struct/.tag/.endstruct directives enable you to set constants to symbolic names. Symbolic constants cannot be redefined. The following example shows how these directives can be used:

```
K     .set  1024 ;constant definitions
maxbuf .set  2*K
value  .set .  0
delta .set .  1

item  .struct ;item structure definition
    .int  value ;constant offsets value = 0
    .int  delta ;constant offsets delta = 1
i_len .endstruct

array .tag  item ;array declaration
    .bss array, i_len*K
```

The assembler also has several predefined symbolic constants; these are discussed in the next section.
3.8.3 Defining Symbolic Constants (–d Option)

The –d option equates a constant value with a symbol. The symbol can then be used in place of a value in assembly source. The format of the –d option is as follows:

\[ \text{asm500} \quad \text{–d} \ name = \text{[value]} \]

The \textit{name} is the name of the symbol you want to define. The \textit{value} is the value you want to assign to the symbol. If the \textit{value} is omitted, the symbol is set to 1.

Within assembler source, you may test the symbol with the following directives:

<table>
<thead>
<tr>
<th>Type of Test</th>
<th>Directive Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existence</td>
<td>\texttt{.if $isdefed(&quot;name&quot;)}</td>
</tr>
<tr>
<td>Nonexistence</td>
<td>\texttt{.if $isdefed(&quot;name&quot;) = 0}</td>
</tr>
<tr>
<td>Equal to value</td>
<td>\texttt{.if name = value}</td>
</tr>
<tr>
<td>Not equal to value</td>
<td>\texttt{.if name \neq value}</td>
</tr>
</tbody>
</table>

Note that the argument to the \$isdefed built-in function must be enclosed in quotes. The quotes cause the argument to be interpreted literally rather than as a substitution symbol.

3.8.4 Predefined Symbolic Constants

The assembler has several predefined symbols, including the following:

- \$ is the dollar sign character, represents the current value of the section program counter (SPC).
- \textit{Register symbols}, including AR0 – AR7
- \textit{Memory-mapped registers} are set up as symbols by the assembler.
3.8.5 Substitution Symbols

Symbols can be assigned a string value (variable). This enables you to alias character strings by equating them to symbolic names. Symbols that represent character strings are called substitution symbols. When the assembler encounters a substitution symbol, its string value is substituted for the symbol name. Unlike symbolic constants, substitution symbols can be redefined.

A string can be assigned to a substitution symbol anywhere within a program; for example:

```assembly
.asg "errct", AR2 ; register 2
.asg "+", INC ; indirect auto-increment
.asg "-", DEC ; indirect auto-decrement
```

When you are using macros, substitution symbols are important because macro parameters are actually substitution symbols that are assigned a macro argument. The following code shows how substitution symbols are used in macros:

```assembly
add2 .macro ADDRA,ADDRB ; add2 macro definition
    LD ADDRA, A
    ADD ADDRB, A
    STL A, ADDRB
    .endm

; add2 invocation
    add2 LOC1, LOC2 ; add "LOC1" argument to a second argument "LOC2".

; instructions for expanded macro:
;    LD LOC1, A
;    ADD LOC2, A
;    STL A, LOC2
```

For more information about macros, see Chapter 5, *Macro Language*. 
3.8.6 Local Labels

Local labels are special labels whose scope and effect are temporary. A local label can be defined in two ways:

- $n$, where $n$ is a decimal digit in the range of 0–9. For example, $4$ and $1$ are valid local labels.

- name?, where name is any legal symbol name as described above. The assembler replaces the question mark with a period followed by a unique number. When the source code is expanded, you will not see the unique number in the listing file. Your label appears with the question mark as it did in the macro definition. You cannot declare this label as global.

Normal labels must be unique (they can be declared only once), and they can be used as constants in the operand field. Local labels, however, can be undefined and defined again or automatically generated. Local labels cannot be defined by directives.

A local label can be undefined, or reset, in one of four ways:

- By using the .newblock directive
- By changing sections (using a .sect, .text, or .data directive)
- By entering an include file (specifying the .include or .copy directive)
- By leaving an include file (reaching the end of an included file)

Example 3–1 demonstrates the $n$ form of local labels. This example assumes that symbols ADDRA, ADDRB, ADDRC have been defined previously.

Example 3–1. $n$ Local Labels

(a) Code that uses a local label legally

<table>
<thead>
<tr>
<th>Label</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1</td>
<td>LD ADDRA, A ; Load Address A to Accumulator A.</td>
</tr>
<tr>
<td></td>
<td>SUB ADDRB, A ; Subtract Address B.</td>
</tr>
<tr>
<td></td>
<td>BC $1$, ALT ; If less than zero, branch to $1$;</td>
</tr>
<tr>
<td></td>
<td>LD ADDRB, A ; otherwise, load ADDRB to A</td>
</tr>
<tr>
<td></td>
<td>B $2$ ; and branch to $2$.</td>
</tr>
<tr>
<td>$2</td>
<td>LD ADDRA, A ; $1$: load ADDRA to Accumulator A.</td>
</tr>
<tr>
<td></td>
<td>ADD ADDRC, A ; $2$: add ADDRC.</td>
</tr>
<tr>
<td></td>
<td>.newblock ; Undefined $1$ so it can be used</td>
</tr>
<tr>
<td></td>
<td>; again.</td>
</tr>
<tr>
<td></td>
<td>BC $1$, ALT ; If less than zero, branch to $1$.</td>
</tr>
<tr>
<td></td>
<td>STL A, ADDRC ; Store ACC low in ADDRC.</td>
</tr>
<tr>
<td>$1</td>
<td>NOP</td>
</tr>
</tbody>
</table>

3-22
(b) Code that uses a local label illegally

<table>
<thead>
<tr>
<th>Label</th>
<th>Instruction</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1</td>
<td>LD ADDRA, A</td>
<td>$1: Load ADDRA To Accumulator A.</td>
</tr>
<tr>
<td></td>
<td>SUB ADDRB, A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BC $1, ALT</td>
<td>If less than zero, branch to $1;</td>
</tr>
<tr>
<td></td>
<td>LD ADDRB, A</td>
<td>otherwise, load ADDRB To A</td>
</tr>
<tr>
<td></td>
<td>B $2</td>
<td>and Branch to $2.</td>
</tr>
<tr>
<td>$1</td>
<td>LD ADDRA, A</td>
<td></td>
</tr>
<tr>
<td>$2</td>
<td>ADD ADDRC, A</td>
<td>$2: Add ADDRC.</td>
</tr>
<tr>
<td></td>
<td>BC $1, ALT</td>
<td>If less than 0, branch to $1.</td>
</tr>
<tr>
<td></td>
<td>STL A, ADDRC</td>
<td>Store Acc low in ADDRC.</td>
</tr>
<tr>
<td>$1</td>
<td>NOP</td>
<td>WRONG: $1 is multiply defined.</td>
</tr>
</tbody>
</table>

Local labels are especially useful in macros. If a macro contains a normal label and is called more than once, the assembler issues a multiple-definition error. If you use a local label and .newblock within a macro, however, the local label is used and reset each time the macro is expanded.

Up to ten local labels of the $n form can be in effect at one time. Local labels of the form name? are not limited. After you undefine a local label, you can define it and use it again. Local labels do not appear in the object code symbol table.

The maximum label length is shortened to allow for the unique suffix. If the macro is expanded fewer than 10 times, the maximum label length is 126 characters. If the macro is expanded from 10 to 99 times, the maximum label length is 125.

Example 3–2 demonstrates the name? form of a local label.
Example 3–2. Local Labels

```
; First definition of local label ‘mylab’
nop
mylab? nop
b mylab?

; Include file has second definition of ‘mylab’
.copy “a.inc”

; Third definition of ‘mylab’, reset upon exit from include
mylab? nop
b mylab?

; Fourth definition of ‘mylab’ in macro, macros use different namespace to avoid conflicts
mymac .macro
mylab? nop
b mylab?
.endm

; Macro invocation
mymac

; Reference to third definition of ‘mylab’, note that definition is not reset by macro invocation nor conflicts with same name defined in macro
b mylab?

; Changing section, allowing fifth definition of ‘mylab’
.sect “Secto_One”

mylab? .word 0
nop

; .newblock directive, allowing sixth definition of ‘mylab’
.newblock

mylab? .word 0
nop

```

3.9 Expressions

An expression is a constant, a symbol, or a series of constants and symbols separated by arithmetic operators. The range of valid expression values is –32 768 to 32 767. Three main factors influence the order of expression evaluation:

**Parentheses**

Expressions that are enclosed in parentheses are always evaluated first. 

*8 / (4 / 2) = 4, but 8 / 4 / 2 = 1*

You *cannot* substitute braces ({} or brackets ([])) for parentheses.

**Precedence groups**

The C54x assembler uses the same order of precedence as the C language does as summarized in Table 3–1. This differs from the order of precedence of other TMS320 assemblers. When parentheses do not determine the order of expression evaluation, the highest precedence operation is evaluated first.

*8 + 4 / 2 = 10*  
*(4 / 2 is evaluated first)*

**Left-to-right evaluation**

When parentheses and precedence groups do not determine the order of expression evaluation, the expressions are evaluated as happens in the C language.

*8 / 4 * 2 = 4, but 8 / (4 * 2) = 1*
Expressions

3.9.1 Operators

Table 3–1 lists the operators that can be used in expressions.

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Operators</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>Unary plus</td>
<td>Right to left</td>
</tr>
<tr>
<td>−</td>
<td>Minus</td>
<td>Left to right</td>
</tr>
<tr>
<td>~</td>
<td>1s complement</td>
<td></td>
</tr>
<tr>
<td>!</td>
<td>Logical negation</td>
<td></td>
</tr>
<tr>
<td>*</td>
<td>Multiplication</td>
<td>Left to right</td>
</tr>
<tr>
<td>/</td>
<td>Division</td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>Modulo</td>
<td></td>
</tr>
<tr>
<td>+</td>
<td>Addition</td>
<td>Left to right</td>
</tr>
<tr>
<td>−</td>
<td>Subtraction</td>
<td></td>
</tr>
<tr>
<td>&lt;&lt;</td>
<td>Left shift</td>
<td>Left to right</td>
</tr>
<tr>
<td>&gt;&gt;</td>
<td>Right shift</td>
<td></td>
</tr>
<tr>
<td>&lt;</td>
<td>Less than</td>
<td>Left to right</td>
</tr>
<tr>
<td>&lt;=</td>
<td>LT or equal</td>
<td></td>
</tr>
<tr>
<td>&gt;</td>
<td>Greater than</td>
<td></td>
</tr>
<tr>
<td>&gt;=</td>
<td>GT or equal</td>
<td></td>
</tr>
<tr>
<td>! =, =</td>
<td>Not equal to, equal to</td>
<td>Left to right</td>
</tr>
<tr>
<td>&amp;</td>
<td>Bitwise AND</td>
<td>Left to right</td>
</tr>
<tr>
<td>^</td>
<td>Bitwise exclusive OR</td>
<td>Left to right</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bitwise OR</td>
</tr>
</tbody>
</table>

Note: Unary +, −, and * have higher precedence than the binary forms.

3.9.2 Expression Overflow and Underflow

The assembler checks for overflow and underflow conditions when arithmetic operations are performed at assembly time. It issues a Value Truncated warning whenever an overflow or underflow occurs. The assembler does not check for overflow or underflow in multiplication.
3.9.3 Well-Defined Expressions

Some assembler directives require well-defined expressions as operands. Well-defined expressions contain only symbols or assembly-time constants that are defined before they are encountered in the expression. The evaluation of a well-defined expression must be absolute.

Example 3–3. Well-Defined Expressions

```
.data
label1 .word 0
      .word 1
      .word 2
label2 .word 3
X      .set 50h
goodsym1 .set 100h + X : Because value of X is defined before referenced, this is a valid well-defined expression

goodsym2 .set $ ; All references to previously defined local
goodsym3 .set label1 ; labels, including the current SPC ($), are considered to be well-defined.
goodsym4 .set label2 - label1 ; Although label1 and label2 are not absolute symbols, because they are local labels defined in the same section, their difference can be computed by the assembler. The difference is absolute, so the expression is well-defined.
```

3.9.4 Conditional Expressions

The assembler supports relational operators that can be used in any expression; they are especially useful for conditional assembly. Relational operators include the following:

- `=` Equal to
- `!=` Not equal to
- `<` Less than
- `<=` Less than or equal to
- `>` Greater than
- `>=` Greater than or equal to

Conditional expressions evaluate to 1 if true and 0 if false; they can be used only on operands of equivalent types, for example, absolute value compared to absolute value, but not absolute value compared to relocatable value.
Expressions

3.9.5 Relocatable Symbols and Legal Expressions

Table 3–2 summarizes valid operations on absolute, relocatable, and external symbols. An expression cannot contain multiplication or division by a relocatable or external symbol. An expression cannot contain unresolved symbols that are relocatable to other sections.

Symbols or registers that have been defined as global with the .global directive can also be used in expressions; in Table 3–2, these symbols and registers are referred to as external.

Relocatable registers can be used in expressions; the addresses of these registers are relocatable with respect to the register section they were defined in, unless they have been declared as external.

Table 3–2. Expressions With Absolute and Relocatable Symbols

<table>
<thead>
<tr>
<th>If A is...</th>
<th>and</th>
<th>If B is...</th>
<th>, then</th>
<th>A + B is...</th>
<th>and</th>
<th>A – B is...</th>
</tr>
</thead>
<tbody>
<tr>
<td>absolute</td>
<td>absolute</td>
<td>absolute</td>
<td>absolute</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>absolute</td>
<td>external</td>
<td>external</td>
<td>illegal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>absolute</td>
<td>relocatable</td>
<td>relocatable</td>
<td>illegal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>relocatable</td>
<td>absolute</td>
<td>relocatable</td>
<td>relocatable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>relocatable</td>
<td>relocatable</td>
<td>illegal</td>
<td>absolute †</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>relocatable</td>
<td>external</td>
<td>illegal</td>
<td>illegal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>external</td>
<td>absolute</td>
<td>external</td>
<td>external</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>external</td>
<td>relocatable</td>
<td>illegal</td>
<td>illegal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>external</td>
<td>external</td>
<td>illegal</td>
<td>illegal</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† A and B must be in the same section; otherwise, this is illegal.

Following are examples of expressions that use relocatable and absolute symbols. These examples use four symbols that are defined in the same section:

```assembly
.globl extern_1     ; Defined in an external module
intern_1: .word "D" ; Relocatable, defined in current module
LAB1: .set 2        ; LAB1 = 2
intern_2             ; Relocatable, defined in current module
```

Example 1

The statements in this example use an absolute symbol, LAB1 (which is defined above to have a value of 2). The first statement loads the value 51 into the accumulator:

```
LD #LAB1 + ((4+3) * 7), A ; ACC A = 51
LD #LAB1 + 4 + (3*7), A ; ACC A = 27
```
Expressions

Example 2

All legal expressions can be reduced to one of two forms:

relocatable symbol ± absolute symbol

or

absolute value

Unary operators can be applied only to absolute values; they cannot be applied to relocatable symbols. Expressions that cannot be reduced to contain only one relocatable symbol are illegal. The first statement in the following example is valid; the statements that follow it are invalid.

LD extern_1 - 10, B ; Legal
LD 10-extern_1, B ; Can’t negate reloc. symbol
LD -(intern_1), B ; Can’t negate reloc. symbol
LD extern_1/10, B ; / isn’t additive operator
LD intern_1 + extern_1, B ; Multiple relocatables

Example 3

The first statement below is legal; although intern_1 and intern_2 are relocatable, their difference is absolute because they’re in the same section. Subtracting one relocatable symbol from another reduces the expression to relocatable symbol + absolute value. The second statement is illegal because the sum of two relocatable symbols is not an absolute value.

LD intern_1 – intern_2 + extern_1, B ; Legal
LD intern_1 + intern_2 + extern_1, B ; Illegal

Example 4

An external symbol’s placement is important to expression evaluation. Although the statement below is similar to the first statement in the previous example, it is illegal because of left-to-right operator precedence; the assembler attempts to add intern_1 to extern_1.

LD intern_1 + extern_1 - intern_2, B ; Illegal
3.10 Built-in Functions

The assembler supports built-in functions for conversions and various math computations. Table 3–3 describes the built-in functions. Note that expr must be a constant value. See Table 5–1 for a description of the assembler’s non-mathematical built-in functions.

Table 3–3. Assembler Built-In Math Functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$acos(expr)</td>
<td>returns the arc cosine of expr as a floating-point value</td>
</tr>
<tr>
<td>$asin(expr)</td>
<td>returns the arc sine of expr as a floating-point value</td>
</tr>
<tr>
<td>$atan(expr)</td>
<td>returns the arc tangent of expr as a floating-point value</td>
</tr>
<tr>
<td>$atan2(expr)</td>
<td>returns the arc tangent of expr as a floating-point value (–pi to pi)</td>
</tr>
<tr>
<td>$ceil(expr)</td>
<td>returns the smallest integer that is not less than the expression</td>
</tr>
<tr>
<td>$cosh(expr)</td>
<td>returns the hyperbolic cosine of expr as a floating-point value</td>
</tr>
<tr>
<td>$cos(expr)</td>
<td>returns the cosine of expr as a floating-point value</td>
</tr>
<tr>
<td>$cvf(expr)</td>
<td>converts expr to floating-point value</td>
</tr>
<tr>
<td>$cvi(expr)</td>
<td>converts expr to integer value</td>
</tr>
<tr>
<td>$exp(expr)</td>
<td>returns the result of raising e to the expr power</td>
</tr>
<tr>
<td>$fabs(expr)</td>
<td>returns absolute value of expr as a floating-point value</td>
</tr>
<tr>
<td>$floor(expr)</td>
<td>returns the largest integer that is not greater than the expression</td>
</tr>
<tr>
<td>$fmod(expr1, expr2)</td>
<td>returns the remainder after dividing expr1 and expr2</td>
</tr>
<tr>
<td>$int(expr)</td>
<td>returns 1 if expr has an integer result</td>
</tr>
<tr>
<td>$ldexp(expr1, expr2)</td>
<td>returns the result of expr1 multiplied by 2 raised to the expr2 power</td>
</tr>
<tr>
<td>$log10(expr)</td>
<td>returns the base 10 logarithm of expr</td>
</tr>
<tr>
<td>$log(expr)</td>
<td>returns the natural logarithm of expr</td>
</tr>
<tr>
<td>$max(expr1, expr2)</td>
<td>returns the maximum of 2 expressions</td>
</tr>
<tr>
<td>$min(expr1, expr2)</td>
<td>returns the minimum of 2 expressions</td>
</tr>
</tbody>
</table>
Table 3–3. Assembler Built-In Math Functions (Continued)

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{pow}(\text{expr1, expr2})$</td>
<td>raises $\text{expr1}$ to the power $\text{expr2}$</td>
</tr>
<tr>
<td>$\text{round}(\text{expr})$</td>
<td>returns the result of $\text{expr}$ rounded to the nearest integer</td>
</tr>
<tr>
<td>$\text{sgn}(\text{expr})$</td>
<td>returns the sign of $\text{expr}$</td>
</tr>
<tr>
<td>$\text{sin}(\text{expr})$</td>
<td>returns the sine of $\text{expr}$ as a floating-point value</td>
</tr>
<tr>
<td>$\text{sinh}(\text{expr})$</td>
<td>returns the hyperbolic sine of $\text{expr}$ as a floating-point value</td>
</tr>
<tr>
<td>$\text{sqrt}(\text{expr})$</td>
<td>returns the square root of $\text{expr}$ as a floating-point value</td>
</tr>
<tr>
<td>$\text{tan}(\text{expr})$</td>
<td>returns the tangent of $\text{expr}$ as a floating-point value</td>
</tr>
<tr>
<td>$\text{tanh}(\text{expr})$</td>
<td>returns the hyperbolic tangent of $\text{expr}$ as a floating-point value</td>
</tr>
<tr>
<td>$\text{trunc}(\text{expr})$</td>
<td>returns the result of $\text{expr}$ rounded toward zero</td>
</tr>
</tbody>
</table>
3.11 Loading Values into Extended Program Memory

The assembler accepts a pseudo-op, LDX, for loading the value of a label, function, etc. that resides (or may reside) in extended program memory. LDX is used to load the upper 8 bits of a 24-bit address.

For example, if a function, F1, is in extended program memory (which is 24 bits instead of 16), the value or address of F1 may be loaded as follows:

LDX #F1,16,A ;loads the upper 8 bits of the 24-bit address of F1
OR #F1,A,A ;adds in the lower 16 bits of the address of F1
BACC A ;all 24 bits of F1 have been loaded into accumulator A

Note that it is necessary to use both LDX and OR to load the entire 24-bit address.
3.12 Source Listings

A source listing shows source statements and the object code they produce. To obtain a listing file, invoke the assembler with the –l (lowercase L) option.

Two banner lines, a blank line, and a title line are at the top of each source listing page. Any title supplied by a .title directive is printed on the title line; a page number is printed to the right of the title. If you don’t use the .title directive, the name of the source file is printed. The assembler inserts a blank line below the title line.

Each line in the source file may produce a line in the listing file that shows a source statement number, an SPC value, the object code assembled, and the source statement. A source statement may produce more than one word of object code. The assembler lists the SPC value and object code on a separate line for each additional word. Each additional line is listed immediately following the source statement line.

Field 1: Source Statement Number

Line Number

The source statement number is a decimal. The assembler numbers source lines as it encounters them in the source file; some statements increment the line counter but are not listed. (For example, .title statements and statements following a .nolist are not listed.) The difference between two consecutive source line numbers indicates the number of intervening statements in the source file that are not listed.

Include File Letter

The assembler may precede a line with a letter; the letter indicates that the line is assembled from an included file.

Nesting Level Number

The assembler may precede a line with a number; the number indicates the nesting level of macro expansions or loop blocks.

Field 2: Section Program Counter

This field contains the section program counter (SPC) value, which is hexadecimal. All sections (.text, .data, .bss, and named sections) maintain separate SPCs. Some directives do not affect the SPC and leave this field blank.
Field 3: Object Code

This field contains the hexadecimal representation of the object code. All machine instructions and directives use this field to list object code. This field also indicates the relocation type by appending one of the following characters to the end of the field:

- ! undefined external reference
- ' .text relocatable
- " .data relocatable
- + .sect relocatable
- – .bss, .usect relocatable
- % complex relocation expression

Field 4: Source Statement Field

This field contains the characters of the source statement as they were scanned by the assembler. Spacing in this field is determined by the spacing in the source statement.

Example 3–4 shows an assembler listing with each of the four fields identified.
Example 3–4. Assembler Listing

(a) Mnemonic example

```
.initmac .macro
  * initialize macro
  SSBX OVM ; disable oflow
  LD #0, DP ; dp = 0
  LD #7, ARP ; arp = ar7
  LD #037h, A ; acc = 03fh
  RSBX INTM ; enable ints
.endm

17 0000000 .sect "reset"
18 0000000 F073 RESET: B init
0000001 0008+
19 0000002 F073 INT0: B ISR0
0000003 0000!
20 0000004 F073 INT1: B ISR1
0000005 0000!
21 0000006 F073 INT2: B ISR2
0000007 0000!
22
23 24 0000000 .sect "ints"
25 0000000 F073 TINT B time
0000001 0000!
26 0000002 F073 RINT B rcv
0000003 0000!
27 0000004 F073 XINT B xmt
0000005 0000!
28 0000006 F073 USER B proc
0000007 0000!
29
30 31 000008 init: initmac
1  * initialize macro
1 000008 F7B9 SSBX OVM ; disable oflow
1 000009 EA00 LD #0, DP ; dp = 0
1 00000a F4A7 LD #7, ARP ; arp = ar7
1 00000b EB37 LD #037h, A ; acc = 03fh
1 00000c F6BB RSBX INTM ; enable ints
```

Source Listings
Example 3–4. Assembler Listing (Continued)

(b) Algebraic example

```assembly
initmac .macro
  * initialize macro
  OVM = 1 ; disable oflow
  DP = #0 ; dp = 0
  ARP = #7 ; arp = ar7
  A = #037h ; acc = 03fh
  INTM = 0 ; enable ints
.endm

reset: goto init
INT0: goto ISR0
INT1: goto ISR1
INT2: goto ISR2
INTS: goto proc
```
3.13 Cross-Reference Listings

A cross-reference listing shows symbols and their definitions. To obtain a cross-reference listing, invoke the assembler with the –x option or use the .option directive. The assembler will append the cross-reference to the end of the source listing.

Note that when the assembler generates a cross-reference listing for an assembly file that contains .include directives, it keeps a record of the include file and line number in which a symbol is defined/referenced. It does this by assigning a letter reference (A, B, C, etc.) for each include file. The letters are assigned in the order in which the .include directives are encountered in the assembly source file.

Example 3–5. Sample Cross-Reference Listing

<table>
<thead>
<tr>
<th>LABEL</th>
<th>VALUE</th>
<th>DEFN</th>
<th>REF</th>
</tr>
</thead>
<tbody>
<tr>
<td>INT0</td>
<td>0002+</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>INT1</td>
<td>0004+</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>INT2</td>
<td>0006+</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>ISR0</td>
<td>REF</td>
<td></td>
<td>4 14</td>
</tr>
<tr>
<td>ISR1</td>
<td>REF</td>
<td></td>
<td>4 15</td>
</tr>
<tr>
<td>ISR2</td>
<td>REF</td>
<td></td>
<td>4 16</td>
</tr>
<tr>
<td>RESET</td>
<td>0000+</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>RINT</td>
<td>0002+</td>
<td>24</td>
<td>3</td>
</tr>
<tr>
<td>TINT</td>
<td>0000+</td>
<td>23</td>
<td>3</td>
</tr>
<tr>
<td>VECSS</td>
<td>0006+</td>
<td>26</td>
<td>3</td>
</tr>
<tr>
<td>XINT</td>
<td>0004+</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>init</td>
<td>0000+</td>
<td>34</td>
<td>13</td>
</tr>
</tbody>
</table>

Label column contains each symbol that was defined or referenced during the assembly.

Value column contains a hexadecimal number, which is the value assigned to the symbol or a name that describes the symbol’s attributes. A value may also be followed by a character that describes the symbol’s attributes. Table 3–4 lists these characters and names.

Definition (DEFN) column contains the statement number that defines the symbol. This column is blank for undefined symbols.

Reference (REF) column lists the line numbers of statements that reference the symbol. A blank in this column indicates that the symbol was never used.
Table 3–4. Symbol Attributes

<table>
<thead>
<tr>
<th>Character or Name</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>REF</td>
<td>External reference (.global symbol)</td>
</tr>
<tr>
<td>UNDF</td>
<td>Undefined</td>
</tr>
<tr>
<td>'</td>
<td>Symbol defined in a .text section</td>
</tr>
<tr>
<td>&quot;</td>
<td>Symbol defined in a .data section</td>
</tr>
<tr>
<td>+</td>
<td>Symbol defined in a .sect section</td>
</tr>
<tr>
<td>–</td>
<td>Symbol defined in a .bss or .usect section</td>
</tr>
</tbody>
</table>

For example, the following source files:

(a) incl0.asm

```asm
.globl ABC
nop
nop
```

(b) incl1.asm

```asm
.globl ABC
ld ABC, A
```

(c) incl2.asm

```asm
.globl ABC
stl A,ABC
```

(d) xref.asm

```asm
start:
    .include "incl0.asm"
    .include "incl1.asm"
    add #10, A
    .include "incl2.asm"

    nop
    nop
    b start

.globl start
.bss ABC,2
```
produce the cross-reference listing below. The A in the cross-reference listing refers to incl0.asm (the first file included). B refers to incl1.asm; C refers to incl2.asm.

```
xref.asm                        PAGE     1
1 000000        start:
2                  .include "incl0.asm"
3                  .include "incl1.asm"
4  000003 F000    add #10,A
      000004 000A
5                  .include "incl2.asm"
6
7  000006 F495      nop
8  000007 F495      nop
9  000008 F073      b start
      000009 0000!
10
11                  .global start
12
13  000000          .bss ABC,2
```

```
xref.asm                        PAGE     2

<table>
<thead>
<tr>
<th>LABEL</th>
<th>VALUE</th>
<th>DEFN</th>
<th>REF</th>
</tr>
</thead>
<tbody>
<tr>
<td>.TMS320C540</td>
<td>000001</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>.TMS320C541</td>
<td>000000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>.TMS320C542</td>
<td>000000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>.TMS320C543</td>
<td>000000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>.TMS320C544</td>
<td>000000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>.TMS320C545</td>
<td>000000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>.TMS320C546</td>
<td>000000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>.TMS320C546LP</td>
<td>000000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>.TMS320C548</td>
<td>000000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>.start</td>
<td>000000’</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

| ABC         | 000000–| 12 A 1 B 1 B 2 |
|             |       | C 1 C 2       |

| __far_mode  | 000000| 0    |
| __lflags    | 000000| 0    |
| start       | REF   | 9 11 |
```
Assembler directives supply data to the program and control the assembly process. Assembler directives enable you to do the following:

- Assemble code and data into specified sections
- Reserve space in memory for uninitialized variables
- Control the appearance of listings
- Initialize memory
- Assemble conditional blocks
- Declare global variables
- Specify libraries from which the assembler can obtain macros
- Examine symbolic debugging information

This chapter is divided into two parts: the first part (Sections 4.1 through 4.10) describes the directives according to function, and the second part (Section 4.11) is an alphabetical reference.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1 Directives Summary</td>
<td>4-2</td>
</tr>
<tr>
<td>4.2 Compatibility With the TMS320C1x/C2x/C2xx/C5x Assembler Directives</td>
<td>4-8</td>
</tr>
<tr>
<td>4.3 Directives That Define Sections</td>
<td>4-9</td>
</tr>
<tr>
<td>4.4 Directives That Initialize Constants</td>
<td>4-11</td>
</tr>
<tr>
<td>4.5 Directives That Align the Section Program Counter</td>
<td>4-15</td>
</tr>
<tr>
<td>4.6 Directives That Format the Output Listing</td>
<td>4-17</td>
</tr>
<tr>
<td>4.7 Directives That Reference Other Files</td>
<td>4-19</td>
</tr>
<tr>
<td>4.8 Conditional Assembly Directives</td>
<td>4-20</td>
</tr>
<tr>
<td>4.9 Assembly-Time Symbol Directives</td>
<td>4-21</td>
</tr>
<tr>
<td>4.10 Miscellaneous Directives</td>
<td>4-23</td>
</tr>
<tr>
<td>4.11 Directives Reference</td>
<td>4-25</td>
</tr>
</tbody>
</table>
4.1 Directives Summary

This section summarizes the assembler directives.

Assembler directives and their parameters must be specified entirely on one line.

Besides the assembler directives documented here, the TMS320C54x™ software tools support the following directives:

- The assembler uses several directives for macros. The macro directives are listed in this chapter, but they are described in detail in Chapter 5, Macro Language.
- The absolute lister also uses directives. Absolute listing directives are not entered by the user but are inserted into the source program by the absolute lister. Chapter 8, Absolute Lister Description, discusses these directives; they are not discussed in this chapter.
- The C/C++ compiler uses directives for symbolic debugging. Unlike other directives, symbolic debugging directives are not used in most assembly language programs. Appendix B, Symbolic Debugging Directives, discusses these directives; they are not discussed in this chapter.

Note: Labels and Comments in Syntax

In most cases, a source statement that contains a directive may also contain a label and a comment. Labels begin in the first column (they are the only elements, except comments, that can appear in the first column), and comments must be preceded by a semicolon or an asterisk if the comment is the only statement on the line. To improve readability, labels and comments are not shown as part of the directive syntax. For some directives, however, a label is required and will be shown in the syntax.

Table 4–1. Assembler Directives Summary

(a) Directives that define sections

<table>
<thead>
<tr>
<th>Mnemonic and Syntax</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>.bss symbol, size in words [, blocking] [, alignment ]</code></td>
<td>Reserve size words in the .bss (uninitialized data) section</td>
<td>4-30</td>
</tr>
<tr>
<td><code>.clink [&quot;section name&quot;]</code></td>
<td>Enables conditional linking for the current or specified section</td>
<td>4-34</td>
</tr>
<tr>
<td><code>.data</code></td>
<td>Assemble into the .data (initialized data) section</td>
<td>4-39</td>
</tr>
<tr>
<td><code>.sect [&quot;section name&quot;]</code></td>
<td>Assemble into a named (initialized) section</td>
<td>4-80</td>
</tr>
<tr>
<td><code>.text</code></td>
<td>Assemble into the .text (executable code) section</td>
<td>4-90</td>
</tr>
<tr>
<td><code>symbol .usect [&quot;section name&quot;, size in words [, blocking] [,alignment ]</code></td>
<td>Reserve size words in a named (uninitialized) section</td>
<td>4-95</td>
</tr>
</tbody>
</table>
## Table 4–1. Assembler Directives Summary (Continued)

(b) Directives that initialize constants (data and memory)

<table>
<thead>
<tr>
<th>Mnemonic and Syntax</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>.bes size in bits</td>
<td>Reserve size bits in the current section; note that a label points to the last addressable word in the reserved space</td>
<td>4-82</td>
</tr>
<tr>
<td>.byte value1 [,...,value_n]</td>
<td>Initialize one or more successive words in the current section</td>
<td>4-33</td>
</tr>
<tr>
<td>.char value1 [,...,value_n]</td>
<td>Initialize one or more 64-bit, IEEE double-precision, floating-point constants</td>
<td>4-40</td>
</tr>
<tr>
<td>.double value1 [,...,value_n]</td>
<td>Initialize one or more 64-bit, IEEE double-precision, floating-point constants</td>
<td>4-40</td>
</tr>
<tr>
<td>.field value [size in bits]</td>
<td>Initialize a variable-length field</td>
<td>4-47</td>
</tr>
<tr>
<td>.float value1 [,...,value_n]</td>
<td>Initialize one or more 32-bit, IEEE single-precision, floating-point constants</td>
<td>4-50</td>
</tr>
<tr>
<td>.half value1 [,...,value_n]</td>
<td>Initialize one or more 16-bit integers</td>
<td>4-54</td>
</tr>
<tr>
<td>.short value1 [,...,value_n]</td>
<td>Initialize one or more 16-bit integers</td>
<td>4-58</td>
</tr>
<tr>
<td>.int value1 [,...,value_n]</td>
<td>Initialize one or more 32-bit integers</td>
<td>4-64</td>
</tr>
<tr>
<td>.long value1 [,...,value_n]</td>
<td>Initialize one or more text strings (packed).</td>
<td>4-85</td>
</tr>
<tr>
<td>.pstring ”string1” [,...,”string_n”]</td>
<td>Reserve size bits in the current section; note that a label points to the beginning of the reserved space</td>
<td>4-82</td>
</tr>
<tr>
<td>.string ”string1” [,...,”string_n”]</td>
<td>Initialize one or more text strings</td>
<td>4-85</td>
</tr>
<tr>
<td>.ubyte value1 [,...,value_n]</td>
<td>Initialize one or more successive words in the current section</td>
<td>4-33</td>
</tr>
<tr>
<td>.uchar value1 [,...,value_n]</td>
<td>Initialize one or more unsigned 16-bit integers</td>
<td>4-54</td>
</tr>
<tr>
<td>.uhalf value1 [,...,value_n]</td>
<td>Initialize one or more unsigned 16-bit integers</td>
<td>4-58</td>
</tr>
<tr>
<td>.ushort value1 [,...,value_n]</td>
<td>Initialize one or more unsigned 32-bit integers</td>
<td>4-64</td>
</tr>
<tr>
<td>.uint value1 [,...,value_n]</td>
<td>Initialize one or more unsigned 32-bit integers</td>
<td>4-64</td>
</tr>
<tr>
<td>.ulong value1 [,...,value_n]</td>
<td>Initialize one or more unsigned 32-bit integers</td>
<td>4-64</td>
</tr>
<tr>
<td>.uword value1 [,...,value_n]</td>
<td>Initialize one or more unsigned 16-bit integers.</td>
<td>4-58</td>
</tr>
<tr>
<td>.word value1 [,...,value_n]</td>
<td>Initialize one or more unsigned 16-bit integers.</td>
<td>4-58</td>
</tr>
<tr>
<td>.xfloat value1 [,...,value_n]</td>
<td>Initialize one or more 32-bit, IEEE single-precision, floating-point constants, but do not align on long word boundary.</td>
<td>4-50</td>
</tr>
<tr>
<td>.xlong value1 [,...,value_n]</td>
<td>Initialize one or more 32-bit integers, but do not align on long word boundary.</td>
<td>4-64</td>
</tr>
</tbody>
</table>
Table 4–1. Assembler Directives Summary (Continued)

(c) Directives that align the section program counter (SPC)

<table>
<thead>
<tr>
<th>Mnemonic and Syntax</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>.align [size in words]</td>
<td>Align the SPC on a word boundary specified by the parameter; the parameter must be a power of 2, or default to page boundary. Aligns to word (1), even (2), etc.</td>
<td>4-27</td>
</tr>
<tr>
<td>.even</td>
<td>Align the SPC to a word boundary.</td>
<td>4-27</td>
</tr>
</tbody>
</table>

(d) Directives that format the output listing

<table>
<thead>
<tr>
<th>Mnemonic and Syntax</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>.drlist</td>
<td>Enable listing of all directive lines (default)</td>
<td>4-41</td>
</tr>
<tr>
<td>.drnolist</td>
<td>Suppress listing of certain directive lines</td>
<td>4-41</td>
</tr>
<tr>
<td>.fclist</td>
<td>Allow false conditional code block listing (default)</td>
<td>4-46</td>
</tr>
<tr>
<td>.fcnolist</td>
<td>Suppress false conditional code block listing</td>
<td>4-46</td>
</tr>
<tr>
<td>.length page length</td>
<td>Set the page length of the source listing</td>
<td>4-61</td>
</tr>
<tr>
<td>.list</td>
<td>Restart the source listing</td>
<td>4-62</td>
</tr>
<tr>
<td>.mlist</td>
<td>Allow macro listings and loop blocks (default)</td>
<td>4-70</td>
</tr>
<tr>
<td>.mnolist</td>
<td>Suppress macro listings and loop blocks</td>
<td>4-70</td>
</tr>
<tr>
<td>.nolist</td>
<td>Stop the source listing</td>
<td>4-62</td>
</tr>
<tr>
<td>.option {B</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>.page</td>
<td>Eject a page in the source listing</td>
<td>4-78</td>
</tr>
<tr>
<td>.sslist</td>
<td>Allow expanded substitution symbol listing</td>
<td>4-83</td>
</tr>
<tr>
<td>.ssnolist</td>
<td>Suppress expanded substitution symbol listing (default)</td>
<td>4-83</td>
</tr>
<tr>
<td>.tab size</td>
<td>Set tab size</td>
<td>4-89</td>
</tr>
<tr>
<td>.title &quot;string&quot;</td>
<td>Print a title in the listing page heading</td>
<td>4-91</td>
</tr>
<tr>
<td>.width page width</td>
<td>Set the page width of the source listing</td>
<td>4-61</td>
</tr>
</tbody>
</table>
Table 4–1. Assembler Directives Summary (Continued)

(e) Directives that reference other files

<table>
<thead>
<tr>
<th>Mnemonic and Syntax</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>.copy [&quot;filename&quot;]</td>
<td>Include source statements from another file</td>
<td>4-36</td>
</tr>
<tr>
<td>.def symbol1, ..., symboln</td>
<td>Identify one or more symbols that are defined in the current module and may be used in other modules</td>
<td>4-51</td>
</tr>
<tr>
<td>.global symbol1, ..., symboln</td>
<td>Identify one or more global (external) symbols</td>
<td>4-51</td>
</tr>
<tr>
<td>.include [&quot;filename&quot;]</td>
<td>Include source statements from another file</td>
<td>4-36</td>
</tr>
<tr>
<td>.ref symbol1, ..., symboln</td>
<td>Identify one or more symbols that are used in the current module but may be defined in another module</td>
<td>4-51</td>
</tr>
</tbody>
</table>

(f) Directives that define macros

<table>
<thead>
<tr>
<th>Mnemonic and Syntax</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>.macro</td>
<td>Identify the source statement as the first line of a macro definition. You must place .macro in the opcode field</td>
<td>4-67</td>
</tr>
<tr>
<td>.mlib [&quot;filename&quot;]</td>
<td>Define macro library</td>
<td>4-68</td>
</tr>
<tr>
<td>.mexit</td>
<td>Go to .endm. This directive is useful when error testing confirms that macro expansion will fail.</td>
<td>5-3</td>
</tr>
<tr>
<td>.endm</td>
<td>End .macro code block</td>
<td>4-44</td>
</tr>
<tr>
<td>.var</td>
<td>Define a local macro substitution symbol</td>
<td>4-98</td>
</tr>
</tbody>
</table>

(g) Directives that control conditional assembly

<table>
<thead>
<tr>
<th>Mnemonic and Syntax</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>.break [well-defined expression]</td>
<td>End .loop assembly if condition is true. The .break construct is optional.</td>
<td>4-66</td>
</tr>
<tr>
<td>.else</td>
<td>Assemble code block if the .if condition is false. The .else construct is optional. This directive can be used as the default case in a conditional block.</td>
<td>4-56</td>
</tr>
<tr>
<td>.elseif well-defined expression</td>
<td>Assemble code block if the .if condition is false and the .elseif condition is true. The .elseif construct is optional.</td>
<td>4-56</td>
</tr>
<tr>
<td>.endif</td>
<td>End .if code block</td>
<td>4-56</td>
</tr>
<tr>
<td>.endloop</td>
<td>End .loop code block</td>
<td>4-66</td>
</tr>
<tr>
<td>.if well-defined expression</td>
<td>Assemble code block if the condition is true</td>
<td>4-56</td>
</tr>
<tr>
<td>.loop [well-defined expression]</td>
<td>Begin repeatable assembly of a code block. The well-defined expression is a loop count.</td>
<td>4-66</td>
</tr>
</tbody>
</table>
Table 4–1. Assembler Directives Summary (Continued)

(h) Directives that define symbols at assembly time

<table>
<thead>
<tr>
<th>Mnemonic and Syntax</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>.asg &quot;character string&quot;, substitution symbol</td>
<td>Assign a character string to a substitution symbol</td>
<td>4-28</td>
</tr>
<tr>
<td>.endstruct</td>
<td>End structure definition</td>
<td>4-86</td>
</tr>
<tr>
<td>.endunion</td>
<td>End union definition</td>
<td>4-92</td>
</tr>
<tr>
<td>.equ</td>
<td>Equate a value with a symbol</td>
<td>4-81</td>
</tr>
<tr>
<td>.eval well-defined expression, substitution symbol</td>
<td>Perform arithmetic on numeric substitution symbols</td>
<td>4-28</td>
</tr>
<tr>
<td>.label symbol</td>
<td>Define a load-time relocatable label in a section</td>
<td>4-60</td>
</tr>
<tr>
<td>.set</td>
<td>Equate a value with a symbol</td>
<td>4-81</td>
</tr>
<tr>
<td>.struct</td>
<td>Begin structure definition</td>
<td>4-86</td>
</tr>
<tr>
<td>.tag</td>
<td>Assign structure attributes to a label</td>
<td>4-86</td>
</tr>
<tr>
<td>.union</td>
<td>Begin union definition</td>
<td>4-92</td>
</tr>
</tbody>
</table>
Table 4–1. Assembler Directives Summary (Continued)

(i) Miscellaneous directives

<table>
<thead>
<tr>
<th>Mnemonic and Syntax</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>.algebraic</td>
<td>Signifies that the file contains algebraic assembly source</td>
<td>4-26</td>
</tr>
<tr>
<td>.c_mode</td>
<td>Signifies that calls and branches are within the normal 16-bit address range.</td>
<td>4-35</td>
</tr>
<tr>
<td>.emsg string</td>
<td>Send user-defined error messages to the output device</td>
<td>4-42</td>
</tr>
<tr>
<td>.end</td>
<td>End program</td>
<td>4-44</td>
</tr>
<tr>
<td>.far_mode</td>
<td>Signifies that calls and branches are far calls</td>
<td>4-45</td>
</tr>
<tr>
<td>.mmregs</td>
<td>Enter memory-mapped registers into the symbol table</td>
<td>4-71</td>
</tr>
<tr>
<td>.mmsg string</td>
<td>Send user-defined messages to the output device</td>
<td>4-42</td>
</tr>
<tr>
<td>.newblock</td>
<td>Undefine local labels</td>
<td>4-74</td>
</tr>
<tr>
<td>.noremark [num]</td>
<td>Identify the beginning of a block of code in which the assembler will suppress the assembler remark identified by num. If num is not specified, all remarks are suppressed.</td>
<td>4-75</td>
</tr>
<tr>
<td>.remark [num]</td>
<td>Resume the default behavior of generating the remark(s) previously suppressed by .noremark.</td>
<td>4-75</td>
</tr>
<tr>
<td>.sblock [&quot;]section name[&quot;], ... , &quot;section name&quot;]</td>
<td>Designates sections for blocking</td>
<td>4-79</td>
</tr>
<tr>
<td>.version [value]</td>
<td>Specify the device for which processor instructions are being built</td>
<td>4-99</td>
</tr>
<tr>
<td>.wmsg string</td>
<td>Send user-defined warning messages to the output device</td>
<td>4-42</td>
</tr>
</tbody>
</table>
4.2 Compatibility With the TMS320C1x/C2x/C2xx/C5x Assembler Directives

This section explains how the TMS320C54x assembler directives differ from the TMS320C1x/C2x/C2xx/C5x assembler directives.

- The 'C54x .long and .float directives place the most significant word of the value at the lower address, while the 'C1x/C2x/C2xx/C5x assembler directives place the least significant word at the lower address. Also, the 'C54x .long and .float directives automatically align the SPC on an even word boundary, while the 'C1x/C2x/C2xx/C5x assembler directives do not.

- Without arguments, the 'C54x and the 'C1x/C2x/C2xx/C5x assemblers both align the SPC at the next 128-word boundary. However, the 'C54x .align directive also accepts a constant argument, which must be a power of 2, and this argument causes alignment of the SPC on that word boundary. The .align directive for the 'C1x/C2x/C2xx/C5x assembler does not accept this constant argument.

- The .field directive for the 'C54x packs fields into words starting at the most significant bit of the word. The 'C1x/C2x/C2xx/C5x assembler .field directive places fields into words starting at the least significant bit of the word.

- The .field directive for the 'C54x handles values of 1 to 32 bits, contrasted with the 'C1x/C2x/C2xx/C5x assembler which handles values of 1 to 16 bits. With the 'C54x assembler, objects that are 16 bits or larger start on a word boundary and are placed with the most significant bits at the lower address.

- The 'C54x .bss and .usect directives have an additional flag called the alignment flag which specifies alignment on an even word boundary. The 'C1x/C2x/C2xx/C5x .bss and .usect directives do not use this flag.

- The .string directive for the 'C54x initializes one character per word, unlike the 'C1x/C2x/C2xx/C5x assembler .string, which packs two characters per word. The new .pstring directive packs two characters per word, as the former .string did.

- The following directives are new with the 'C54x assembler and are not supported by the 'C1x/C2x/C2xx/C5x assembler:

<table>
<thead>
<tr>
<th>Directive</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>.xfloat</td>
<td>Same as .float without automatic alignment</td>
</tr>
<tr>
<td>.xlong</td>
<td>Same as .long without automatic alignment</td>
</tr>
<tr>
<td>.pstring</td>
<td>Same as .string, but packs two chars/word</td>
</tr>
</tbody>
</table>
4.3 Directives That Define Sections

These directives associate portions of an assembly language program with the appropriate sections:

- `.bss` reserves space in the `.bss` section for uninitialized variables.
- `.clink` sets the STYP_CLINK flag in the type field for the named section. The `.clink` directive can be applied to initialized or uninitialized sections. The STYP_CLINK flag enables conditional linking by telling the linker to leave the section out of the final COFF output of the linker if there are no references found to any symbol in the section.
- `.data` identifies portions of code in the `.data` section. The `.data` section usually contains initialized data.
- `.sect` defines initialized named sections and associates subsequent code or data with that section. A section defined with `.sect` can contain executable code or data.
- `.text` identifies portions of code in the `.text` section. The `.text` section usually contains executable code.
- `.usect` reserves space in an uninitialized named section. The `.usect` directive is similar to the `.bss` directive, but it allows you to reserve space separately from the `.bss` section.


Example 4–1 shows how you can use sections directives to associate code and data with the proper sections. This is an output listing; column 1 shows line numbers, and column 2 shows the SPC values. (Each section has its own program counter, or SPC.) When code is first placed in a section, its SPC equals 0. When you resume assembling into a section after other code is assembled, the section’s SPC resumes counting as if there had been no intervening code.

The directives in Example 4–1 perform the following tasks:

- `.text` initializes words with the values 1, 2, 3, 4, 5, 6, 7, and 8.
- `.data` initializes words with the values 9, 10, 11, 12, 13, 14, 15, and 16.
- `.var_defs` initializes words with the values 17 and 18.
- `.bss` reserves 19 words.
- `.usect` reserves 20 words.

The `.bss` and `.usect` directives do not end the current section or begin new sections; they reserve the specified amount of space, and then the assembler resumes assembling code or data into the current section.
### Example 4–1. Sections Directives

```assembly
1                     **************************************************
2     *     Start assembling into the .text section    *
3                     **************************************************
4 000000 .text
5 000000 0001 .word 1,2
6 000002 0003 .word 3,4

7                     **************************************************
8     *     Start assembling into the .data section    *
9                     **************************************************
10 000000 .data
11 000000 0009 .word 9, 10
12 000002 000B .word 11, 12

14                     **************************************************
15     *       Start assembling into a named,           *
16     *       initialized section, var_defs            *
17                     **************************************************
18 000000 .sect "var_defs"
19 000000 0011 .word 17, 18

22                     **************************************************
23     *    Resume assembling into the .data section    *
24                     **************************************************
25 000004 .data
26 000004 001D .word 13, 14
27 000000 .bss sym, 19 ; Reserve space in .bss
28 000006 001F .word 15, 16 ; Still in .data

30                     **************************************************
31     *    Resume assembling into the .text section    *
32                     **************************************************
33 000004 .text
34 000004 0005 .word 5, 6
35 000000 usym .usect "xy", 20 ; Reserve space in xy
36 000006 0007 .word 7, 8 ; Still in .text

000007 0008
```
4.4 Directives That Initialize Constants

This section describes several directives that assemble values for the current section.

- The .bes and .space directives reserve a specified number of bits in the current section. The assembler fills these reserved bits with 0s.

  You can reserve words by multiplying the desired number of words by 16.

  - When you use a label with .space, it points to the first word that contains reserved bits.
  - When you use a label with .bes, it points to the last word that contains reserved bits.

Figure 4–1 shows the .space and .bes directives. Assume the following code has been assembled for this example:

```
1          ** .space and .bes directives
2
3 4 000000 0100 .word 100h, 200h
      000001 0200
5 000002 Res_1: .space 17
6 000004 000f .word 15
7 000006 Res_2: .bes 20
9 000007 00ba .byte 0BAh
8 000007 ** reserve 3 words
10 000008 Res_3: .space 3*16
11 00000b 000a .word 10
```

Res_1 points to the first word in the space reserved by .space. Res_2 points to the last word in the space reserved by .bes.

*Figure 4–1. The .space and .bes Directives*
Directives That Initialize Constants

- The `.byte`, `.ubyte`, `.char`, and `.uchar` directives place one or more 8-bit values into consecutive words of the current section. These directives are similar to `.word` and `.uword`, except that the width of each value is restricted to 8 bits.

- The `.field` directive places a single value into a specified number of bits in the current word. With `.field`, you can pack multiple fields into a single word; the assembler does not increment the SPC until a word is filled.

Figure 4–2 shows how fields are packed into a word. For this example, assume the following code has been assembled; notice that the SPC doesn’t change for the first three fields (the fields are packed into the same word):

```assembly
4 000000 6000 .field 3, 3
5 000000 6400 .field 8, 6
6 000000 6440 .field 16, 5
7 000001 0123 .field 01234h,20
000002 4000
8 000003 0000 .field 01234h,32
000004 1234
```

Figure 4–2. The `.field` Directive

- `.float` and `.xfloat` calculate the single-precision (32-bit) IEEE floating-point representation of a single floating-point value and store it in two con-
secutive words in the current section. The most significant word is stored first. The .float directive automatically aligns to the nearest long word boundary, and .xfloat does not.

- **.int, .uint, .half, .uhalf, .short, .ushort, .word, and .uword** place one or more 16-bit values into consecutive words in the current section.

- **.double** and **.ldouble** calculate the single-precision (32-bit) IEEE floating-point representation of one or more floating-point values and store them in two consecutive words in the current section. The .double directive automatically aligns to the long word boundary.

- **.long, .ulong, and .xlong** place 32-bit values into two consecutive words in the current section. The most significant word is stored first. The .long directive automatically aligns to a long word boundary, and the .xlong directive does not.

- **.string** and **.pstring** place 8-bit characters from one or more character strings into the current section. The .string directive is similar to .byte, placing an 8-bit character in each consecutive word of the current section. The .pstring also has a width of 8 bits but packs two characters into a word. For .pstring, the last word in a string is padded with null characters (0) if necessary.

**Note:** These Directives in a .struct/.endstruct Sequence

The directives listed above do not initialize memory when they are part of a .struct/.endstruct sequence; rather, they define a member’s size. For more information about the .struct/.endstruct directives, see Section 4.9, Assembly-Time Symbol Directives, on page 4-21.

Figure 4–3 compares the .byte, .int, .long, .xlong, .float, .xfloat, .word, and .string directives. For this example, assume that the following code has been assembled:
Directives That Initialize Constants

1 000000 00aa .byte 0AAh, 0BBh
2 000001 00bb
3 000002 0ccc .word OCCh
4 000003 0eee .xlong 0EEEEFFFFh
5 000004 efff
6 000005 0068 .string "help"
7 000006 0065
8 000007 006c
9 000008 0070

Figure 4–3. Initialization Directives

<table>
<thead>
<tr>
<th>Word</th>
<th>15</th>
<th>0</th>
<th>15</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0, 1</td>
<td>0 0 A A 0 0 B B</td>
<td>.byte 0AAh, 0BBh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0 C C C</td>
<td>.word OCCh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3, 4</td>
<td>0 E E E E F F F</td>
<td>.xlong 0EEEEFFFFh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6, 7</td>
<td>E E E E F F F F</td>
<td>.long 0EEEEFFFFh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>D D D D</td>
<td>.int 0DDDDh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9, a</td>
<td>3 F F F F F A C</td>
<td>.xfloat 1.99999</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c, d</td>
<td>3 F F F F F A C</td>
<td>.float 1.99999</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e, f</td>
<td>0 0 6 8 0 0 6 5</td>
<td>.string &quot;help&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10, 11</td>
<td>0 0 6 C 0 0 7 0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4-14
4.5 Directives That Align the Section Program Counter

The .align directive aligns the SPC at a 1-word to 128-word boundary. This ensures that the code following the directive begins on an x-word or page boundary. If the SPC is already aligned at the selected boundary, it is not incremented. Operands for the .align directive must equal a power of 2 between 2^0 and 2^{16} (although directives beyond 2^7 are not meaningful). For example:

- Operand of 1 aligns SPC to word boundary
- 2 aligns SPC to long word/even boundary
- 128 aligns SPC to page boundary

The .align directive with no operands defaults to a page boundary.

The .even directive aligns the SPC so that it points to the next word boundary. It is equivalent to specifying the .align directive with an operand of 1. Using .even with an operand of 2 aligns the SPC to the next long word boundary. Any unused bits in the current word are filled with 0s.

Figure 4–4 demonstrates the .align directive. Assume that the following code has been assembled:

```
1 000000 4000 .field 2, 3
2 000000 4160 .field 11, 8
3 .align 2
4 000002 0045 .string "Errorcnt"
  000003 0072
  000004 0072
  000005 006f
  000006 0072
  000007 0063
  000008 006e
  000009 0074
5 .align
6 000080 0004 .byte 4
```
Figure 4–4. The .align Directive

(a) Result of .align 2

(b) Result of .align without an argument
4.6 Directives That Format the Output Listing

The following directives format the listing file:

- You can use the `.drnolist` directive to suppress the printing of the following directives in the listing:
  - .asg .eval .length .mnolist .var
  - .break .fclist .mlist .sslist .width
  - .emsg .fcnolist .mmsg .ssnolist .wmsg

  You can use the `.drlist` directive to turn on the listing of these directives again.

- The listing file contains a listing of false conditional blocks that do not generate code. The `.fclist` and `.fcnolist` directives turn this listing on and off. You can use the .fclist directive to list false conditional blocks exactly as they appear in the source code. This is the default behavior of the assembler. You can use the .fcnolist directive to list only the conditional blocks that are actually assembled.

- The `.length` directive controls the page length of the listing file. You can use this directive to adjust listings for various output devices.

- The `.list` and `.nolist` directives turn the output listing on and off. You can use the .nolist directive to stop the assembler from printing selected source statements in the listing file. Use the .list directive to turn the listing on again.

- The listing file contains a listing of macro expansions and loop blocks. The `.mlist` and `.mnolist` directives turn this listing on and off. You can use the .mlist directive to print all macro expansions and loop blocks to the listing (the default behavior of the assembler), and the .mnolist directive to suppress this listing.

- The `.option` directive controls certain features in the listing file. This directive has the following operands:
  - **A** turns on listing of all directives and data, and subsequent expansions, macros, and blocks
  - **B** limits the listing of .byte directives to one line.
  - **D** turns off the listing of certain directives (same effect as `.drnolist`)
  - **H** limits the listing of .half and .short directives to one line.
  - **L** limits the listing of .long directives to one line.
  - **M** turns off macro expansions in the listing.
  - **N** turns off listing (performs .nolist)
Directives That Format the Output Listing

O  turns on listing (performs .list)
R  resets the B, M, T, and W options.
T  limits the listing of .string directives to one line.
W  limits the listing of .word directives to one line.
X  produces a symbol cross-reference listing. (You can also obtain a cross-reference listing by invoking the assembler with the –x option.)

☐ The .page directive causes a page eject in the output listing.

☐ The .sslist and .ssnolist directives allow and suppress substitution symbol expansion listing. These directives are useful for debugging the expansion of substitution symbols.

☐ The .tab directive defines tab size.

☐ The .title directive supplies a title that the assembler prints at the top of each page.

☐ The .width directive controls the page width of the listing file. You can use this directive to adjust listings for various output devices.
4.7 Directives That Reference Other Files

These directives supply information for or about other files:

- The `.copy` and `.include` directives tell the assembler to begin reading source statements from another file. When the assembler finishes reading the source statements in the copy/include file, it resumes reading source statements from the current file immediately following the point at which the `.copy` or `.include` directive occurred. The statements read from a copied file are printed in the listing file; the statements read from an included file are not printed in the listing file.

- The `.def` directive identifies a symbol that is defined in the current module and that can be used by another module. The assembler includes the symbol in the symbol table.

- The `.global` directive declares a symbol external so that it is available to other modules at link time. (For more information about global symbols, see subsection 2.8.1, *External Symbols*, on page 2-21.) The `.global` directive does double duty, acting as a `.def` for defined symbols and as a `.ref` for undefined symbols. The linker resolves an undefined global symbol only if it is used in the program.

- The `.ref` directive identifies a symbol that is used in the current module but defined in another module. The assembler marks the symbol as an undefined external symbol and enters it in the object symbol table so that the linker can resolve its definition.
4.8 Conditional Assembly Directives

Conditional assembly directives enable you to instruct the assembler to assemble certain sections of code according to a true or false evaluation of an expression. Two sets of directives allow you to assemble conditional blocks of code:

- The `.if/.elseif/.else/.endif` directives tell the assembler to conditionally assemble a block of code according to the evaluation of an expression. The expression must be entirely specified on the same line as the directive.
  - `.if expression` marks the beginning of a conditional block and assembles code if the `.if` condition is true.
  - `.elseif expression` marks a block of code to be assembled if the `.if` condition is false and `.elseif` is true.
  - `.else` marks a block of code to be assembled if the `.if` condition is false.
  - `.endif` marks the end of a conditional block and terminates the block.

- The `.loop/.break/.endloop` directives tell the assembler to repeatedly assemble a block of code according to the evaluation of an expression. The expression must be entirely specified on the same line as the directive.
  - `.loop expression` marks the beginning a block of code that is assembled repeatedly up to the number of times indicated by the `expression`. The `expression` is the loop count.
  - `.break expression` tells the assembler to continue to repeatedly assemble when the `.break expression` is false, and to go to the code immediately after `.endloop` when the expression is true.
  - `.endloop` marks the end of a repeatable block.

The assembler supports several relational operators that are useful for conditional expressions. For more information about relational operators, see subsection 3.9.4, Conditional Expressions, on page 3-27.
4.9 Assembly-Time Symbol Directives

Assembly-time symbol directives equate meaningful symbol names to constant values or strings.

- The `.asg` directive assigns a character string to a substitution symbol. The value is stored in the substitution symbol table. When the assembler encounters a substitution symbol, it replaces the symbol with its character string value. Substitution symbols can be redefined.

```
.asg "10, 20, 30, 40", coefficients
.byte coefficients
```

- The `.eval` directive evaluates an expression, translates the results into a character, and assigns the character string to a substitution symbol. This directive is most useful for manipulating counters:

```
.asg 1, x
.loop
.byte x*10h
.break x = 4
.eval x+1, x
.endloop
```

- The `.label` directive defines a special symbol that refers to the loadtime address within the current section. This is useful when a section loads at one address but runs at a different address. For example, you may want to load a block of performance-critical code into slower off-chip memory to save space, and move the code to high-speed on-chip memory to run.

- The `.set` and `.equ` directives set a value to a symbol. The symbol is stored in the symbol table and cannot be refined. For example:

```
bval .set 0100h
.byte bval, bval*2, bval+12
B bval
```

The `.set` and `.equ` directives produce no object code. The two directives are identical and can be used interchangeably.

- The `.struct /.endstruct` directives set up C-like structure definitions, and the `.tag` directive assigns the C-like structure characteristics to a label. The `.struct /.endstruct` directives allow you to organize your information into structures, so that similar elements can be grouped together. Element offset calculation is then left up to the assembler. The `.struct /.endstruct` directives do not allocate memory. They simply create a symbolic template that can be used repeatedly.
The .tag directive associates structure characteristics with a label symbol. This simplifies the symbolic representation and also provides the ability to define structures that contain other structures. The .tag directive does not allocate memory, and the structure tag (stag) must be defined before it is used.

```assembly
.type .struct           ; structure tag definition
X   .int
Y   .int
T_LEN .endstruct

COORD .tag type         ; declare COORD (coordinate)
ADD   COORD.Y, A

.bss COORD, T_LEN ; actual memory allocation
```

The .union/.endunion directives create a symbolic template that can be used repeatedly, providing a way to manipulate several different kinds of data in the same storage area. The union sets up a C-like union definition. While it does not allocate any memory, it allows alternate definitions of size and type that may be temporarily stored in the same memory space.

The .tag directive associates union characteristics with a label symbol. A union can be defined and given a tag, and later it can be declared as a member of a structure by using the .tag directive. A union may also be declared without a tag, in which case all of its members will be entered in the symbol table, and each member must have a unique name. A union may also be defined within a structure, in which case any reference to such a union must be made via with the structure that encloses it. For example:

```assembly
.data
s2_tag .struct ; structure tag definition
    .union ; union is first structure member
    .struct ; structure is union member
h1  .half   ; h1, h2, and w1
h2  .uhalf  ; exist in the same memory
.endstruct
w1  .word   ; word is another union member
.endunion
w2  .word   ; second structure member
s2_len .endstruct

XYZ .tag s2_tag
 .bss XYZ,s2_len ; declare instance of structure
ADD   XYZ.h2, A
```
4.10 Miscellaneous Directives

These directives enable miscellaneous functions or features:

- The `.algebraic` directive tells the assembler that the file contains algebraic assembly source code. This must be the first line in the file if the `-mg` assembler option is not used.

- The `.c_mode` directive tells the assembler that calls and branches are within the normal 16-bit address range. This is the default behavior of the assembler.

- The `.end` directive terminates assembly. It should be the last source statement of a program. This directive has the same effect as an end-of-file.

- The `.far_mode` directive tells the assembler that calls are far calls.

- The `.mmregs` directive defines symbolic names for the memory-mapped register. Using `.mmregs` is the same as executing a `.set` for all memory-mapped registers. See Table 4–2 on page 4-71 for a list of memory-mapped registers.

- The `.newblock` directive resets local labels. Local labels are symbols of the form $n or name?. They are defined when they appear in the label field. Local labels are temporary labels that can be used as operands for jump instructions. The `.newblock` directive limits the scope of local labels by resetting them after they are used. For more information about local labels, see subsection 3.8.6, Local Labels, on page 3-22.

- The `.sblock` directive designates sections for blocking. Blocking is an address alignment mechanism similar to page alignment, but weaker. A blocked section is guaranteed not to cross a page boundary (128 words) if it is smaller than a page, or to start on a page boundary if it is larger than a page. Note that this directive allows specification of blocking for initialized sections only, not uninitialized sections declared with `.usect` or the `.bss` section. The section names may or may not be enclosed in quotes.

- The `.noremark` directive begins a block of code in which the assembler will suppress the specified assembler remark (or all remarks). A remark is an informational assembler message that is less severe than a warning. The `.remark` directive re-enables the remark(s) previously suppressed by `.noremark`.

- The `.version` directive determines the processor for which instructions are being built. Each C54x device has its own value.
These three directives enable you to define your own error and warning messages:

- The **.emsg** directive sends error messages to the standard output device. The .emsg directive generates errors in the same manner as the assembler, incrementing the error count and preventing the assembler from producing an object file.

- The **.mmsg** directive sends assembly-time messages to the standard output device. The .mmsg directive functions in the same manner as the .emsg and .wmsg directives but does not increment the error count or the warning count. It does not affect the creation of the object file.

- The **.wmsg** directive sends warning messages to the standard output device. The .wmsg directive functions in the same manner as the .emsg directive but increments the warning count, rather than the error count. It does not affect the creation of the object file.
4.11 Directives Reference

The remainder of this chapter is a reference. Generally, the directives are organized alphabetically, one directive per page. Related directives (such as .if/.else/.endif), however, are presented together on one page.

<table>
<thead>
<tr>
<th>Directive</th>
<th>Page</th>
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<tr>
<td>.algebraic</td>
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<tr>
<td>.align</td>
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<td>.bes</td>
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<td>.end</td>
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<td>4-66</td>
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<td>.endm</td>
<td>4-44</td>
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<td>.endunion</td>
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<td>.eval</td>
<td>4-28</td>
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<td>4-46</td>
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<td>.if/.else/.endif</td>
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<td>4-36</td>
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<td>4-58</td>
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<td>4-66</td>
</tr>
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<td>4-67</td>
</tr>
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<td>.milo</td>
<td>4-68</td>
</tr>
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<td>4-70</td>
</tr>
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<td>.mmregs</td>
<td>4-71</td>
</tr>
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<td>.mmsg</td>
<td>4-42</td>
</tr>
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<td>4-70</td>
</tr>
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<td>.newblock</td>
<td>4-74</td>
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<td>.nolist</td>
<td>4-62</td>
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<td>4-51</td>
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<td>4-79</td>
</tr>
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<td>.short/.ushort</td>
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<tr>
<td>.space</td>
<td>4-82</td>
</tr>
<tr>
<td>.sslist</td>
<td>4-83</td>
</tr>
<tr>
<td>.ssnolist</td>
<td>4-83</td>
</tr>
<tr>
<td>.struct</td>
<td>4-86</td>
</tr>
<tr>
<td>.tab</td>
<td>4-89</td>
</tr>
<tr>
<td>.tag</td>
<td>4-86</td>
</tr>
<tr>
<td>.text</td>
<td>4-90</td>
</tr>
<tr>
<td>.title</td>
<td>4-91</td>
</tr>
<tr>
<td>.union</td>
<td>4-92</td>
</tr>
<tr>
<td>.usect</td>
<td>4-95</td>
</tr>
<tr>
<td>.version</td>
<td>4-99</td>
</tr>
<tr>
<td>.width</td>
<td>4-61</td>
</tr>
<tr>
<td>.wmsg</td>
<td>4-42</td>
</tr>
<tr>
<td>.word/.uword</td>
<td>4-58</td>
</tr>
<tr>
<td>.var</td>
<td>4-98</td>
</tr>
<tr>
<td>.xfloat</td>
<td>4-50</td>
</tr>
<tr>
<td>.xlong</td>
<td>4-64</td>
</tr>
</tbody>
</table>
.algebraic File Contains Algebraic Assembly Source

Syntax

```
.algebraic
```

Description

The `.algebraic` directive tells the assembler that this file contains algebraic assembly source code. This directive must be the first line in the file if the `-mg` option is not used.

**Note: Mixing Algebraic and Mnemonic Assembly Code**

Algebraic and mnemonic assembly code cannot be mixed within the same source file.

The `.algebraic` directive does not provide a method for mixing algebraic and mnemonic statements within the same source file. It provides a means of selecting algebraic assembly without specifying the `-mg` assembler option.
### Syntax

<table>
<thead>
<tr>
<th>Syntax</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>.align [size]</code></td>
</tr>
<tr>
<td><code>.even</code></td>
</tr>
</tbody>
</table>

### Description

The `.align` directive aligns the section program counter (SPC) on the next boundary, depending on the `size` parameter. The `size` may be any power of 2, although only certain values are useful for alignment.

An operand of 128 aligns the SPC on the next page boundary, and this is the default if no `size` is given. The assembler assembles words containing null values (0) up to the next x-word boundary.

- **Operand of 1** aligns SPC to word boundary
- **2** aligns SPC to long word/even boundary
- **128** aligns SPC to page boundary

The `.even` directive aligns the SPC on a long word/even boundary. This directive is equivalent to the `.align` directive with an operand of 2.

Using the `.align` directive has two effects:

- The assembler aligns the SPC on a boundary within the current section.
- The assembler sets a flag that forces the linker to align the section so that individual alignments remain intact when a section is loaded into memory.

### Example

This example shows several types of alignment, including `.even`, `.align 4`, and a default `.align`.

```
1 000000 0004 .byte 4
2
3 000002 0045 .even
    000003 0072
    000004 0072
    000005 006F
    000006 0072
    000007 0063
    000008 006E
    000009 0074
4 000080 6000 .align
5 000080 6000 .field 3,3
6 000080 6A00 .field 5,4
7
8 000082 6000 .align 2
9 000082 6000 .field 3,3
10 000088 5000 .align 8
11 000088 5000 .field 5,4
12 000100 0004 .byte 4
```
.asg/.eval  
Assign Character Strings to Substitution Symbols

Syntax

| .asg [ " ]character string[ " ], substitution symbol
| .eval well-defined expression, substitution symbol |

Description

The .asg directive assigns character strings to substitution symbols. Substitution symbols are stored in the substitution symbol table. The .asg directive can be used in many of the same ways as the .set directive, but while .set assigns a constant value (which cannot be redefined) to a symbol, .asg assigns a character string (which can be redefined) to a substitution symbol.

- The assembler assigns the character string to the substitution symbol. The quotation marks are optional. If there are no quotation marks, the assembler reads characters up to the first comma and removes leading and trailing blanks. In either case, a character string is read and assigned to the substitution symbol.

- The substitution symbol must be a valid symbol name. The substitution symbol may be 32 characters long and must begin with a letter. Remaining characters of the symbol can be a combination of alphanumeric characters, the underscore (_), and the dollar sign ($).

The .eval directive performs arithmetic on substitution symbols, which are stored in the substitution symbol table. This directive evaluates the expression and assigns the string value of the result to the substitution symbol. The .eval directive is especially useful as a counter in .loop/.endloop blocks.

- The well-defined expression is an alphanumeric expression consisting of legal values that have been previously defined, so that the result is an absolute.

- The substitution symbol must be a valid symbol name. The substitution symbol may be 32 characters long and must begin with a letter. Remaining characters of the symbol can be a combination of alphanumeric characters, the underscore (_), and the dollar sign ($).
Example

This example shows how .asg and .eval can be used.

```
1                    .sslist; show expanded sub. symbols
2            *
3            * .asg/.eval example
4            *
5            .asg  *+, INC
6            .asg  AR0, FP
7
8 000000 f000      ADD  #100, A
9 000001 0064      MAR  *FP+
8 000002 6d90      MAR  *AR0+
9
10
11
12            .asg  0, x
13            .loop  5
14            .eval  x+1, x
15            .word  x
16            .endloop
11
17
18            .eval  x+1, x
19            .eval  0+1, x
17
19
21            .word  x
22            .word  1
19
24            .eval  x+1, x
25            .eval  1+1, x
24
26            .word  x
27            .word  2
25
29            .eval  x+1, x
30            .eval  2+1, x
29
32            .word  x
33            .word  3
30
35            .eval  x+1, x
36            .eval  3+1, x
35
38            .word  x
39            .word  4
36
41            .eval  x+1, x
42            .eval  4+1, x
41
44            .word  x
45            .word  5
```
.bss Reserve Space in the .bss Section

Syntax

\[ \text{.bss symbol, size in words [, (blocking flag) [, alignment flag ]] \]}

Description

The .bss directive reserves space for variables in the .bss section. This directive is typically used to allocate variables in RAM.

- The symbol is a required parameter. It defines a label that points to the first location reserved by the directive. The symbol name corresponds to the variable that you’re reserving space for.

- The size is a required parameter; it must be an absolute expression. The assembler allocates size words in the .bss section. There is no default size.

- The blocking flag is an optional parameter. If you specify a non-zero value for this parameter, the assembler allocates size words contiguously. This means that the allocated space will not cross a page boundary unless size is greater than a page, in which case, the object will start on a page boundary.

- The alignment flag is an optional parameter. This flag causes the assembler to allocate size on long word boundaries.

Note: Specifying an Alignment Flag Only

To specify an alignment flag without a blocking flag, you can insert two commas before the alignment flag, or you can specify 0 for the blocking flag.

The assembler follows two rules when it allocates space in the .bss section:

Rule 1 Whenever a hole is left in memory (as shown in Figure 4–5), the .bss directive attempts to fill it. When a .bss directive is assembled, the assembler searches its list of holes left by previous .bss directives and tries to allocate the current block into one of the holes. (This is the standard procedure whether the contiguous allocation option has been specified or not.)

Rule 2 If the assembler does not find a hole large enough to contain the requested space, it checks to see whether the blocking option is requested.

- If you do not request blocking, the memory is allocated at the current SPC.

- If you request blocking, the assembler checks to see whether there is enough space between the current SPC and the page boundary. If there is not enough space, the assembler creates another hole and allocates the space at the beginning of the next page.
The blocking option allows you to reserve up to 128 words in the .bss section and ensure that they fit on one page of memory. (Of course, you can reserve more than 128 words at a time, but they cannot fit on a single page.) The following example code reserves two blocks of space in the .bss section.

```
memptr: .bss     A, 64, 1
memptr1: .bss     B, 70, 1
```

Each block must be contained within the boundaries of a single page; after the first block is allocated, however, the second block cannot fit on the current page. As Figure 4–5 shows, the second block is allocated on the next page.

Figure 4–5. Allocating .bss Blocks Within a Page

Section directives for initialized sections (.text, .data, and .sect) end the current section and begin assembling into another section. The .bss directive, however, does not affect the current section. The assembler assembles the .bss directive and then resumes assembling code into the current section. For more information about COFF sections, see Chapter 2, Introduction to Common Object File Format.
Example

In this example, the .bss directive is used to allocate space for two variables, TEMP and ARRAY. The symbol TEMP points to 4 words of uninitialized space (at .bss SPC = 0). The symbol ARRAY points to 100 words of uninitialized space (at .bss SPC = 04h); this space must be allocated contiguously within a page. Note that symbols declared with the .bss directive can be referenced in the same manner as other symbols and can also be declared external.

```
1    *******************************************
2    ** Assemble into the .text section. **    
3    *******************************************
4 000000 .text                             
5 000000 e800 LD #0, A                    
6    *******************************************
7    ** Allocate 4 words in .bss for TEMP. **
8    *******************************************
9 000000 Var_1: .bss TEMP, 4              
10                                           
11                                           
12    *******************************************
13    ** Still in .text **                  
14    *******************************************
15 000001 f000 ADD #56h, A                
16 000002 0056                             
17 000003 f066 MPY #73h, A                
18 000004 0073                             
19                                           
20                                           
21                                           
22 000004 .bss ARRAY, 100, 1              
23                                           
24                                           
25                                           
26    *******************************************
27 000005 8000– STL A, Var_1               
28                                           
29                                           
30                                           
31                                           
32                                           
33                                           
```

```
1                                           
2                                           
3                                           
4                                           
5                                           
6                                           
7                                           
8                                           
9                                           
10                                          
11                                          
12                                          
13                                          
14                                          
15                                          
16                                          
17                                          
18                                          
19                                          
20                                          
21                                          
22                                          
23                                          
24                                          
25                                          
26                                          
27                                          
28                                          
29                                          
30                                          
31                                          
32                                          
33                                          
```
Initialize Bytes .byte

Syntax

\[
\begin{align*}
\text{.byte} & \ \text{value}_1 \ [\ldots, \text{value}_n] \\
\text{.ubyte} & \ \text{value}_1 \ [\ldots, \text{value}_n] \\
\text{.char} & \ \text{value}_1 \ [\ldots, \text{value}_n] \\
\text{.uchar} & \ \text{value}_1 \ [\ldots, \text{value}_n]
\end{align*}
\]

Description

The .byte, .ubyte, .char, and .uchar directives place one or more bytes into consecutive words of the current section. Each byte is placed in a word by itself; the 8 MSBs are filled with 0s. A value can be:

- An expression that the assembler evaluates and treats as an 8-bit signed or unsigned number
- A character string enclosed in double quotes. Each character in a string represents a separate value.

Values are not packed or sign-extended; each byte occupies the 8 least significant bits of a full 16-bit word. The assembler truncates values greater than 8 bits. You can use up to 100 value parameters, but the total line length cannot exceed 200 characters.

If you use a label, it points to the location where the assembler places the first byte.

Note that when you use these directives in a .struct/.endstruct sequence, they define a member’s size; they do not initialize memory. For more information about .struct/.endstruct, see Section 4.9, Assembly-Time Symbol Directives, on page 4-21.

Example

In this example, 8-bit values (10, –1, abc, and a) are placed into consecutive words in memory. The label strx has the value 100h, which is the location of the first initialized word.

```
1 0000               .space 100h * 16
2 000100 000a STRX    .byte 10, –1, "abc", ‘a’
     000101 00ff
     000102 0061
     000103 0062
     000104 0063
     000105 0061
```
**.clink**  *Conditionally Leave Section Out of COFF Output*

**Syntax**

```
.clink ["section name"]
```

**Description**

The `.clink` directive sets up conditional linking for a section by setting the STYP_CLINK flag in the type field for `section name`. The `.clink` directive can be applied to initialized or uninitialized sections.

If `.clink` is used without a section name, it applies to the current initialized section. If `.clink` is applied to an uninitialized section, the section name is required. The section name is significant to 200 characters and must be enclosed in double quotes. A section name can contain a subsection name in the form of `section name:subsection name`.

The STYP_CLINK flag tells the linker to leave the section out of the final COFF output of the linker if there are no references found to any symbol in the section.

A section in which the entry point of a C program is defined cannot be marked as a conditionally linked section.

**Example**

In this example, the Vars and Counts sections are set for conditional linking.

```
1 000000 .sect "Vars"
2       ; Vars section is conditionally linked
3 .clink
4
5 000000 001A X: .word 01Ah
6 000001 001A Y: .word 01Ah
7 000002 001A Z: .word 01Ah
8 000000 .sect "Counts"
9       ; Counts section is conditionally linked
10 .clink
11
12 000000 001A Xcount: .word 01Ah
13 000001 001A Ycount: .word 01Ah
14 000002 001A Zcount: .word 01Ah
15       ; By default, .text is unconditionally linked
16 000000 .text
17       ; Reference to symbol X cause the Vars section
18       ; to be linked into the COFF output
19 000000 E800 LD #0, A
20 000001 8000+ STL A, X
```
Specify C Runtime Environment  .c_mode

Syntax

| .c_mode |

Description

The `.c_mode` directive is generated as a header for any assembly file created by the C compiler.

This directive works primarily in conjunction with the `–mf` assembler option or the `.far_mode` directive to facilitate linking a program that uses extended addressing.

If your program uses extended addressing, but your assembly code was not generated by the C compiler, you should add the `.c_mode` directive to your assembly files.
**.copy/.include**  Read Source File

### Syntax

```plaintext
.copy [""]filename[""]
.include [""]filename[""]
```

### Description

The `.copy` and `.include` directives tell the assembler to read source statements from a different file. The statements that are assembled from a copy file are printed in the assembly listing. The statements that are assembled from an included file are *not* printed in the assembly listing, regardless of the number of `.list/.nolist` directives assembled. The assembler:

1) Stops assembling statements in the current source file.
2) Assembles the statements in the copied/included file.
3) Resumes assembling statements in the main source file, starting with the statement that follows the `.copy` or `.include` directive.

The `filename` is a required parameter that names a source file. It may be enclosed in double quotes and must follow operating system conventions. You can specify a full pathname (for example, `c:\dsp\file1.asm`). If you do not specify a full pathname, the assembler searches for the file in:

1) The directory that contains the current source file.
2) Any directories named with the `–i` assembler option.
3) Any directories specified by the environment variable `A_DIR`.

For more information about the `–i` option and `A_DIR`, see Section 3.4, *Naming Alternate Directories for Assembler Input*, on page 3-8.

The `.copy` and `.include` directives can be nested within a file being copied or included. The assembler limits nesting to 32 levels; the host operating system may set additional restrictions. The assembler precedes the line numbers of copied files with a letter code to identify the level of copying. An A indicates the first copied file, B indicates a second copied file, etc.
Example 1

In this example, the .copy directive is used to read and assemble source statements from other files; then the assembler resumes assembling into the current file.

The original file, copy.asm, contains a .copy statement copying the file byte.asm. When copy.asm assembles, the assembler copies byte.asm into its place in the listing (note listing below). The copy file byte.asm contains a .copy statement for a second file, word.asm.

When it encounters the .copy statement for word.asm, the assembler switches to word.asm to continue copying and assembling. Then the assembler returns to its place in byte.asm to continue copying and assembling. After completing assembly of byte.asm, the assembler returns to copy.asm to assemble its remaining statement.

<table>
<thead>
<tr>
<th>copy.asm</th>
<th>byte.asm</th>
<th>word.asm</th>
</tr>
</thead>
<tbody>
<tr>
<td>(source file)</td>
<td>(first copy file)</td>
<td>(second copy file)</td>
</tr>
<tr>
<td>.space 29</td>
<td>** In byte.asm</td>
<td>** In word.asm</td>
</tr>
<tr>
<td>.copy &quot;byte.asm&quot;</td>
<td>.byte 32,1+ 'A'</td>
<td>.word 0ABCDh, 56q</td>
</tr>
<tr>
<td>**Back in original file</td>
<td>.copy &quot;word.asm&quot;</td>
<td>** Back in byte.asm</td>
</tr>
<tr>
<td>.pstring &quot;done&quot;</td>
<td>** Back in byte.asm</td>
<td>.byte 67h + 3q</td>
</tr>
</tbody>
</table>

Listing file:

```
1 000000 .space 29
2               .copy "byte.asm"
 A 1          ** In byte.asm
 A 2 000002 0020 .byte 32,1+ 'A'
                 000003 0042
 A 3               .copy "word.asm"
 B 1          * In word.asm
 B 2 000004 ABCD .word 0ABCDh, 56q
                 000005 002E
 A 4          ** Back in byte.asm
 A 5 000006 006A .byte 67h + 3q
 3
 4          ** Back in original file
5 000007 646F .pstring "done"
                 000008 6E65
```
Example 2

In this example, the .include directive is used to read and assemble source statements from other files; then the assembler resumes assembling into the current file. The mechanism is similar to the .copy directive, except that statements are not printed in the listing file.

<table>
<thead>
<tr>
<th>include.asm (source file)</th>
<th>byte2.asm (first include file)</th>
<th>word2.asm (second include file)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.space 29</td>
<td>** In byte2.asm</td>
<td>** In word2.asm</td>
</tr>
<tr>
<td>.include “byte2.asm”</td>
<td>.byte 32, 1+ ‘A’</td>
<td></td>
</tr>
<tr>
<td>**Back in original file</td>
<td>.include “word2.asm”</td>
<td></td>
</tr>
<tr>
<td>.string “done”</td>
<td>** Back in byte2.asm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>.byte 67h + 3q</td>
<td></td>
</tr>
</tbody>
</table>

Listing file:

```
1 000000 .space 29
2                .include “byte2.asm”
3
4 ** Back in original file
5 000007 0064 .string “done”
    000008 006F
    000009 006E
    00000a 0065
```
Assign Character Strings to Substitution Symbols

Syntax

`.data`

Description

The `.data` directive tells the assembler to begin assembling source code into the `.data` section; `.data` becomes the current section. The `.data` section is normally used to contain tables of data or preinitialized variables.

The assembler assumes that `.text` is the default section. Therefore, at the beginning of an assembly, the assembler assembles code into the `.text` section unless you use a section control directive.

For more information about COFF sections, see Chapter 2, *Introduction to Common Object File Format*.

Example

In this example, code is assembled into the `.data` and `.text` sections.

```assembly
1          *******************************************
2          **  Reserve space in .data.          **
3          *******************************************
4 000000 .data
5 000000 .space   0CCh
6
7          *******************************************
8          **  Assemble into .text.       **
9          *******************************************
10 000000 .text
11 0000 INDEX .set   0
12 000000 e800 LD    #INDEX, A
13
14          *******************************************
15          **  Assemble into .data.      **
16          *******************************************
17 0000c Table: .data
18 0000d ffff .word   -1  ; Assemble 16-bit
19                            ; constant into .data.
20 0000e 00ff .byte    OFFh  ; Assemble 8-bit
21                            ; constant into .data.
22
23          *******************************************
24          **  Assemble into .text.       **
25          *******************************************
26 00001 .text
27 00001 000c" ADD   Table, A
28
29          *******************************************
30          **  Resume assembling into the .data  **
31          **  section at address 0Fh.      **
32          *******************************************
33 0000f .data
```
.double/.ldouble  Initialize Double-Precision Floating-Point Value

Syntax

```
double value[,...,value_n]
ldouble value[,...,value_n]
```

Description

The .double and .ldouble directives place the IEEE single-precision floating-point representation of one or more floating-point values into the current section. Each value must be a floating-point constant or a symbol that has been equated to a floating-point constant. Each constant is converted to a floating-point value in IEEE single-precision 32-bit format. Floating-point constants are aligned on a word boundary.

The value consists of three fields:

<table>
<thead>
<tr>
<th>Field</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>s</td>
<td>A 1-bit sign field</td>
</tr>
<tr>
<td>e</td>
<td>An 8-bit biased exponent</td>
</tr>
<tr>
<td>f</td>
<td>A 23-bit fraction</td>
</tr>
</tbody>
</table>

The value is stored most significant word first, least significant word second, in the following format:

```
31 30 23 22 0
  s  e  f
```

When you use .double or .ldouble in a .struct/.endstruct sequence, the directives define a member’s size; they do not initialize memory. For more information about .struct/.endstruct, see Section 4.9, Assembly-Time Symbol Directives, on page 4-21.

Example

This example shows the .double and .ldouble directives.

```
1 000000 E904 .double -1.0e25
000001 5951
2 000002 43E4 .ldouble 456.0
000003 0000
```
Controls Listing of Directives \texttt{.drlist/.drnolist}

**Syntax**

<table>
<thead>
<tr>
<th>.drlist</th>
<th>.drnolist</th>
</tr>
</thead>
</table>

**Description**

Two directives enable you to control the printing of assembler directives to the listing file:

The \texttt{.drlist} directive enables the printing of all directives to the listing file.

The \texttt{.drnolist} directive suppresses the printing of the following directives to the listing file:

- \texttt{.asg}
- \texttt{.break}
- \texttt{.eval}
- \texttt{.fclist}
- \texttt{.fcnolist}
- \texttt{.fmsg}
- \texttt{.fnolist}
- \texttt{.list}
- \texttt{.mlist}
- \texttt{.msg}
- \texttt{.mnolist}
- \texttt{.nlist}
- \texttt{.ssnolist}
- \texttt{.sslist}
- \texttt{.ssnolist}
- \texttt{.sslist}

By default, the assembler acts as if the \texttt{.drlist} directive had been specified.

**Example**

This example shows how \texttt{.drnolist} inhibits the listing of the specified directives:

**Source file:**

```
    .asg    0, x
    .loop   2
    .eval   x+1, x
    .endloop
    .drnolist
    .asg    1, x
    .loop   3
    .eval   x+1, x
    .endloop
```

**Listing file:**

```
1 .asg    0, x
2 .asg    1, x
3 .loop   2
4 .loop   1
3 .eval   x+1, x
4 .eval   x+1, x
```

```
5 .drnolist
6
7 .loop   3
8 .loop   1
9 .loop   2
10 .eval  x+1, x
11 .eval  x+1, x
12 .endloop
```

\textit{Assembler Directives} \ 4-41
Define Messages

Syntax

```
.emsg string
.mmsg string
.wmsg string
```

Description

These directives allow you to define your own error and warning messages. The assembler tracks the number of errors and warnings it encounters and prints these numbers on the last line of the listing file.

The `.emsg` directive sends error messages to the standard output device in the same manner as the assembler, incrementing the error count and preventing the assembler from producing an object file.

The `.mmsg` directive sends assembly-time messages to the standard output device in the same manner as the `.emsg` and `.wmsg` directives, but it does not set the error or warning counts, and it does not prevent the assembler from producing an object file.

The `.wmsg` directive sends warning messages to the standard output device in the same manner as the `.emsg` directive, but it increments the warning count rather than the error count, and it does not prevent the assembler from producing an object file.

Example

In this example, the message **ERROR — MISSING PARAMETER** is sent to the standard output device.

Source file:

```assembly
.global PARAM
MSG_EX .macro parm1
    .if $symlen(parm1) = 0
        .emsg "ERROR — MISSING PARAMETER"
    .else
        add parm1, A
    .endif
.endm
MSG_EX PARAM
MSG_EX
```
Define Messages .emsg/.mmsg/.wmsg

Listing file:

1       .global PARAM
2       MSG_EX   .macro parm1
3           .if     $symlen(parm1) = 0
4           .emsg  "ERROR -- MISSING PARAMETER"
5           .else
6           add     parm1, A
7           .endif
8           .endm
9
10      000000        MSG_EX PARAM
11      .if     $symlen(parm1) = 0
12      .emsg  "ERROR -- MISSING PARAMETER"
13      .else
14      000000 0000!   add     PARAM, A
15      .endif
16
17      000001        MSG_EX
18      .if     $symlen(parm1) = 0
19      .emsg  "ERROR -- MISSING PARAMETER"
20      ***** USER ERROR ***** –: ERROR -- MISSING PARAMETER
21      .else
22      000000 0000!   add     PARAM, A
23      .endif
24
In addition, the following messages are sent to standard output by the assembler:

TMS32055xx COFF Assembler       Version x.xx
Copyright (c) 2001    Texas Instruments Incorporated
PASS 1
PASS 2
“emsg.asm”, ERROR! at line 12: [***** USER ERROR ***** –] ERROR -- MISSING PARAMETER
   .emsg "ERROR -- MISSING PARAMETER"

1 Error, No Warnings

Errors in source – Assembler Aborted
.end  End Assembly

Syntax

```
.end
```

Description

The `.end` directive is optional and terminates assembly. It should be the last source statement of a program. The assembler ignores any source statements that follow a `.end` directive.

This directive has the same effect as an end-of-file character. You can use `.end` when you’re debugging and would like to stop assembling at a specific point in your code.

Example

This example shows how the `.end` directive terminates assembly. If any source statements follow the `.end` directive, the assembler ignores them.

Source File:

```
START: .space 300
TEMP .set 15
   .bss LOC1, 48h
ABS A
ADD #TEMP, A
STL A, LOC1
.end
.byte 4
.word CCCh
```

Listing file:

```
1 000000  START: .space 300
2 000000  TEMP .set 15
3 000000   .bss LOC1, 48h
4 000013 F485  ABS A
5 000014 F000  ADD #TEMP, A
6 000016 000F  STL A, LOC1
7               .end
```
The `.far_mode` directive tells the assembler that the assembly file uses extended addressing: calls and branches extend beyond the normal 16-bit range. This directive has the same effect as using the `-mf` assembler option.

If your program uses extended addressing, and your assembly code was not generated by the C compiler, you should add the `.c_mode` directive to your assembly files.
.fclist/.fcnolist  Control the Listing of False Conditional Blocks

Syntax

| .fclist | .fcnolist |

Description

Two directives enable you to control the listing of false conditional blocks.

The .fclist directive allows the listing of false conditional blocks (conditional blocks that do not produce code).

The .fcnolist directive suppresses the listing of false conditional blocks until a .fclist directive is encountered. With .fcnolist, only code in conditional blocks that are actually assembled appears in the listing. The .if, .elseif, .else, and .endif directives do not appear.

By default, all conditional blocks are listed; the assembler acts as if the .fclist directive had been used.

Example

This example shows the assembly language and listing files for code with and without the conditional blocks listed:

Source File:

AAA .set 1
BBB .set 0
   .fclist
   .if   AAA
   ADD   #1024, A
   .else
   ADD   #1024*10, A
   .endif
   .fcnolist
   .if   AAA
   ADD   #1024, A
   .else
   ADD   #1024*10, A
   .endif

Listing file:

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0001 AAA .set 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0000 BBB .set 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>.fclist</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>.if AAA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>ADD #1024, A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>000001 0400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>.else</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>ADD #1024*10, A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>.endif</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>.fcnolist</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>000002 F000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>000003 0400 ADD #1024, A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Syntax

`.field value [, size in bits]`

### Description

The `.field` directive can initialize multiple-bit fields within a single word of memory. This directive has two operands:

- The `value` is a required parameter; it is an expression that is evaluated and placed in the field. If the value is relocatable, `size` must be 16.

- The `size` is an optional parameter; it specifies a number from 1 to 32, which is the number of bits in the field. If you do not specify a size, the assembler assumes that the size is 16 bits. If you specify a size of 16 or more, the field will start on a word boundary. If you specify a value that cannot fit into `size` bits, the assembler truncates the value and issues an error message. For example, `.field 3,1` causes the assembler to truncate the value 3 to 1; the assembler also prints the message:

  
  ***warning – value truncated.

Successive `.field` directives pack values into the specified number of bits starting at the current word. Fields are packed starting at the most significant part of the word, moving toward the least significant part as more fields are added. If the assembler encounters a field size that does not fit into the current word, it writes out the word, increments the SPC, and begins packing fields into the next word. You can use the `.align` directive with an operand of 1 to force the next `.field` directive to begin packing into a new word.

If you use a label, it points to the word that contains the specified field.

When you use `.field` in a `.struct/.endstruct` sequence, `.field` defines a member’s size; it does not initialize memory. For more information about `.struct/.endstruct`, see Section 4.9, Assembly-Time Symbol Directives, on page 4-21.
**Example**

This example shows how fields are packed into a word. Notice that the SPC does not change until a word is filled and the next word is begun.

```
1  ************************************
2  **    Initialize a 14-bit field.  **
3  ************************************
4 000000 2AF0  .field  0ABCh, 14
5
6  ************************************
7  **    Initialize a 5-bit field    **
8  **         in a new word.         **
9  ************************************
10 000001 5000  L_F:  .field  0Ah, 5
11
12  ************************************
13  **    Initialize a 4-bit field    **
14  **         in the same word.      **
15  ************************************
16 000001 5600  x:    .field  0Ch, 4
17
18  ************************************
19  **    16-bit relocatable field    **
20  **         in the next word.      **
21  ************************************
22 000002 0001'  .field  x
23
24  ************************************
25  **    Initialize a 32-bit field.  **
26  ************************************
27 000003 0000  .field  04321h, 32
28 000004 4321
```
Figure 4–6 shows how the directives in this example affect memory.

### Figure 4–6. The .field Directive

<table>
<thead>
<tr>
<th>Word</th>
<th>Code</th>
<th>15</th>
<th>0</th>
<th>14-bit field</th>
<th>4-bit field</th>
<th>5-bit field</th>
<th>15</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) 0</td>
<td>.field 0ABCh, 14</td>
<td>0 0 1 0 1 0 1 0 1 1 1 1 0 0</td>
<td>14-bit field</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b) 0 1</td>
<td>.field 00Ah, 5</td>
<td>0 0 1 0 1 0 1 0 1 1 1 1 0 0 0 0</td>
<td>5-bit field</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c) 1</td>
<td>.field 000Ch, 4</td>
<td>0 1 0 1 0 1 1 0 0</td>
<td>4-bit field</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(d) 1 2</td>
<td>.field x</td>
<td>0 1 0 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(e) 3 4</td>
<td>.field 04321,32</td>
<td>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>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
.float/.xfloat Initialize Floating-Point Value

Syntax

```
.float value₁ [, ..., valueₙ]
.xfloat value₁ [, ..., valueₙ]
```

Description

The .float and .xfloat directives place the floating-point representation of one or more floating-point constants into the current data section. The `value` must be a floating-point constant or a symbol that has been equated to a floating-point constant. Each constant is converted to a floating-point value in IEEE single-precision 32-bit format. Floating-point constants are aligned on the long-word boundaries unless the .xfloat directive is used. The .xfloat directive performs the same function as the .float directive but does not align the result on the long word boundary.

The 32-bit value consists of three fields:

<table>
<thead>
<tr>
<th>Field</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>s</td>
<td>A 1-bit sign field</td>
</tr>
<tr>
<td>e</td>
<td>An 8-bit biased exponent</td>
</tr>
<tr>
<td>f</td>
<td>A 23-bit mantissa</td>
</tr>
</tbody>
</table>

The value is stored most significant word first, least significant word second, in the following format:

```
31 30 23 22 0
```

When you use .float in a .struct/.endstruct sequence, .float defines a member’s size; it does not initialize memory. For more information about .struct/.endstruct, see Section 4.9, Assembly-Time Symbol Directives, on page 4-21.

Example

This example shows the .float directive.

```
1 000000 E904 .float -1.0e25
   000001 5951
2 000002 4040 .float 3
   000003 0000
3 000004 42F6 .float 123
   000005 0000
```
Identify Global Symbols

**Syntax**

```
.global symbol1 [ , ... , symboln]
def symbol1 [ , ... , symboln]
.ref symbol1 [ , ... , symboln]
```

**Description**

The `.global`, `.def`, and `.ref` directives identify global symbols, which are defined externally or can be referenced externally.

The `.def` directive identifies a symbol that is defined in the current module and can be accessed by other files. The assembler places this symbol in the symbol table.

The `.ref` directive identifies a symbol that is used in the current module but defined in another module. The linker resolves this symbol's definition at link time.

The `.global` directive acts as a `.ref` or a `.def`, as needed.

A global symbol is defined in the same manner as any other symbol; that is, it appears as a label or is defined by the `.set`, `.bss`, or `.usect` directive. As with all symbols, if a global symbol is defined more than once, the linker issues a multiple-definition error. `.ref` always creates a symbol table entry for a symbol, whether the module uses the symbol or not; `.global`, however, creates an entry only if the module actually uses the symbol.

A symbol may be declared global for two reasons:

- If the symbol is *not defined in the current module* (including macro, copy, and include files), the `.global` or `.ref` directive tells the assembler that the symbol is defined in an external module. This prevents the assembler from issuing an unresolved reference error. At link time, the linker looks for the symbol's definition in other modules.

- If the symbol is *defined in the current module*, the `.global` or `.def` directive declares that the symbol and its definition can be used externally by other modules. These types of references are resolved at link time.

**Example**

This example shows four files:

- **file1.lst and file3.lst** are equivalent. Both files define the symbol `Init` and make it available to other modules; both files use the external symbols `x`, `y`, and `z`. `file1.lst` uses the `.global` directive to identify these global symbols; `file3.lst` uses `.ref` and `.def` to identify the symbols.

- **file2.lst and file4.lst** are equivalent. Both files define the symbols `x`, `y`, and `z` and make them available to other modules; both files use the external symbol `Init`. `file2.lst` uses the `.global` directive to identify these global symbols; `file4.lst` uses `.ref` and `.def` to identify the symbols.
file1.lst:
1 ; Global symbol defined in this file
2 .global INIT
3 ; Global symbols defined in file2.lst
4 .global X, Y, Z
5 000000 INIT:
6 000000 F000 ADD #56h, A
000001 0056
7 000002 0000! .word X
8 ;
9 ;
10 ;
11 .end

file2.lst:
1 ; Global symbols defined in this file
2 .global X, Y, Z
3 ; Global symbol defined in file1.lst
4 .global INIT
5 0001 X: .set 1
6 0002 Y: .set 2
7 0003 Z: .set 3
8 000000 0000! .word INIT
9 ;
10 ;
11 ;
12 .end

file3.lst:
1 ; Global symbol defined in this file
2 .def INIT
3 ; Global symbols defined in file4.lst
4 .ref X, Y, Z
5 000000 INIT:
6 000000 F000 ADD #56h, A
000001 0056
7 000002 0000! .word X
8 ;
9 ;
10 ;
11 .end
Identify Global Symbols  .global/.def/.ref

file4.lst:

1 ; Global symbols defined in this file
2 .def X, Y, Z
3 ; Global symbol defined in file3.lst
4 .ref INIT
5 0001 X: .set 1
6 0002 Y: .set 2
7 0003 Z: .set 3
8 000000 0000! .word INIT
9 ;
10 ;
11 ;
12 .end
**.half/.uhalf/.short/.ushort** *Initialize 16-bit Integer*

### Syntax

```
.half  value_1 [ , ... , value_n ]
.uhalf value_1 [ , ... , value_n ]
.short  value_1 [ , ... , value_n ]
.ushort value_1 [ , ... , value_n ]
```

### Description

The **.half**, **.uhalf**, **.short**, and **.ushort** directives place one or more values into consecutive 16-bit fields in the current section. A value can be:

- An expression that the assembler evaluates and treats as an 16-bit signed or unsigned number
- A character string enclosed in double quotes. Each character in a string represents a separate value.

The values can be either absolute or relocatable expressions. If an expression is relocatable, the assembler generates a relocation entry that refers to the appropriate symbol; the linker can then correctly patch (relocate) the reference. This allows you to initialize memory with pointers to variables or labels.

The assembler truncates values greater than 16 bits. You can use as many values as fit on a single line, but the total line length cannot exceed 200 characters. If you use a label, it points to the first initialized word.

When you use **.half**, **.uhalf**, **.short**, or **.ushort** in a **.struct/.endstruct** sequence, they define a member’s size; they do not initialize memory. For more information about **.struct/.endstruct**, see Section 4.9, *Assembly-Time Symbol Directives*, on page 4-21.
**Example**

In this example, the `.half` directive is used to place 16-bit values (10, −1, abc, and a) into memory; `.short` is used to place 16-bit values (8, −3, def, and b) into memory. The label STRN has the value 106h, which is the location of the first initialized word.

```
1 000000 .space 100h * 16
2
3 000100 000A .half 10, -1, "abc", 'a'
   000101 FFFF
   000102 0061
   000103 0062
   000104 0063
   000105 0061
4 000106 0008 STRN .short 8, -3, "def", 'b'
   000107 FFFD
   000108 0064
   000109 0065
   00010a 0066
   00010b 0062
5
```
### Syntax

```
.if   well-defined expression
.elseif well-defined expression
.else
.endif
```

### Description

The following directives provide conditional assembly:

The `.if` directive marks the beginning of a conditional block. The *well-defined expression* is a required parameter, and must be entirely specified on the same line as the directive.

- If the expression evaluates to *true* (nonzero), the assembler assembles the code that follows the expression (up to a `.elseif`, `.else`, or `.endif`).

- If the expression evaluates to *false* (0), the assembler assembles code that follows a `.elseif` (if present), `.else` (if present), or `.endif` (if no `.elseif` or `.else` is present).

The `.elseif` directive identifies a block of code to be assembled when the `.if` expression is false (0) and the `.elseif` expression is true (nonzero). When the `.elseif` expression is false, the assembler continues to the next `.elseif` (if present), `.else` (if present) or `.endif` (if no `.elseif` or `.else` is present). The `.elseif` directive is optional in the conditional blocks, and more than one `.elseif` can be used. If an expression is false and there is no `.elseif` statement, the assembler continues with the code that follows a `.else` (if present) or a `.endif`.

The `.else` directive identifies a block of code that the assembler assembles when the `.if` expression and all `.elseif` expressions are false (0). This directive is optional in the conditional block; if an expression is false and there is no `.else` statement, the assembler continues with the code that follows the `.endif`.

The `.endif` directive terminates a conditional block.

The `.elseif` and `.else` directives can be used in the same conditional assembly block and the `.elseif` directive can be used more than once within a conditional assembly block.

For information about relational operators, see subsection 3.9.4, *Conditional Expressions*, on page 3-27.
Example

This example shows conditional assembly.

```assembly
1              SYM1   .set    1
2              SYM2   .set    2
3              SYM3 .set    3
4              SYM4 .set    4
5
6             If_4:  .if     SYM4 = SYM2 * SYM2
7 000000 0004  .byte   SYM4       ; Equal values
8              .else
9                   .byte   SYM2 * SYM2 ; Unequal values
10             .endif
11
12             If_5:  .if     SYM1 <= 10
13 000001 000a  .byte   10       ; Less than / equal
14              .else
15                   .byte   SYM1     ; Greater than
16             .endif
17
18             If_6:  .if     SYM3 * SYM2 != SYM4 + SYM2
19                   .byte   SYM3 * SYM2  ; Unequal value
20              .else
21 000002 0008  .byte   SYM4 + SYM4  ; Equal values
22             .endif
23
24             If_7:  .if     SYM1 = 2
25                   .byte   SYM1
26              .elseif SYM2 + SYM3 = 5
27 000003 0005  .byte   SYM2 + SYM3
28             .endif
```
.int/.uint/.word/.uword  Initialize 16-bit Integer

Syntax

```plaintext
.int  value1 [ , ... , value_n]
.uint value1 [ , ... , value_n]
.word  value1 [ , ... , value_n]
.uword value1 [ , ... , value_n]
```

Description

The .int, .uint, .word, and .uword directives are equivalent; they place one or more values into consecutive 16-bit fields in the current section. A value can be either:

- An expression that the assembler evaluates and treats as an 16-bit signed or unsigned number

- A character string enclosed in double quotes. Each character in a string represents a separate value.

The values can be either absolute or relocatable expressions. If an expression is relocatable, the assembler generates a relocation entry that refers to the appropriate symbol; the linker can then correctly patch (relocate) the reference. This allows you to initialize memory with pointers to variables or labels.

You can use as many values as fit on a single line (200 characters). If you use a label, it points to the first word that is initialized.

When you use these directives in a .struct/.endstruct sequence, they define a member’s size; they do not initialize memory. For more information about .struct/.endstruct, see Section 4.9, Assembly-Time Symbol Directives, on page 4-21.
Example 1  
In this example, the .int directive is used to initialize words.

```
1 000000  .space 73h
2 000000  .bss    PAGE, 128
3 000080  .bss    SYMPTR, 3
4 000008 E856 INST:  LD     #056h, A
5 000009 000A .int  10, SYMPTR, –1, 35 + ’a’, INST
              0000a 0080–
              0000b FFFF
              0000c 0084
              0000d 0008’
```

Example 2  
In this example, the .word directive is used to initialize words. The symbol WordX points to the first word that is reserved.

```
1 000000 C80  WORDX:  .word  3200, 1 + ‘AB’, –0AFh, ‘X’
              000001 4143
              000002 FF51
              000003 0058
```
.label  Create a Relocatable Label

Syntax

```
.label  symbol
```

Description

The .label directive defines a special symbol that refers to the loadtime address rather than the runtime address within the current section. Most sections created by the assembler have relocatable addresses. The assembler assembles each section as if it started at 0, and the linker relocates it to the address at which it loads and runs.

For some applications, it is desirable to have a section load at one address and run at a different address. For example, you may wish to load a block of performance-critical code into slower off-chip memory to save space, and then move the code to high-speed on-chip memory to run it.

Such a section is assigned two addresses at link time: a load address and a run address. All labels defined in the section are relocated to refer to the runtime address so that references to the section (such as branches) are correct when the code runs.

The .label directive creates a special label that refers to the loadtime address. This function is useful primarily to designate where the section was loaded for purposes of the code that relocates the section.

Example

This example shows the use of a loadtime address label.

```
.sect  ".EXAMP"

.label EXAMP_LOAD  ; load address of section.
START:            ; run address of section.
<code>
FINISH:           ; run address of section end.
.label EXAMP_END  ; load address of section end.
```

For more information about assigning runtime and loadtime addresses in the linker, see Section 7.9, Specifying a Section’s Runtime Address, on page 7-44.
Set Listing Page Size  .length/.width

Syntax

```
.length  page length
.width   page width
```

Description

The `.length` directive sets the page length of the output listing file. It affects the current and following pages. You can reset the page length with another `.length` directive.

- Default length: 60 lines
- Minimum length: 1 line
- Maximum length: 32 767 lines

The `.width` directive sets the page width of the output listing file. It affects the next line assembled and the lines following; you can reset the page width with another `.width` directive.

- Default width: 80 characters
- Minimum width: 80 characters
- Maximum width: 200 characters

The width refers to a full line in a listing file; the line counter value, SPC value, and object code are counted as part of the width of a line. Comments and other portions of a source statement that extend beyond the page width are truncated in the listing.

The assembler does not list the `.width` and `.length` directives.

Example

In this example, the page length and width are changed.

```
*****************************************************************************
**     Page length = 65 lines.     **
**     Page width  = 85 characters.    **
*****************************************************************************
.length    65
.width     85
*****************************************************************************
**     Page length = 55 lines.     **
**     Page width  = 100 characters.    **
*****************************************************************************
.length    55
.width     100
```
.list/.nolist  Start/Stop Source Listing

Syntax

<table>
<thead>
<tr>
<th>.list</th>
<th>.nolist</th>
</tr>
</thead>
</table>

Description

Two directives enable you to control the printing of the source listing:

- The .list directive allows the printing of the source listing.
- The .nolist directive suppresses the source listing output until a .list directive is encountered. The .nolist directive can be used to reduce assembly time and the source listing size. It can be used in macro definitions to suppress the listing of the macro expansion.

The assembler does not print the .list or .nolist directives or the source statements that appear after a .nolist directive. However, it continues to increment the line counter. You can nest the .list/.nolist directives; each .nolist needs a matching .list to restore the listing.

By default, the source listing is printed to the listing file; the assembler acts as if the .list directive had been specified. However, if you don’t request a listing file when you invoke the assembler, the assembler ignores the .list directive.

Example

This example shows how the .copy directive inserts source statements from another file. The first time this directive is encountered, the assembler lists the copied source lines in the listing file. The second time this directive is encountered, the assembler does not list the copied source lines, because a .nolist directive was assembled. Note that the .nolist, the second .copy, and the .list directives do not appear in the listing file. Note also that the line counter is incremented, even when source statements are not listed.
Source file:

.copy "copy2.asm"
* Back in original file
NOP
.nolist
.copy "copy2.asm"
.list
* Back in original file
.string "Done"

Listing file:

1                    .copy "copy2.asm"
A 1            * In copy2.asm (copy file)
A 2 000000 0020        .word 32, 1 + 'A'
     000001 0042
2            * Back in original file
3 000002 F495        NOP
7            * Back in original file
8 000005 0044        .string "Done"
     000006 006F
     000007 006E
     000008 0065
.long/.ulong/.xlong  Initialize Long Word

Syntax

<table>
<thead>
<tr>
<th></th>
<th>.long</th>
<th>.ulong</th>
<th>.xlong</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>value₁ [ , ... , valueₙ]</td>
<td>value₁ [ , ... , valueₙ]</td>
<td>value₁ [ , ... , valueₙ]</td>
</tr>
</tbody>
</table>

Description

The .long, .ulong, and .xlong directives place one or more 32-bit values into consecutive words in the current section. The most significant word is stored first. The .long and .ulong directives align the result on the long word boundary, while the .xlong directive does not. A value can be:

- An expression that the assembler evaluates and treats as a 32-bit signed or unsigned number

- A character string enclosed in double quotes. Each character in a string represents a separate value.

The value operand can be either an absolute or relocatable expression. If an expression is relocatable, the assembler generates a relocation entry that refers to the appropriate symbol; the linker can then correctly patch (relocate) the reference. This allows you to initialize memory with pointers to variables or with labels.

You can use up to 100 values, but they must fit on a single source statement line. If you use a label, it points to the first word that is initialized.

When you use the directives in a .struct/.endstruct sequence, they define a member’s size; they do not initialize memory. For more information about .struct/.endstruct, see Section 4.9, Assembly-Time Symbol Directives, on page 4-21.
Initialize Long Word .long/.ulong/.xlong

Example

This example shows how the .long and .xlong directives initialize double words.

1 000000 0000
   000001 ABCD
   000002 0000
   000003 0141
   000004 0000
   000005 0067
   000006 0000
   000007 006F

2 000008 0000'
   .xlong DAT1, 0AABBCCDDh
   000009 0000
   00000a AABB
   00000b CCDD

3 00000c DAT2:
Assign Character Strings to Substitution Symbols

Syntax

```
.loop [well-defined expression]
.break [well-defined expression]
.endloop
```

Description

Three directives enable you to repeatedly assemble a block of code.

The `.loop` directive begins a repeatable block of code. The optional expression evaluates to the loop count (the number of times to repeat the assembly of the code contained in the loop). If there is no expression, the loop count defaults to 1024, unless the assembler first encounters a `.break` directive with an expression that is true (nonzero) or omitted.

The `.break` directive is optional, along with its expression. When the expression is false (0), the loop continues. When the expression is true (nonzero), or omitted, the assembler breaks the loop and assembles the code after the `.endloop` directive.

The `.endloop` directive terminates a repeatable block of code; it executes when the `.break` directive is true (nonzero) or when number of loops performed equals the loop count given by `.loop`.

Example

This example illustrates how these directives can be used with the `.eval` directive.

```
1                  .eval       0,x
2            COEF
3                  .word       x*100
4                  .eval       x+1, x
5                  .break      x = 6
6                  .endloop
1        000000 0000      .word       0*100
1                         .eval       0+1, x
1                         .break      1 = 6
1        000001 0064      .word       1*100
1                         .eval       1+1, x
1                         .break      2 = 6
1        000002 00C8      .word       2*100
1                         .eval       2+1, x
1                         .break      3 = 6
1        000003 012C      .word       3*100
1                         .eval       3+1, x
1                         .break      4 = 6
1        000004 0190      .word       4*100
1                         .eval       4+1, x
1                         .break      5 = 6
1        000005 01F4      .word       5*100
1                         .eval       5+1, x
1                         .break      6 = 6
```
Define Macro .macro

Syntax

```
macname .macro [parameter1] [, ... parametern]
model statements or macro directives
.endm
```

Description

The `.macro` directive is used to define macros.

You can define a macro anywhere in your program, but you must define the macro before you can use it. Macros can be defined at the beginning of a source file, in an `.include/.copy` file, or in a macro library.

- `macname` names the macro. You must place the name in the source statement’s label field.
- `.macro` identifies the source statement as the first line of a macro definition. You must place `.macro` in the opcode field.
- `[parameters]` are optional substitution symbols that appear as operands for the `.macro` directive.
- `model statements` are instructions or assembler directives that are executed each time the macro is called.
- `macro directives` are used to control macro expansion.
- `.endm` terminates the macro definition.

Macros are explained in further detail in Chapter 5, “Macro Language”.

Assembler Directives 4-67
.mlib  Define Macro Library

Syntax

.mlilib ["filename"]

Description

The .mlilib directive provides the assembler with the name of a macro library. A macro library is a collection of files that contain macro definitions. These files are bound into a single file (called a library or archive) by the archiver. Each member of a macro library may contain one macro definition that corresponds to the name of the file. Macro library members must be source files (not object files).

The filename of a macro library member must be the same as the macro name, and its extension must be .asm. The filename must follow host operating system conventions; it may be enclosed in double quotes. You can specify a full pathname (for example, c:\dsp\macs.lib). If you do not specify a full pathname, the assembler searches for the file in:

1) The directory that contains the current source file
2) Any directories named with the –i assembler option
3) Any directories specified by the environment variable A_DIR

For more information about the –i option and the environment variable, see Section 3.4, Naming Alternate Directories for Assembler Input, on page 3-8.

When the assembler encounters a .mlilib directive, it opens the library and creates a table of the library’s contents. The assembler enters the names of the individual library members into the opcode table as library entries. This redefines any existing opcodes or macros that have the same name. If one of these macros is called, the assembler extracts the entry from the library and loads it into the macro table. The assembler expands the library entry in the same way it expands other macros, but it does not place the source code into the listing. Only macros that are actually called from the library are extracted, and they are extracted only once.
Example

This example creates a macro library that defines two macros, incr and decr. The file incr.asm contains the definition of incr, and decr.asm contains the definition of decr.

<table>
<thead>
<tr>
<th>incr.asm</th>
<th>decr.asm</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Macro for incrementing incr .macro ADD #1,A ADD #1,B .endm</td>
<td>* Macro for zero accumulators decr .macro SUB A,A SUB B,B .endm</td>
</tr>
</tbody>
</table>

Use the archiver to create a macro library:

```
ar500 -a mac incr.asm decr.asm
```

Now you can use the .mlib directive to reference the macro library and define the incr and decr macros:

```
1 .mlib "mac.lib" 2
2 000000 decr ; Macro call
1 000000 F420 SUB A,A
1 000001 F720 SUB B,B
3 000002 incr ; Macro call
1 000002 F000 ADD #1,A
 000003 0001
1 000004 F300 ADD #1,B
 000005 0001
```
Two directives enable you to control the listing of macro and repeatable block expansions in the listing file:

- The .mlist directive allows macro and .loop/.endloop block expansions in the listing file.
- The .mnolist directive suppresses macro and .loop/.endloop block expansions in the listing file.

By default, the assembler behaves as if the .mlist directive had been specified.

### Example

This example defines a macro named `STR_3`. The second time the macro is called, the macro expansion is not listed, because a .mnolist directive was assembled. The third time the macro is called, the macro expansion is listed, because a .mlist directive was assembled.

```assembly
1            STR_3 .macro   P1, P2, P3
2                   .string ":p1:\“, ":p2:\“, ":p3:\“
3                   .endm
4
5 000000            STR_3 "as", "I", "am"
6                   .string ":p1:\“, ":p2:\“, ":p3:\“
7 000000 003A       .string ":p1:\“, ":p2:\“, ":p3:\“
8 000001 0070
9 000002 0031
10 000003 003A
11 000004 003A
12 000005 0070
13 000006 0032
14 000007 003A
15 000008 003A
16 000009 0070
17 00000a 0033
18 00000b 003A
19                   .mnolist
20 00000c            STR_3 "as", "I", "am"
21                   .mlist
22 000018            STR_3 "as", "I", "am"
23                   .string ":p1:\“, ":p2:\“, ":p3:\“
24 000019 0070
25 00001a 0031
26 00001b 003A
27 00001c 003A
28 00001d 0070
29 00001e 0032
30 00001f 003A
31 000020 003A
32 000021 0070
33 000022 0033
34 000023 003A
```
Assign Memory–Mapped Register Names as Global Symbols  

.mmregs

Syntax

.mmregs

Description

The .mmregs directive defines global symbolic names for the C54x registers and places them in the global symbol table. It is equivalent to executing AL .set 8, AH .set 9, etc. The symbols are local and absolute. Using the .mmregs directive makes it unnecessary to define these symbols.

Table 4–2. Memory-Mapped Registers

<table>
<thead>
<tr>
<th>Name</th>
<th>Hexadecimal Address</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMR</td>
<td>0000</td>
<td>Interrupt mask register</td>
</tr>
<tr>
<td>IFR</td>
<td>0001</td>
<td>Interrupt flag register</td>
</tr>
<tr>
<td>–</td>
<td>2–5</td>
<td>Reserved</td>
</tr>
<tr>
<td>ST0</td>
<td>0006</td>
<td>Status 0 register</td>
</tr>
<tr>
<td>ST1</td>
<td>0007</td>
<td>Status 1 register</td>
</tr>
<tr>
<td>AL</td>
<td>0008</td>
<td>A accumulator low (A [15:0])</td>
</tr>
<tr>
<td>AH</td>
<td>0009</td>
<td>A accumulator high (A [31:16])</td>
</tr>
<tr>
<td>AG</td>
<td>000A</td>
<td>A accumulator guard (A [39:32])</td>
</tr>
<tr>
<td>BL</td>
<td>000B</td>
<td>B accumulator low (B [15:0])</td>
</tr>
<tr>
<td>BH</td>
<td>000C</td>
<td>B accumulator high (B [31:16])</td>
</tr>
<tr>
<td>BG</td>
<td>000D</td>
<td>B accumulator guard (B [39:32])</td>
</tr>
<tr>
<td>T</td>
<td>000E</td>
<td>Temporary register</td>
</tr>
<tr>
<td>TRN</td>
<td>000F</td>
<td>Transition register</td>
</tr>
<tr>
<td>BK</td>
<td>0019</td>
<td>Circular size register</td>
</tr>
<tr>
<td>BRC</td>
<td>001A</td>
<td>Block repeat counter</td>
</tr>
<tr>
<td>RSA</td>
<td>001B</td>
<td>Block repeat start address</td>
</tr>
<tr>
<td>REA</td>
<td>001C</td>
<td>Block repeat end address</td>
</tr>
<tr>
<td>PMST</td>
<td>001D</td>
<td>PMST register</td>
</tr>
<tr>
<td>DRR0</td>
<td>0020</td>
<td>Data receive register 0</td>
</tr>
<tr>
<td>BDRR</td>
<td>0020</td>
<td>Data receive register</td>
</tr>
</tbody>
</table>

Note: Duplication of address values in the table supports the different names of the registers as they are implemented on different C54x devices.
### Table 4–2. Memory-Mapped Registers (Continued)

<table>
<thead>
<tr>
<th>Name</th>
<th>Hexadecimal Address</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BDDR0</td>
<td>0020</td>
<td>BSP0 data receive register</td>
</tr>
<tr>
<td>DRR</td>
<td>0020</td>
<td>Data receive register</td>
</tr>
<tr>
<td>DXR0</td>
<td>0021</td>
<td>Data transmit register 0</td>
</tr>
<tr>
<td>BDXR</td>
<td>0021</td>
<td>Data transmit register</td>
</tr>
<tr>
<td>BDXR0</td>
<td>0021</td>
<td>Data transmit register</td>
</tr>
<tr>
<td>DXR</td>
<td>0021</td>
<td>Data transmit register</td>
</tr>
<tr>
<td>SPC0</td>
<td>0022</td>
<td>Serial port control register 0</td>
</tr>
<tr>
<td>BSPC</td>
<td>0022</td>
<td>Serial port control register</td>
</tr>
<tr>
<td>SPC</td>
<td>0022</td>
<td>Serial port control register</td>
</tr>
<tr>
<td>BSPCE</td>
<td>0023</td>
<td>BSP control extension register</td>
</tr>
<tr>
<td>BSPCE0</td>
<td>0023</td>
<td>BSP control extension register</td>
</tr>
<tr>
<td>SPCE</td>
<td>0023</td>
<td>BSP control extension register</td>
</tr>
<tr>
<td>TIM</td>
<td>0024</td>
<td>Timer register</td>
</tr>
<tr>
<td>PRD</td>
<td>0025</td>
<td>Period register</td>
</tr>
<tr>
<td>TCR</td>
<td>0026</td>
<td>Timer control register</td>
</tr>
<tr>
<td>PDWSR</td>
<td>0028</td>
<td>Program/data S/W wait-state register</td>
</tr>
<tr>
<td>SWWSR</td>
<td>0028</td>
<td>Program/data S/W wait-state register</td>
</tr>
<tr>
<td>IOWSR</td>
<td>0029</td>
<td>Bank-switching control register</td>
</tr>
<tr>
<td>BSCR</td>
<td>0029</td>
<td>Bank-switching control register</td>
</tr>
<tr>
<td>HPIC</td>
<td>002C</td>
<td>HPI control register</td>
</tr>
<tr>
<td>DRR1</td>
<td>0030</td>
<td>Data receive register 1</td>
</tr>
<tr>
<td>TRCV</td>
<td>0030</td>
<td>Data receive register</td>
</tr>
<tr>
<td>DXR1</td>
<td>0031</td>
<td>Data transmit register 1</td>
</tr>
<tr>
<td>TDXR</td>
<td>0031</td>
<td>Data transmit register</td>
</tr>
</tbody>
</table>

**Note:** Duplication of address values in the table supports the different names of the registers as they are implemented on different C54x devices.
### Table 4–2. Memory-Mapped Registers (Continued)

<table>
<thead>
<tr>
<th>Name</th>
<th>Hexadecimal Address</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPC1</td>
<td>0032</td>
<td>Serial port control register 1</td>
</tr>
<tr>
<td>TSPC</td>
<td>0032</td>
<td>Serial port control register</td>
</tr>
<tr>
<td>TRAD</td>
<td>0035</td>
<td>TDM receive address register</td>
</tr>
<tr>
<td>AXR</td>
<td>0038</td>
<td>ABU transmit address register</td>
</tr>
<tr>
<td>TCSR</td>
<td>0033</td>
<td>TDM channel select register</td>
</tr>
<tr>
<td>TRTA</td>
<td>0034</td>
<td>TDM receive/transmit register</td>
</tr>
<tr>
<td>AXR0</td>
<td>0038</td>
<td>ABU transmit address register</td>
</tr>
<tr>
<td>ARX</td>
<td>0038</td>
<td>ABU transmit address register</td>
</tr>
<tr>
<td>BKX</td>
<td>0039</td>
<td>ABU transmit buffer size register</td>
</tr>
<tr>
<td>BKX0</td>
<td>0039</td>
<td>ABU transmit buffer size register</td>
</tr>
<tr>
<td>ARR</td>
<td>003A</td>
<td>ABU receive address register</td>
</tr>
<tr>
<td>ARR0</td>
<td>003A</td>
<td>ABU receive address register</td>
</tr>
<tr>
<td>BKR</td>
<td>003B</td>
<td>ABU receive buffer size register</td>
</tr>
<tr>
<td>AXR1</td>
<td>003C</td>
<td>ABU transmit address register</td>
</tr>
<tr>
<td>BKX1</td>
<td>003D</td>
<td>ABU transmit buffer size register</td>
</tr>
<tr>
<td>ARR1</td>
<td>003E</td>
<td>ABU receive address register</td>
</tr>
<tr>
<td>BKR1</td>
<td>003F</td>
<td>ABU receive buffer size register</td>
</tr>
<tr>
<td>BDRR1</td>
<td>0040</td>
<td>BSP data receive register</td>
</tr>
<tr>
<td>BDXR1</td>
<td>0041</td>
<td>Data transmit register</td>
</tr>
<tr>
<td>BSPC1</td>
<td>0042</td>
<td>BSP control register</td>
</tr>
<tr>
<td>BSPCE1</td>
<td>0043</td>
<td>BSP control extension register</td>
</tr>
<tr>
<td>CLKMD</td>
<td>0058</td>
<td>Clock modes register</td>
</tr>
<tr>
<td>XPC</td>
<td>001E</td>
<td>Extended memory map register</td>
</tr>
</tbody>
</table>

**Note:** Duplication of address values in the table supports the different names of the registers as they are implemented on different C54x devices.
.newblock  Terminate Local Symbol Block

Syntax

```
.newblock
```

Description

The `.newblock` directive undefines any local labels currently defined. Local labels, by nature, are temporary; the `.newblock` directive resets them and terminates their scope.

A local label is a label in the form $n$, where $n$ is a single decimal digit. A local label, like other labels, points to an instruction word. Unlike other labels, local labels cannot be used in expressions. Local labels are not included in the symbol table.

After a local label has been defined and (perhaps) used, you should use the `.newblock` directive to reset it. The .text, .data, and named sections also reset local labels. Local labels that are defined within an include file are not valid outside of the local file.

Example

This example shows how the local label $1$ is declared, reset, and then declared again.

```
1  .ref   ADDRA, ADDRB, ADDRC
2       0076  B  .set   76h
3
4 000000 1000! LABEL1:  LD   ADDRA, A
5 000001 F010  SUB    #B, A
   000002 0076
6 000003 F843  BC     $1, ALT
   000004 0008'
7 000005 1000!  LD   ADDRB, A
8 000006 F073  B      $2
   000007 0009'
9
10 000008 1000! $1   LD   ADDRA, A
11 000009 0000! $2   ADD   ADDRC, A
12 .newblock ; Undefine $1 to reuse
13 00000a F843  BC     $1, ALT
   00000b 000D'
14 00000c 8000!   STL   A, ADDRC
15 00000d F495  $1   NOP
```
Control Remarks  

Syntax

.noremark [num]
.remark [num]

Description

The .noremark directive suppresses the assembler remark identified by num. If num is not specified, all remarks will be suppressed. A remark is an informational assembler message that is less severe than a warning.

This directive is equivalent to using the –r[num] assembler option.

The .remark directive re-enables the remark(s) previously suppressed.
.option  Select Listing Options

Syntax

```
.option  option list
```

Description

The `.option` directive selects several options for the assembler output listing. *Option list* is a list of options separated by vertical lines; each option selects a listing feature. These are valid options:

- **B**: limits the listing of `.byte` directives to one line.
- **L**: limits the listing of `.long` directives to one line.
- **M**: turns off macro expansions in the listing.
- **R**: resets the B, M, T, and W options.
- **T**: limits the listing of `.string` directives to one line.
- **W**: limits the listing of `.word` directives to one line.
- **X**: produces a symbol cross-reference listing. (You can also obtain a cross-reference listing by invoking the assembler with the `-x` option.)

Options are not case sensitive.
Example

This example shows how to limit the listings of the `.byte`, `.word`, `.long`, and `.string` directives to one line each.

```
1    ****************************************
2    ** Limit the listing of .byte, .word, **
3    ** .long, and .string directives    **
4    **       to 1 line each.            **
5    ****************************************
6    .option B, W, L, T
7 000000 00BD .byte -'C', 0B0h, 5
8 000004 AABB .long 0AABBCCDDh, 536 + 'A'
9 000008 15AA .word 5546, 78h
10 0000a 0045 .string “Extended Registers”
12    ****************************************
13    **     Reset the listing options.    **
14    ****************************************
15    .option R
16 00001c 00BD .byte -'C', 0B0h, 5
17 000020 AABB .long 0AABBCCDDh, 536 + 'A'
18 000024 15AA .word 5546, 78h
19 000026 0045 .string “Extended Registers”
```

Assembler Directives  4-77
.page  Eject Page in Listing

Syntax  

```
.page
```

Description  

The .page directive produces a page eject in the listing file. The .page directive is not printed in the source listing, but the assembler increments the line counter when it encounters it. Using the .page directive to divide the source listing into logical divisions improves program readability.

Example  

This example shows how the .page directive causes the assembler to begin a new page of the source listing.

Source file:

```
.title   "**** Page Directive Example ****"
;        
;        
;        
.page
```

Listing file:

```
**** Page Directive Example ****                                PAGE    1
2            ;        
3            ;        
4            ;        
TMS320C54x COFF Assembler       Version x.xx
Copyright (c) 2001    Texas Instruments Incorporated
**** Page Directive Example ****                                PAGE    2
`
Specify Blocking for an Initialized Section  .sblock

Syntax

```markdown
**.sblock ["section name"] [, "section name", ... ]
```

Description

The `.sblock` directive designates sections for blocking. Blocking is an address alignment mechanism similar to page alignment, but weaker. A blocked section is guaranteed to not cross a page boundary (128 words) if it is smaller than a page, or to start on a page boundary if it is larger than a page. This directive allows specification of blocking for initialized sections only, not uninitialized sections declared with .usect or the .bss directives. The `section names` may optionally be enclosed in quotes.

Example

This example designates the .text and .data sections for blocking.

```plaintext
1 ****************************************
2 ** Specify blocking for the .text **
3 ** and .data sections.            **
4 ****************************************
5 .sblock .text, .data
```
.sect  Assign Character Strings to Substitution Symbols

Syntax

```
.sect  "section name"
```

Description

The .sect directive defines a named section that can be used like the default .text and .data sections. The .sect directive begins assembling source code into the named section.

The `section name` identifies a section that the assembler assembles code into. The name can be up to 200 characters and must be enclosed in double quotes. A section name can contain a subsection name in the form `section name:subsection name`. For COFF1 formatted files, only the first 8 characters are significant.

For more information about COFF sections, see Chapter 2, Introduction to Common Object File Format.

Example

This example defines a special-purpose section named Vars and assembles code into it.

```
1  ******************************************************
2  ** Begin assembling into .text section.  **
3  ******************************************************
4  000000          .text
5  000000 E878    LD      #78h, A ; Assembled into .text
6  000001 F000    ADD     #36h, A ; Assembled into .text
     000002 0036
7  ******************************************************
8  ** Begin assembling into Vars section. **
9  ******************************************************
10 000000          .sect  "Vars"
11  0010 WORD_LEN  .set    16
12  0020 DWORD_LEN  .set    WORD_LEN * 2
13  0008 BYTE_LEN  .set    WORD_LEN / 2
14  ******************************************************
15  ** Resume assembling into .text section. **
16  ******************************************************
17  000003          .text
18  000003 F000    ADD     #42h, A ; Assembled into .text
     000004 0042
19  000005 0003    .byte   3, 4    ; Assembled into .text
     000006 0004
20  ******************************************************
21  ** Resume assembling into Vars section. **
22  ******************************************************
23  000000          .sect  "Vars"
24  000000 000D    .field  13, WORD_LEN
25  000001 0A00    .field  0Ah, BYTE_LEN
26  000002 0000    .field  10q, DWORD_LEN
     000003 0008
27
```
Define Assembly-Time Constant .set/.equ

Syntax
symbol .set value
symbol .equ value

Description
The .set and .equ directives equate a value to a symbol. The symbol can then be used in place of a value in assembly source. This allows you to equate meaningful names with constants and other values.

- The symbol is a label that must appear in the label field.
- The value must be a well-defined expression; that is, all symbols in the expression must be previously defined in the current source module.

Undefined external symbols and symbols that are defined later in the module cannot be used in the expression. If the expression is relocatable, the symbol to which it is assigned is also relocatable.

The value of the expression appears in the object field of the listing. This value is not part of the actual object code and is not written to the output file.

Symbols defined with .set or .equ can be made externally visible with the .def or .global directive. In this way, you can define global absolute constants.

Example
This example shows how symbols can be assigned with .set and .equ.

```assembly
1  **********************************************
2  ** Equate symbol AUX_R1 to register AR1 **
3  ** and use it instead of the register. **
4  **********************************************
5  0011  AUX_R1  .set    AR1
6  000000 7711          STM     #56h, AUX_R1
7  000001 0056
8  **********************************************
9  ** Set symbol index to an integer expr. **
10  ** and use it as an immediate operand. **
11  **********************************************
12  0035  INDEX   .equ    100/2 +3
13  000002 F000          ADD     #INDEX, A
14  000003 0035
15  **********************************************
16  ** Set symbol SYMTAB to a relocatable expr. **
17  ** and use it as a relocatable operand. **
18  **********************************************
19  000004 000A  LABEL   .word   10
20  000005  SYMTAB   .set    LABEL + 1
21
22  **********************************************
23  ** Set symbol NSYMS equal to the symbol **
24  ** INDEX and use it as you would INDEX. **
25  **********************************************
26  0035  NSYMS   .set    INDEX
27  000005 0035          .word   NSYMS
```

Assembler Directives 4-81
.space/.bes  Reserve Space

Syntax

```
.space size in bits
.bes size in bits
```

Description

The .space and .bes directives reserve `size` number of bits in the current section and fill them with 0s.

When you use a label with the .space directive, it points to the first word reserved. When you use a label with the .bes directive, it points to the last word reserved.

Example

This example shows how memory is reserved with the .space and .bes directives.

```
000000  *********************************************
** Begin assembling into .text section. **
000000  *********************************************
000000               .text
000000 0F0h
00000f 0100          .word   100h, 200h
000010 0200
000000  *********************************************
** Begin assembling into .data section. **
000000  *********************************************
000000 0049          .string "In .data"
000001 006E
000002 0020
000003 002E
000004 0064
000005 0061
000006 0074
000007 0061
000008  *********************************************
** Reserve 100 bits in the .data section; **
** RES_1 points to the first word that **
** contains reserved bits. **
000008 000F          .word   15
000010 0008"          .word   RES_1
000010  *********************************************
** Reserve 20 bits in the .data section; **
** RES_2 points to the last word that **
** contains reserved bits. **
000012 0012          .word   36h
000014 0012"          .word   RES_2
```
Control Listing of Substitution Symbols  .sslist/.ssnolist

Syntax

| .sslist | .ssnolist |

Description

Two directives enable you to control substitution symbol expansion in the listing file:

- The `.sslist` directive allows substitution symbol expansion in the listing file. The expanded line appears below the actual source line.

- The `.ssnolist` directive suppresses substitution symbol expansion in the listing file.

By default, all substitution symbol expansion in the listing file is inhibited. Lines with the pound (#) character denote expanded substitution symbols.

Example

This example shows code that, by default, suppresses the listing of substitution symbol expansion, and it shows the `.sslist` directive assembled, instructing the assembler to list substitution symbol code expansion.

(a) Mnemonic example

```
1 000000 .bss ADDRX, 1
2 000001 .bss ADDRY, 1
3 000002 .bss ADDRA, 1
4 000003 .bss ADDR, 1
5 ADD2 .macro ADDRA, ADDRB
6 LD ADDRA, A
7 ADD ADDR, A
8 STL A, ADDR
9 .endm
10
11 0000008094 STL A, *AR4+
12 000001 ADD2 ADDRX, ADDRY
1 0000011000 LD ADDRX, A
1 0000020001 ADD ADDR, A
1 0000038001 STL A, ADDRY
13
14 .sslist
15
16 000004 8094 STL A, *AR4+
17 000005 8090 STL A, *AR0+
18
19 000006 ADD2 ADDRX, ADDRY
1 0000061000 LD ADDRA, A
# LD ADDRA, A
1 0000070001 ADD ADDR, A
# ADD ADDR, A
1 0000088001 STL A, ADDR
# STL A, ADDR
```
(b) Algebraic example

1 000000 .bss ADDRX, 1
2 000001 .bss ADDRY, 1
3 000002 .bss ADDRA, 1
4 000003 .bss ADDRB, 1
5 ADD2 .macro ADDRA, ADDRB
6 A = @ADDRA
7 A = A + @ADDRB
8 @ADDRB = A
9 .endm
10
11 0000008094 *AR4+ = A
12 000001 ADD2 ADDRX, ADDRY
    1 0000001000– A = @ADDRX
    1 0000020001– A = A + @ADDRY
    1 0000038001– @ADDY = A
13
14 .sslist
15
16 000004 8094 *AR4+ = A
17 000005 8090 *AR0+ = A
18
19 000006 ADD2 ADDRX, ADDRY
    1 0000061000– A = @ADDRA
    # A = @ADDRX
    1 0000070001– A = A + @ADDRB
    # A = A + @ADDY
    1 0000088001– @ADDY = A
    # @ADDY = A

4-84
**Syntax**

```
.string "string1" [, ..., "stringn"]
.pstring "string1" [, ..., "stringn"]
```

**Description**

The `.string` and `.pstring` directives place 8-bit characters from a character string into the current section. With the `.string` directive, each 8-bit character has its own 16-bit word, but with the `.pstring` directive, the data is packed so that each word contains two 8-bit bytes. Each `string` is either:

- An expression that the assembler evaluates and treats as a 16-bit signed number, or
- A character string enclosed in double quotes. Each character in a string represents a separate byte.

With `.pstring`, values are packed into words starting with the most significant byte of the word. Any unused space is padded with null bytes.

The assembler truncates any values that are greater than 8 bits. You may have up to 100 operands, but they must fit on a single source statement line.

If you use a label, it points to the location of the first word that is initialized.

Note that when you use `.string` in a `.struct/.endstruct` sequence, `.string` defines a member’s size; it does not initialize memory. For more information about `.struct/.endstruct`, see Section 4.9, *Assembly-Time Symbol Directives*, on page 4-21.

**Example**

This example shows 8-bit values placed into words in the current section.

```
1 000000 0041 Str_Ptr: .string "ABCD"
  000001 0042
  000002 0043
  000003 0044
2 000004 0041 .string 41h, 42h, 43h, 44h
  000005 0042
  000006 0043
  000007 0044
3 000008 4175 .pstring "Austin", "Houston"
  000009 7374
  00000a 696E
  00000b 486F
  00000c 7573
  00000d 746F
  00000e 6E00
4 00000f 0030 .string 36 + 12
```
**.struct/.endstruct/.tag**  Declare Structure Type

### Syntax

```
[ stag ] .struct [ expr ]
[ mem0 ]   element [ expr0 ]
[ mem1 ]   element [ expr1 ]
  .
  .
[ memn ]   .tag stag [ exprn ]
  .
  .
[ memN ]   element [ exprN ]
[ size ] .endstruct

label .tag stag
```

### Description

The **.struct** directive assigns symbolic offsets to the elements of a data structure definition. This enables you to group similar data elements together and then let the assembler calculate the element offset. This is similar to a C structure or a Pascal record. A .struct definition may contain a .union definition, and .structs and .unions may be nested. The .struct directive does not allocate memory; it merely creates a symbolic template that can be used repeatedly.

The **.endstruct** directives terminates the structure definition.

The **.tag** directive gives structure characteristics to a `label`, simplifying the symbolic representation and providing the ability to define structures that contain other structures. The **.tag** directive does not allocate memory. The structure tag (stag) of a .tag directive must have been previously defined.

- **stag** is the structure’s tag. Its value is associated with the beginning of the structure. If no stag is present, the assembler puts the structure members in the global symbol table with the value of their absolute offset from the top of the structure. Stag is optional for .struct, but required for .tag.

- **expr** is an optional expression indicating the beginning offset of the structure. Structures default to start at 0. This parameter can only be used with a top-level structure. It cannot be used when defining a nested structure.
mem\textsubscript{n} is an optional label for a member of the structure. This label is absolute and equates to the present offset from the beginning of the structure. A label for a structure member cannot be declared global.

\textit{element} is one of the following descriptors: .byte, .char, .double, field, .float, .half, .int, .long, .short, .string, .ubyte, .uchar, .uhalt, .uint, .ulong, .ushort, .uword, and .word. An element can also be a complete declaration of a nested structure or union, or a structure or union declared by its tag. Following a .struct directive, these directives describe the element’s size. They do not allocate memory.

expr\textsubscript{n} is an optional expression for the number of elements described. This value defaults to 1. A .string element is considered to be one word in size, and a .field element is one bit.

\textit{size} is an optional label for the total size of the structure.

\textbf{Note: Directives That Can Appear in a .struct/.endstruct Sequence}

The only directives that can appear in a .struct/.endstruct sequence are element descriptors, structure and union tags, conditional assembly directives, and the .align directive, which aligns the member offsets on word boundaries. Empty structures are illegal.

These examples show various uses of the .struct, .tag, and .endstruct directives.
\textbf{.struct/.endstruct/.tag} \textit{Declare Structure Types}

Example 1

\begin{verbatim}
1             REAL_REC .struct ; stag
2 0000 NOM .int ; member1 = 0
3 0001 DEN .int ; member2 = 1
4 0002 REAL_LEN .endstruct ; real_len = 2
5 6 00000 0001– ADD REAL + REAL_REC.DEN, A ; access structure element
6 00000 .bss REAL, REAL_LEN ; allocate mem rec
\end{verbatim}

Example 2

\begin{verbatim}
10           CPLX_REC .struct ; stag
11 0000 REALI .tag REAL_REC ; member1 = 0
12 0002 IMAGI .tag REAL_REC
13 0004 CPLX_LEN .endstruct ; cplx_len = 4
14           COMPLEX .tag CPLX_REC ; assign structure attrib
15 17 000002 .bss COMPLEX, CPLX_LEN
16 19 000001 0002– ADD COMPLEX.REALI, A ; access structure
17 000002 8002– STL A, COMPLEX.REALI
18 22 000003 0104– ADD COMPLEX.IMAGI, B ; allocate space
\end{verbatim}

Example 3

\begin{verbatim}
1 .struct ; no stag puts mems into
global symbol table
3 0000 X .int ; create 3 dim templates
4 0001 Y .int
5 0002 Z .int
6 0003 .endstruct
\end{verbatim}

Example 4

\begin{verbatim}
1           BIT_REC .struct ; stag
2 0000 STREAM .string 64
3 0040 BIT7 .field 7 ; bits1 = 64
4 0040 BIT9 .field 9 ; bits2 = 64
5 0041 BIT10 .field 10 ; bits3 = 65
6 0042 X_INT .int ; x_int = 66
7 0043 BIT_LEN .endstruct ; length = 67
8 9 BITS .tag BIT_REC
10 000000 0040– ADD BITS.BIT7, A ; move into acc
11 000001 f030 AND #007Fh, A ; mask off garbage bits
000002 007f
12 13 000000 .bss BITS, BIT_REC
\end{verbatim}

4-88
Define Tab Size .tab

Syntax

| .tab size |

Description

The .tab directive defines the tab size. Tabs encountered in the source input are translated to size spaces in the listing. The default tab size is eight spaces.

Example

Each of the following lines consists of a single tab character followed by an NOP instruction.

Source file:

```assembly
; default tab size
NOP
NOP
NOP
.tab 4
NOP
NOP
NOP
.tab 16
NOP
NOP
NOP
```

Listing file:

```
1 ; default tab size
2 000000 F495 NOP
3 000001 F495 NOP
4 000002 F495 NOP
5
7 000003 F495 NOP
8 000004 F495 NOP
9 000005 F495 NOP
10
12 000006 F495 NOP
13 000007 F495 NOP
14 000008 F495 NOP
```
.text  Assemble Into .text Sections

Syntax

```
.text
```

Description

The `.text` directive tells the assembler to begin assembling into the `.text` section, which usually contains executable code. The section program counter is set to 0 if nothing has yet been assembled into the `.text` section. If code has already been assembled into the `.text` section, the section program counter is restored to its previous value in the section.

`.text` is the default section. Therefore, at the beginning of an assembly, the assembler assembles code into the `.text` section unless you specify a different sections directive (.data or .sect).

For more information about COFF sections, see Chapter 2, Introduction to Common Object File Format.

Example

This example assembles code into the `.text` and `.data` sections. The `.data` section contains integer constants, and the `.text` section contains executable code.

```
1            *****************************************
2            ** Begin assembling into .data section.**
3            *****************************************
4 000000     .data
5 000000 000a .byte 0Ah, 0Bh
   000001 000b
6            ******************************************
7            ** Begin assembling into .text section. **
8            ******************************************
9 000000     .text
10 000000 0041 START: .string "A","B","C"
11 000001 0042
12 000002 0043
13 000003 0058 END:  .string "X","Y","Z"
14 000004 0059
15 000005 005a
16 000006 0000'    ADD     START, A
17 000007 0003'    ADD     END, A
18            **********************************************
19            ** Resume assembling into .data section.**
20            **********************************************
21 000002     .data
22 000002 000c .byte 0Ch, 0Dh
23 000003 000d
24 000008     .text
25 000008 0051 .string "Quit"
```

4-90
**Define Page Title** `.title`

**Syntax**

```
.title "string"
```

**Description**

The `.title` directive supplies a title that is printed in the heading on each listing page. The source statement itself is not printed, but the line counter is incremented.

The *string* is a quote-enclosed title of up to 65 characters. If you supply more than 65 characters, the assembler truncates the string and issues a warning.

The assembler prints the title on the page that follows the directive, and on subsequent pages until another .title directive is processed. If you want a title on the first page, the first source statement must contain a .title directive.

**Example**

In this example, one title is printed on the first page and a different title on succeeding pages.

**Source file:**

```
.title "**** Fast Fourier Transforms ****"
;        .
;        .
;        .
.title "**** Floating-Point Routines ****"
.page
```

**Listing file:**

```
COFF Assembler       Version x.xx
Copyright (c) 2001    Texas Instruments Incorporated
**** Fast Fourier Transforms ****                               PAGE    1
  2            ;        .
  3            ;        .
  4            ;        .
COFF Assembler       Version x.xx
Copyright (c) 2001    Texas Instruments Incorporated
**** Floating-Point Routines ****                               PAGE    2
```

**Assembler Directives**
.union/.endunion/.tag  Declare Union Type

Syntax

```
[ utag ] .union [ expr ]
[ mem0 ] element [ expr0 ]
[ mem1 ] element [ expr1 ]
  .  .  .
[ memn ] .tag utagn[, exprn]
  .  .  .
[ memN ] element [ exprN ]
[ size ] .endunion
label .tag utag
```

Description

The `.union` directive assigns symbolic offsets to the elements of alternate data structure definitions to be allocated in the same memory space. This enables you to define several alternate structures and then let the assembler calculate the element offset. This is similar to a C union. The `.union` directive does not allocate any memory; it merely creates a symbolic template that can be used repeatedly.

A `.struct` definition may contain a `.union` definition, and `.structs` and `.unions` may be nested.

The `.endunion` directive terminates the union definition.

The `.tag` directive gives structure or union characteristics to a `label`, simplifying the symbolic representation and providing the ability to define structures or unions that contain other structures or unions. The `.tag` directive does not allocate memory. The structure or union tag of a `.tag` directive must have been previously defined.
Declare Union Type  .union/.endunion/.tag

*utag*  is the union’s tag. Its value is associated with the beginning of the union. If no utag is present, the assembler puts the union members in the global symbol table with the value of their absolute offset from the top of the union. In this case, each member must have a unique name.

*expr*  is an optional expression indicating the beginning offset of the union. Unions default to start at 0. This parameter can only be used with a top-level union. It cannot be used when defining a nested union.

*memn*  is an optional label for a member of the union. This label is absolute and equates to the present offset from the beginning of the union. A label for a union member cannot be declared global.

*element*  is one of the following descriptors: .byte, .char, .double, field, .float, .half, .int, .long, .short, .string, .ubyte, .uchar, .uhalt, .uint, .ulong, .ushort, .uword, and .word. An element can also be a complete declaration of a nested structure or union, or a structure or union declared by its tag. Following a .union directive, these directives describe the element’s size. They do not allocate memory.

*exprn*  is an optional expression for the number of elements described. This value defaults to 1. A .string element is considered to be one word in size, and a .field element is one bit.

*size*  is an optional label for the total size of the union.

### Note: Directives That Can Appear in a .union/.endunion Sequence

The only directives that can appear in a .union/.endunion sequence are element descriptors, structure and union tags, conditional assembly directives, and the .align directive, which aligns the member offsets on word boundaries. Empty structures are illegal.
These examples show unions with and without tags.

Example 1

```
1 .global employid
2  example .union ; utag
3  0000  ival .word ; member1 = int
4  0000  fval .float ; member2 = float
5  0000  sval .string ; member3 = string
6  0002  real_len .endunion ; real_len = 2
7
8 000000 .bss employid, real_len ; allocate memory
9
10 employid .tag xample ; name an instance
11 000000 0000- ADD employid.fval, A ; access union element
```

Example 2

```
1
2  .union ; utag
3  0000  x  .long ; member1 = long
4  0000  y  .float ; member2 = float
5  0000  z  .word ; member3 = word
6  0002  size_u .endunion ; real_len = 2
7
```
Reserve Uninitialized Space \texttt{.usect}

**Syntax**

\texttt{symbol \texttt{.usect} "section name", size in words[, [blocking flag] [alignment flag]]}

**Description**

The \texttt{.usect} directive reserves space for variables in an uninitialized, named section. This directive is similar to the \texttt{.bss} directive; both simply reserve space for data and have no contents. However, \texttt{.usect} defines additional sections that can be placed anywhere in memory, independently of the \texttt{.bss} section.

- \texttt{symbol} points to the first location reserved by this invocation of the \texttt{.usect} directive. The symbol corresponds to the name of the variable for which you're reserving space.

- \texttt{section name} must be enclosed in double quotes. This parameter names the uninitialized section. The name can be up to 200 characters. For COFF1 formatted files, only the first 8 characters are significant. A section name can contain a subsection name in the form \texttt{section name:subsection name}.

- \texttt{size in words} is an expression that defines the number of words that are reserved in \texttt{section name}.

- \texttt{blocking flag} is an optional parameter. If specified and nonzero, the flag means that this section will be blocked. Blocking is an address mechanism similar to alignment, but weaker. It means a section is guaranteed to not cross a page boundary (128 words) if it is smaller than a page, and to start on a page boundary if it is larger than a page. This blocking applies to the section, not to the object declared with this instance of the \texttt{.usect} directive.

- \texttt{alignment flag} is an optional parameter. This flag causes the assembler to allocate size on long word boundaries.

**Note: Specifying an Alignment Flag Only**

To specify an alignment flag without a blocking flag, you must insert two commas before the alignment flag, as shown in the syntax.

Other sections directives (\texttt{.text}, \texttt{.data}, and \texttt{.sect}) end the current section and tell the assembler to begin assembling into another section. The \texttt{.usect} and the \texttt{.bss} directives, however, do not affect the current section. The assembler assembles the \texttt{.usect} and the \texttt{.bss} directives and then resumes assembling into the current section.

Variables that can be located contiguously in memory can be defined in the same specified section; to do so, repeat the \texttt{.usect} directive with the same section name.
.usect Reserve Uninitialized Space

For more information about COFF sections, see Chapter 2, *Introduction to Common Object File Format*.

Example

This example uses the .usect directive to define two uninitialized, named sections, var1 and var2. The symbol ptr points to the first word reserved in the var1 section. The symbol array points to the first word in a block of 100 words reserved in var1, and dflag points to the first word in a block of 50 words in var1. The symbol vec points to the first word reserved in the var2 section.

Figure 4–7 on page 4-97 shows how this example reserves space in two uninitialized sections, var1 and var2.

```
1          ******************************************
2          **   Assemble into .text section.   **
3          ******************************************
4 000000       .text
5 000000 E803   LD      #03h, A
6
7          ******************************************
8          ** Reserve 1 word in var1. **
9          ******************************************
10 000000      ptr .usect "var1", 1
11
12          ******************************************
13          ** Reserve 100 words in var1. **
14          ******************************************
15 000001      array .usect "var1", 100
16
17 000001 F000   ADD     #037h, A ; Still in .text
18 000002 0037
19
20          ******************************************
21          ** Reserve 50 words in var1. **
22          ******************************************
23 000065      dflag .usect "var1", 50
24
25 000003 F000   ADD     #dflag, A ; Still in .text
26 000004 0065-
27
28          ******************************************
29          ** Reserve 100 words in var2. **
30          ******************************************
31 000000      vec .usect "var2", 100
32
33 000005 F000   ADD     #vec, A ; Still in .text
34 000006 0000-
35          ******************************************
36          ** Declare an external .usect symbol. **
37          ******************************************
38                    .global array
```
Figure 4–7. The .usect Directive

section var1
ptr
array

1 word
100 words
50 words
151 words reserved in var1

section var2
100 words
100 words reserved in var2
Use Substitution Symbols as Local Variables

Syntax

```
.var sym1 [,sym2, ... , symn]
```

Description

The .var directive allows you to use substitution symbols as local variables within a macro. With this directive, you can define up to 32 local macro substitution symbols (including parameters) per macro.

The .var directive creates temporary substitution symbols with the initial value of the null string. These symbols are not passed in as parameters, and they are lost after expansion.

For more information on macros, see Chapter 5.
**Determine Device**  
**.version**

<table>
<thead>
<tr>
<th><strong>Syntax</strong></th>
<th><code>.version  value</code></th>
</tr>
</thead>
</table>

| **Description** | The `.version` directive determines for which processor instructions are built. Use one of the following for `value`:
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>541</td>
<td></td>
</tr>
<tr>
<td>542</td>
<td></td>
</tr>
<tr>
<td>543</td>
<td></td>
</tr>
<tr>
<td>545</td>
<td></td>
</tr>
<tr>
<td>545LP</td>
<td></td>
</tr>
<tr>
<td>546LP</td>
<td></td>
</tr>
<tr>
<td>548</td>
<td></td>
</tr>
<tr>
<td>54_ext</td>
<td>(for all other C54x devices with extended program space)</td>
</tr>
</tbody>
</table>
The assembler supports a macro language that enables you to create your own instructions. This is especially useful when a program executes a particular task several times. The macro language lets you:

- Define your own macros and redefine existing macros
- Simplify long or complicated assembly code
- Access macro libraries created with the archiver
- Define conditional and repeatable blocks within a macro
- Manipulate strings within a macro
- Control expansion listing

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1 Using Macros</td>
<td>5-2</td>
</tr>
<tr>
<td>5.2 Defining Macros</td>
<td>5-3</td>
</tr>
<tr>
<td>5.3 Macro Parameters/Substitution Symbols</td>
<td>5-6</td>
</tr>
<tr>
<td>5.4 Macro Libraries</td>
<td>5-14</td>
</tr>
<tr>
<td>5.5 Using Conditional Assembly in Macros</td>
<td>5-15</td>
</tr>
<tr>
<td>5.6 Using Labels in Macros</td>
<td>5-17</td>
</tr>
<tr>
<td>5.7 Producing Messages in Macros</td>
<td>5-19</td>
</tr>
<tr>
<td>5.8 Formatting the Output Listing</td>
<td>5-21</td>
</tr>
<tr>
<td>5.9 Using Recursive and Nested Macros</td>
<td>5-22</td>
</tr>
<tr>
<td>5.10 Macro Directives Summary</td>
<td>5-25</td>
</tr>
</tbody>
</table>
Using Macros

5.1 Using Macros

Programs often contain routines that are executed several times. Instead of repeating the source statements for a routine, you can define the routine as a macro, then call the macro in the places where you would normally repeat the routine. This simplifies and shortens your source program.

If you want to call a macro several times, but with different data each time, you can assign parameters within a macro. This enables you to pass different information to the macro each time you call it. The macro language supports a special symbol called a substitution symbol, which is used for macro parameters.

Using a macro is a three-step process.

Step 1: Define the macro. You must define macros before you can use them in your program. There are two methods for defining macros:

- Macros can be defined at the beginning of a source file or in a .copy/.include file. See Section 5.2, Defining Macros, for more information.

- Macros can be defined in a macro library. A macro library is a collection of files in archive format created by the archiver. Each member of the archive file (macro library) contains one macro definition corresponding to the member name. You can access a macro library by using the .mlib directive. See Section 5.4, Macro Libraries, on page 5-14 for more information.

Step 2: Call the macro. After defining a macro, you call it by using the macro name as a mnemonic in the source program. This is referred to as a macro call.

Step 3: Expand the macro. The assembler expands your macros when the source program calls them. During expansion, the assembler passes arguments by variable to the macro parameters, replaces the macro call statement with the macro definition, and assembles the source code. By default, the macro expansions are printed in the listing file. You can turn off expansion listing by using the .mnolist directive. See Section 5.8, Formatting the Output Listing, on page 5-21 for more information.

When the assembler encounters a macro definition, it places the macro name in the opcode table. This redefines any previously defined macro, library entry, directive, or instruction mnemonic that has the same name as the macro. This allows you to expand the functions of directives and instructions, as well as to add new instructions.
5.2 Defining Macros

You can define a macro anywhere in your program, but you must define the macro before you can use it. Macros can be defined at the beginning of a source file, in an .include/.copy file, or in a macro library. For more information about macro libraries, see Section 5.4, Macro Libraries, on page 5-14.

Macro definitions can be nested, and they can call other macros, but all elements of any macro must be defined in the same file. Nested macros are discussed in Section 5.9, Using Recursive and Nested Macros, on page 5-22.

A macro definition is a series of source statements in the following format:

```
macname .macro [parameter1] [, ..., parameterN]
  model statements or macro directives
  [.mexit]
  .endm
```

- `macname` names the macro. You must place the name in the source statement's label field. Only the first 32 characters of a macro name are significant. The assembler places the macro name in the internal opcode table, replacing any instruction or previous macro definition with the same name.
- `.macro` identifies the source statement as the first line of a macro definition. You must place .macro in the opcode field.
- `[parameters]` are optional substitution symbols that appear as operands for the .macro directive. Parameters are discussed in Section 5.3, Macro Parameters/Substitution Symbols, on page 5-6.
- `model statements` are instructions or assembler directives that are executed each time the macro is called.
- `macro directives` are used to control macro expansion.
- `.mexit` functions as a goto .endm statement. The .mexit directive is useful when error testing confirms that macro expansion will fail and completing the rest of the macro is unnecessary.
- `.endm` terminates the macro definition.
If you want to include comments with your macro definition but do not want those comments to appear in the macro expansion, use an exclamation point to precede your comments. If you do want your comments to appear in the macro expansion, use an asterisk or semicolon. For more information about macro comments, see Section 5.7, *Producing Messages in Macros*, on page 5-19.

Example 5–1 shows the definition, call, and expansion of a macro.

**Example 5–1. Macro Definition, Call, and Expansion**

(a) *Mnemonic example*

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td>add3</td>
</tr>
<tr>
<td>4</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>*</td>
<td>ADDRP = P1 + P2 + P3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>add3</td>
<td>.macro P1, P2, P3, ADDRP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>LD</td>
<td>P1, A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>ADD</td>
<td>P2, A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>ADD</td>
<td>P3, A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>STL</td>
<td>A, ADDRP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>.endm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.global abc, def, ghi, adr</td>
</tr>
<tr>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>000000</td>
<td>add3 abc, def, ghi, adr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>000000 1000!</td>
<td>LD abc, A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>000001 0000!</td>
<td>ADD def, A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>000002 0000!</td>
<td>ADD ghi, A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>000003 8000!</td>
<td>STL A, adr</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Example 5–1. Macro Definition, Call, and Expansion (Continued)

(b) Algebraic example

```
1  *
2  *
3  *  add3
4  *
5  *  ADDRP = P1 + P2 + P3
6  *
7  add3 .macro P1, P2, P3, ADDRP
8  *
9  A = @P1
10  A = A + @P2
11  A = A + @P3
12  @ADDRP = A
13  .endm
14  *
15  .global abc, def, ghi, adr
16  *
17  000000 add3 abc, def, ghi, adr
18  *
19  000000 1000! A = @abc
20  000001 0000! A = A + @def
21  000002 0000! A = A + @ghi
22  000003 8000! @adr = A
```
5.3 Macro Parameters/Substitution Symbols

If you want to call a macro several times with different data each time, you can assign parameters within the macro. The macro language supports a special symbol, called a substitution symbol, which is used for macro parameters.

Macro parameters are substitution symbols that represent a character string. These symbols can also be used outside of macros to equate a character string to a symbol name.

Valid substitution symbols can be up to 32 characters long and must begin with a letter. The remainder of the symbol can be a combination of alphanumeric characters, underscores, and dollar signs.

Substitution symbols used as macro parameters are local to the macro they are defined in. You can define up to 32 local substitution symbols (including substitution symbols defined with the .var directive) per macro. For more information about the .var directive, see subsection 5.3.6, Substitution Symbols as Local Variables in Macros, on page 5-13.

During macro expansion, the assembler passes arguments by variable to the macro parameters. The character-string equivalent of each argument is assigned to the corresponding parameter. Parameters without corresponding arguments are set to the null string. If the number of arguments exceeds the number of parameters, the last parameter is assigned the character-string equivalent of all remaining arguments.

If you pass a list of arguments to one parameter, or if you pass a comma or semicolon to a parameter, you must surround these terms with quotation marks.

At assembly time, the assembler replaces the substitution symbol with its corresponding character string, then translates the source code into object code.

Example 5–2 shows the expansion of a macro with varying numbers of arguments.
**Example 5–2. Calling a Macro With Varying Numbers of Arguments**

Macro definition

```
Parms .macro a,b,c
    ; a = :a:
    ; b = :b:
    ; c = :c:
.endm
```

Calling the macro:

```
Parms 100,label Parms 100,label,x,y
    ; a = 100
    ; b = label
    ; c = " ">
```

```
Parms 100,,x Parms "100,200,300",x,y
    ; a = 100
    ; b = " ">
```

```
Parms ""string"",x,y
    ; a = "string"
    ; b = x
    ; c = y
```

5.3.1 Directives That Define Substitution Symbols

You can manipulate substitution symbols with the `.asg` and `.eval` directives.

The `.asg` directive assigns a character string to a substitution symbol.

The syntax of the `.asg` directive is:

```
.asg ["]character string["], substitution symbol
```

The quotation marks are optional. If there are no quotation marks, the assembler reads characters up to the first comma and removes leading and trailing blanks. In either case, a character string is read and assigned to the substitution symbol.

Example 5–3 shows character strings being assigned to substitution symbols.
Example 5–3. The .asg Directive

```
.asg AR0,FP ; frame pointer
.asg *AR1+,Ind ; indirect addressing
.asg *AR1+0b,Rc_Prop ; reverse carry propagation
.asg """"string""",strng ; string
.asg "a,b,c",parms ; parameters
```

The .eval directive performs arithmetic on numeric substitution symbols.

The syntax of the .eval directive is

```
.eval well-defined expression, substitution symbol
```

The .eval directive evaluates the expression and assigns the string value of the result to the substitution symbol. If the expression is not well defined, the assembler generates an error and assigns the null string to the symbol.

Example 5–4 shows arithmetic being performed on substitution symbols.

Example 5–4. The .eval Directive

```
.asg 1,counter
.loop 100
.word counter
.eval counter + 1,counter
.endloop
```

In Example 5–4 the .asg directive could be replaced with the .eval directive without changing the output. In simple cases like this, you can use .eval and .asg interchangeably. However, you must use .eval if you want to calculate a value from an expression. While .asg only assigns a character string to a substitution symbol, the .eval directive evaluates an expression and assigns the character string equivalent to a substitution symbol.

5.3.2 Built-In Substitution Symbol Functions

The following built-in substitution symbol functions enable you to make decisions based on the string value of substitution symbols. These functions always return a value, and they can be used in expressions. Built-in substitution symbol functions are especially useful in conditional assembly expressions. Parameters to these functions are substitution symbols or character-string constants.
In the function definitions shown in Table 5–1, $a$ and $b$ are parameters that represent substitution symbols or character string constants. The term string refers to the string value of the parameter. The symbol $ch$ represents a character constant.

Table 5–1. Functions and Return Values

<table>
<thead>
<tr>
<th>Function</th>
<th>Return Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{symlen}(a)$</td>
<td>length of string $a$</td>
</tr>
<tr>
<td>$\text{symcmp}(a,b)$</td>
<td>$&lt; 0$ if $a &lt; b$  $0$ if $a = b$  $&gt; 0$ if $a &gt; b$</td>
</tr>
<tr>
<td>$\text{firstch}(a,ch)$</td>
<td>index of the first occurrence of character constant $ch$ in string $a$</td>
</tr>
<tr>
<td>$\text{lastch}(a,ch)$</td>
<td>index of the last occurrence of character constant $ch$ in string $a$</td>
</tr>
</tbody>
</table>
| $\text{isdefed}(a)$   | 1 if string $a$ is defined in the symbol table  
                         0 if string $a$ is not defined in the symbol table |
| $\text{ismember}(a,b)$ | top member of list $b$ is assigned to string $a$  
                         0 if $b$ is a null string                                      |
| $\text{iscons}(a)$   | 1 if string $a$ is a binary constant  
                         2 if string $a$ is an octal constant  
                         3 if string $a$ is a hexadecimal constant  
                         4 if string $a$ is a character constant  
                         5 if string $a$ is a decimal constant                                      |
| $\text{isname}(a)$   | 1 if string $a$ is a valid symbol name  
                         0 if string $a$ is not a valid symbol name                           |
| $\text{isreg}(a)$†    | 1 if string $a$ is a valid predefined register name  
                         0 if string $a$ is not a valid predefined register name               |
| $\text{structsz}(a)$ | size of structure represented by structure tag $a$                                |
| $\text{structacc}(a)$ | reference point of structure represented by structure tag $a$               |

†For more information about predefined register names, see Section 3.8, Symbols, on page 3-19.

Example 5–5 shows built-in substitution symbol functions.

Example 5–5. Using Built-In Substitution Symbol Functions

```
.asg label, ADDR ; ADDR = label
.if ($\text{symcmp}(ADDR,"label") = 0); evaluates to true
SUB ADDR, A
.endif
.asg "x,y,z", list ; list = x,y,z
.if ($\text{ismember}(ADDR,list)) ; addr = x, list = y,z
SUB ADDR, A ; sub x
.endif
```
5.3.3 Recursive Substitution Symbols

When the assembler encounters a substitution symbol, it attempts to substitute the corresponding character string. If that string is also a substitution symbol, the assembler performs substitution again. The assembler continues doing this until it encounters a token that is not a substitution symbol or until it encounters a substitution symbol that it has already encountered during this evaluation.

In Example 5–6, the x is substituted for z; z is substituted for y; and y is substituted for x. The assembler recognizes this as infinite recursion and ceases substitution.

Example 5–6. Recursive Substitution

```
.asg "x", z ; declare z and assign z = "x"
.asg "z", y ; declare y and assign y = "z"
.asg "y", x ; declare x and assign x = "y"
add x, A

* add x, A ; recursive expansion
```
5.3.4 Forced Substitution

In some cases, substitution symbols are not recognizable to the assembler. The forced substitution operator, which is a set of colons, enables you to force the substitution of a symbol’s character string. Simply enclose a symbol in colons to force the substitution. Do not include any spaces between the colons and the symbol.

The syntax for the forced substitution operator is

```
:symbol:
```

The assembler expands substitution symbols enclosed in colons before it expands other substitution symbols.

You can use the forced substitution operator only inside macros, and you cannot nest a forced substitution operator within another forced substitution operator.

Example 5–7 shows how the forced substitution operator is used.

**Example 5–7. Using the Forced Substitution Operator**

```
force .macro x
  .loop 8
  AUX:x:.set x
  .eval x+1,x
  .endloop
  .endm
force 0
```

The force macro would generate the following source code:

```
AUX0 .set 0
AUX1 .set 1
  
  
  
AUX7 .set 7
```
5.3.5 Accessing Individual Characters of Subscripted Substitution Symbols

In a macro, you can access the individual characters (substrings) of a substitution symbol with subscripted substitution symbols. You must use the forced substitution operator for clarity.

You can access substrings in two ways:

- \texttt{:symbol (well-defined expression)}:
  
  This method of subscripting evaluates to a character string with one character.

- \texttt{:symbol (well-defined expression}_1, \texttt{well-defined expression}_2):
  
  In this method, \texttt{expression}_1 represents the substring’s starting position, and \texttt{expression}_2 represents the substring’s length. You can specify exactly where to begin subscripting and the exact length of the resulting character string. \textit{The index of substring characters begins with 1, not 0.}

Example 5–8 and Example 5–9 show built-in substitution symbol functions used with subscripted substitution symbols.

In Example 5–8, subscripted substitution symbols redefine the add instruction so that it handles short immediates.

\textbf{Example 5–8. Using Subscripted Substitution Symbols to Redefine an Instruction}

\begin{verbatim}
ADDX .macro ABC
   .var TMP
   .asg :ABC(1):,TMP
   .if $symcmp(TMP,"#") = 0
      ADD ABC, A
   .else
      .emsg "Bad Macro Parameter"
      .endif
   .endm
ADDX #100 ;macro call
ADDX *AR1 ;macro call
\end{verbatim}
In Example 5–9, the subscripted substitution symbol is used to find a substring strg1, beginning at position start in the string strg2. The position of the substring strg1 is assigned to the substitution symbol pos.

Example 5–9. Using Subscripted Substitution Symbols to Find Substrings

```assembly
substr .macro start,strg1,strg2,pos
    .var LEN1,LEN2,I,TMP
    .if $symlen(start) = 0
        .eval 1,start
    .endif
    .eval 0,pos
    .eval 1,i
    .eval $symlen(strg1),LEN1
    .eval $symlen(strg2),LEN2
    .loop
        .break i = (LEN2 - LEN1 + 1)
        .asg ":strg2(i,LEN1):",TMP
        .if $symcmp(strg1,TMP) = 0
            .eval i,pos
            .break
        .else
            .eval i + 1,i
        .endif
    .endloop
.endm

.asg 0,pos
.asg "ar1 ar2 ar3 ar4","regs
substr 1,"ar2","regs,pos
.data
.word pos
```

5.3.6 Substitution Symbols as Local Variables in Macros

If you want to use substitution symbols as local variables within a macro, you can use the .var directive to define up to 32 local macro substitution symbols (including parameters) per macro. The .var directive creates temporary substitution symbols with the initial value of the null string. These symbols are not passed in as parameters, and they are lost after expansion.

```
.var sym1 [,sym2] ... [,symn]
```

The .var directive is used in Example 5–8 and Example 5–9.
5.4 Macro Libraries

One way to define macros is by creating a macro library. A macro library is a collection of files that contain macro definitions. You must use the archiver to collect these files, or members, into a single file (called an archive). Each member of a macro library contains one macro definition. The files in a macro library must be unassembled source files. The macro name and the member name must be the same, and the macro filename's extension must be .asm. For example:

<table>
<thead>
<tr>
<th>Macro Name</th>
<th>Filename in Macro Library</th>
</tr>
</thead>
<tbody>
<tr>
<td>simple</td>
<td>simple.asm</td>
</tr>
<tr>
<td>add3</td>
<td>add3.asm</td>
</tr>
</tbody>
</table>

You can access the macro library by using the .mlib assembler directive (described on page 4-68). The syntax is:

```
.mlib macro library filename
```

When the assembler encounters the .mlib directive, it opens the library and creates a table of the library's contents. The assembler enters the names of the individual members within the library into the opcode tables as library entries; this redefines any existing opcodes or macros that have the same name. If one of these macros is called, the assembler extracts the entry from the library and loads it into the macro table.

The assembler expands the library entry in the same way it expands other macros. You can control the listing of library entry expansions with the .mlist directive. For more information about the .mlist directive, see Section 5.8, Formatting the Output Listing, on page 5-21. Only macros that are actually called from the library are extracted, and they are extracted only once.

You can use the archiver to create a macro library by simply including the desired files in an archive. A macro library is no different from any other archive, except that the assembler expects the macro library to contain macro definitions. The assembler expects only macro definitions in a macro library; putting object code or miscellaneous source files into the library may produce undesirable results.
5.5 Using Conditional Assembly in Macros

The conditional assembly directives are `.if/.elseif/.else/.endif` and `.loop/.break/.endloop`. They can be nested within each other up to 32 levels deep. The format of a conditional block is:

```plaintext
.if well-defined expression
[.elseif well-defined expression]
[.else well-defined expression]
.endif
```

The `.elseif` and `.else` directives are optional in conditional assembly. The `.else` directive can be used more than once within a conditional assembly code block. When `.elseif` and `.else` are omitted, and when the `.if` expression is false (0), the assembler continues to the code following the `.endif` directive. For more information on the `.if/.elseif/.else/.endif` directives, see page 4-56.

The `.loop/.break/.endloop` directives enable you to assemble a code block repeatedly. The format of a repeatable block is:

```plaintext
.loop [well-defined expression]
[.break [well-defined expression]]
.endloop
```

The `.loop` directive’s optional expression evaluates to the loop count (the number of loops to be performed). If the expression is omitted, the loop count defaults to 1024 unless the assembler encounters a `.break` directive with an expression that is true (nonzero). For more information on the `.loop/.break/.endloop` directives, see page 4-66.

The `.break` directive and its expression are optional. If the expression evaluates to false, the loop continues. The assembler breaks the loop when the `.break` expression evaluates to true or when the `.break` expression is omitted. When the loop is broken, the assembler continues with the code after the `.endloop` directive.

Example 5–10, Example 5–11, and Example 5–12 show the `.loop/.break/.endloop` directives, properly nested conditional assembly directives, and built-in substitution symbol functions used in a conditional assembly code block.
Using Conditional Assembly in Macros

Example 5–10. The .loop/.break/.endloop Directives

```
.asg 1,x
.loop
.break (x == 10); if x == 10, quit loop/break with
; expression
.eval x+1,x
.endloop
```

Example 5–11. Nested Conditional Assembly Directives

```
.asg 1,x
.loop
.if (x == 10); if x == 10 quit loop
.break ; force break
.endif
.eval x+1,x
.endloop
```

Example 5–12. Built-In Substitution Symbol Functions Used in a Conditional Assembly Code Block

```
.ref OPZ
.fcnolist
*
*Double Add or Subtract
*
DBL .macro ABC, ADDR, src ; add or subtract double
.if $symcmp(ABC,”+”) == 0
dadd ADDR, src ; add double
.elseif $symcmp(ABC,”-”) == 0
dsub ADDR, src ; subtract double
.else
.emsg “Incorrect Operator Parameter”
.endif
.endm

*Macro Call
DBL -, OPZ, A
```

For more information about conditional assembly directives, see Section 4.8, Conditional Assembly Directives, on page 4-20.
5.6 Using Labels in Macros

All labels in an assembly language program must be unique, including labels in macros. If a macro is expanded more than once, its labels are defined more than once. *Defining labels more than once is illegal*. The macro language provides a method of defining labels in macros so that the labels are unique. Follow the label with a question mark, and the assembler replaces the question mark with a unique number. When the macro is expanded, you will not see the unique number in the listing file. Your label appears with the question mark as it did in the macro definition. You cannot declare this label as global.

The maximum label length is shortened to allow for the unique suffix. If the macro is expanded fewer than 10 times, the maximum label length is 126 characters. If the macro is expanded from 10 to 99 times, the maximum label length is 125. The label with its unique suffix is shown in the cross-listing file.

The syntax for a unique label is:

```
label?
```

Example 5–13 shows unique label generation in a macro.

**Example 5–13. Unique Labels in a Macro**

(a) Mnemonic example

```
1 ; define macro
2 MIN .macro AVAR, BVAR ; find minimum
3
4 LD AVAR, A
5 SUB #BVAR, A
6 BC M1?, ALT
7 LD #BVAR, A
8 B M2?
9 M1? LD AVAR, A
10 M2?
11 .endm
12
13 ; call macro
14 000000 MIN 50, 100
```

```
1
1 000000 1032 LD 50, A
1 000001 F010 SUB #100, A
000002 0064
1 000003 F843 BC M1?, ALT
000004 0008'
1 000005 E864 LD #100, A
1 000006 F073 B M2?
000007 0009'
1 000008 1032 M1? LD 50, A
1 000009 M2?
```
Example 5–13. Unique Labels in a Macro (Continued)

(b) Algebraic example

```
1 ; define macro
2 MIN .macro AVAR, BVAR ; find minimum
3
4       A = @AVAR
5       A = A – #BVAR
6       if (ALT) goto M1?
7       A = #BVAR
8       goto M2?
9     M1?       A = @AVAR
10    M2?
11   .endm
12
13 ; call macro
14 000000 MIN 50, 100
```

```
1 000000 1032  A = @50
1 000001 F010   A = A – #100
1 000002 0064   000004 0008’
1 000005 E864   A = #100
1 000006 F073   goto M2?
1 000007 0009’
1 000008 1032  M1?       A = @50
1 000009     M2?
```
5.7 Producing Messages in Macros

The macro language supports three directives that enable you to define your own assembly-time error and warning messages. These directives are especially useful when you want to create messages specific to your needs. The last line of the listing file shows the error and warning counts. These counts alert you to problems in your code and are especially useful during debugging.

.emsg sends error messages to the listing file. The .emsg directive generates errors in the same manner as the assembler, incrementing the error count and preventing the assembler from producing an object file.

.mmsg sends assembly-time messages to the listing file. The .mmsg directive functions in the same manner as the .emsg directive but does not set the error count or prevent the creation of an object file.

.wmsg sends warning messages to the listing file. The .wmsg directive functions in the same manner as the .emsg directive, but it increments the warning count and does not prevent the generation of an object file.

Macro comments are comments that appear in the definition of the macro but do not show up in the expansion of the macro. An exclamation point in column 1 identifies a macro comment. If you want your comments to appear in the macro expansion, precede your comment with an asterisk or semicolon.

Example 5–14 shows user messages in macros.
Example 5–14. Producing Messages in a Macro

```
1      testparam .macro x,y
2
3                        .if ($symlen(x) == 0)
4                        .emsg "ERROR -- Missing Parameter"
5                        .mexit
6                        .elseif ($symlen(y) == 0)
7                        .emsg "ERROR == Missing Parameter"
8                        .mexit
9                        .else
10                       LD y, A
11                       LD x, B
12                       ADD A, B
13                       .endif
14                       .endm
15
16 000000                 testparam 1,2
1
1                        .if ($symlen(x) == 0)
1                        .emsg "ERROR -- Missing Parameter"
1                        .mexit
1                        .elseif ($symlen(y) == 0)
1                        .emsg "ERROR == Missing Parameter"
1                        .mexit
1                        .else
1 000000 1002            LD 2, A
1 000001 1101            LD 1, B
1 000002 F500            ADD A, B
1                        .endif
17
18 000003                 testparam
1
1                        .if ($symlen(x) == 0)
1                        .emsg "ERROR -- Missing Parameter"
1
11 Error, No Warnings
```
5.8 Formatting the Output Listing

Macros, substitution symbols, and conditional assembly directives may hide information. You may need to see this hidden information, so the macro language supports an expanded listing capability.

By default, the assembler shows macro expansions and false conditional blocks in the output list file. You may want to turn this listing off or on within your listing file. Four sets of directives enable you to control the listing of this information:

- **Macro and Loop Expansion Listing**
  - `.mlist` expands macros and `.loop/.endloop` blocks. The `.mlist` directive prints all code encountered in those blocks.
  - `.mnolist` suppresses the listing of macro expansions and `.loop/.endloop` blocks.

For macro and loop expansion listing, `.mlist` is the default.

- **False Conditional Block Listing**
  - `.fclist` causes the assembler to include in the listing file all conditional blocks that do not generate code (false conditional blocks). Conditional blocks appear in the listing exactly as they appear in the source code.
  - `.fcnolist` suppresses the listing of false conditional blocks. Only the code in conditional blocks that actually assemble appears in the listing. The `.if`, `.elseif`, `.else`, and `.endif` directives do not appear in the listing.

For false conditional block listing, `.fclist` is the default.

- **Substitution Symbol Expansion Listing**
  - `.sslist` expands substitution symbols in the listing. This is useful for debugging the expansion of substitution symbols. The expanded line appears below the actual source line.
  - `.ssnolist` turns off substitution symbol expansion in the listing.

For substitution symbol expansion listing, `.ssnolist` is the default.

- **Directive Listing**
  - `.drlist` causes the assembler to print to the listing file all directive lines.
  - `.drnolist` suppresses the printing of the following directives in the listing file: `.asg`, `.eval`, `.var`, `.sslist`, `.mlist`, `.fclist`, `.ssnolist`, `.mnolist`, `.fcnolist`, `.emsg`, `.wmsg`, `.mmsg`, `.length`, `.width`, and `.break`.

For directive listing, `.drlist` is the default.
5.9 Using Recursive and Nested Macros

The macro language supports recursive and nested macro calls. This means that you can call other macros in a macro definition. You can nest macros up to 32 levels deep. When you use recursive macros, you call a macro from its own definition (the macro calls itself).

When you create recursive or nested macros, you should pay close attention to the arguments that you pass to macro parameters, because the assembler uses dynamic scoping for parameters. This means that the called macro uses the environment of the macro from which it was called.

Example 5–15 shows nested macros. Note that the y in the in_block macro hides the y in the out_block macro. The x and z from the out_block macro, however, are accessible to the in_block macro.

Example 5–15. Using Nested Macros

```
in_block .macro y,a
    ; visible parameters are y,a and
    ;   x,z from the calling macro
    .endm

out_block .macro x,y,z
    ; visible parameters are x,y,z
    in_block x,y ; macro call with x and y as
    ;   arguments
     .
    .
    .endm
out_block ; macro call
```
Example 5–16 shows recursive macros. The fact macro produces assembly code necessary to calculate the factorial of n where n is an immediate value. The result is placed in data memory address loc. The fact macro accomplishes this by calling fact1, which calls itself recursively.

**Example 5–16. Using Recursive Macros**

(a) Mnemonic example

```
; n is an integer constant
; loc memory address = n!
.if N < 2 ; 0! = 1! = 1
    ST #1, loc
.else
    ST #N, loc ; n >= 2 so, store n at loc
    .eval N - 1, N ; decrement n, and do the
    fact1 ; factorial of n - 1
    .endif
    .endm

fact1 .macro
    .if N > 1
    LD loc, T ; multiply present factorial
    MPY #N, A ; by present position
    STL A, loc ; save result
    .eval N - 1, N ; decrement position
    fact1 ; recursive call
    .endif
    .endm
```
Example 5–16. Using Recursive Macros (Continued)

(b) Algebraic example

```
fact .macro N, loc
    ; n is an integer constant
    ; loc memory address = n!
    .if N < 2
        ; 0! = 1! = 1
        @loc = #1
    .else
        ; n >= 2 so, store n at loc
        @loc = #N
        ; decrement n, and do the
        .eval N – 1, N
        ; factorial of n – 1
        factl
        ; call factl with current
        ; environment
    .endif
.endm

factl .macro
    .if N > 1
        ; multiply present factorial
        T = @loc
        ; by present position
        A = T * #N
        ; save result
        @loc = A
        ; decrement position
        .eval N – 1, N
        ; recursive call
    .endif
.endm
```
5.10 Macro Directives Summary

Table 5–2. Creating Macros

<table>
<thead>
<tr>
<th>Mnemonic and Syntax</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>macname .macro [parameter1]...[parameter_n]</code></td>
<td>Define macro.</td>
</tr>
<tr>
<td><code>.mlib filename</code></td>
<td>Identify library containing macro definitions.</td>
</tr>
<tr>
<td><code>.mexit</code></td>
<td>Go to .endm.</td>
</tr>
<tr>
<td><code>.endm</code></td>
<td>End macro definition.</td>
</tr>
</tbody>
</table>

Table 5–3. Manipulating Substitution Symbols

<table>
<thead>
<tr>
<th>Mnemonic and Syntax</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>.asg [&quot;]character string[&quot;], substitution symbol</code></td>
<td>Assign character string to substitution symbol.</td>
</tr>
<tr>
<td><code>.eval well-defined expression, substitution symbol</code></td>
<td>Perform arithmetic on numeric substitution symbols.</td>
</tr>
<tr>
<td><code>.var substitution symbol1 ...[substitution symbol_n]</code></td>
<td>Define local macro symbols.</td>
</tr>
</tbody>
</table>

Table 5–4. Conditional Assembly

<table>
<thead>
<tr>
<th>Mnemonic and Syntax</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>.if well-defined expression</code></td>
<td>Begin conditional assembly.</td>
</tr>
<tr>
<td><code>.elseif well-defined expression</code></td>
<td>Optional conditional assembly block.</td>
</tr>
<tr>
<td><code>.else</code></td>
<td>Optional conditional assembly block.</td>
</tr>
<tr>
<td><code>.endif</code></td>
<td>End conditional assembly.</td>
</tr>
<tr>
<td><code>.loop [well-defined expression]</code></td>
<td>Begin repeatable block assembly.</td>
</tr>
<tr>
<td><code>.break [well-defined expression]</code></td>
<td>Optional repeatable block assembly.</td>
</tr>
<tr>
<td><code>.endloop</code></td>
<td>End repeatable block assembly.</td>
</tr>
</tbody>
</table>
### Macro Directives Summary

#### Table 5–5. Producing Assembly-Time Messages

<table>
<thead>
<tr>
<th>Mnemonic and Syntax</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>.emsg</td>
<td>Send error message to standard output.</td>
</tr>
<tr>
<td>.wmsg</td>
<td>Send warning message to standard output.</td>
</tr>
<tr>
<td>.mmsg</td>
<td>Send warning or assembly-time message to standard output.</td>
</tr>
</tbody>
</table>

#### Table 5–6. Formatting the Listing

<table>
<thead>
<tr>
<th>Mnemonic and Syntax</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>.fclist</td>
<td>Allow false conditional code block listing (default).</td>
</tr>
<tr>
<td>.fcnolist</td>
<td>Inhibit false conditional code block listing.</td>
</tr>
<tr>
<td>.mlist</td>
<td>Allow macro listings (default).</td>
</tr>
<tr>
<td>.mnolist</td>
<td>Inhibit macro listings.</td>
</tr>
<tr>
<td>.sslist</td>
<td>Allow expanded substitution symbol listing.</td>
</tr>
<tr>
<td>.ssnolist</td>
<td>Inhibit expanded substitution symbol listing (default).</td>
</tr>
</tbody>
</table>
The TMS320C54x™ archiver combines several individual files into a single archive file. For example, you can collect several macros into a macro library. The assembler will search the library and use the members that are called as macros by the source file. You can also use the archiver to collect a group of object files into an object library. The linker will include in the library the members that resolve external references during the link.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1 Archiver Overview</td>
<td>6-2</td>
</tr>
<tr>
<td>6.2 Archiver Development Flow</td>
<td>6-3</td>
</tr>
<tr>
<td>6.3 Invoking the Archiver</td>
<td>6-4</td>
</tr>
<tr>
<td>6.4 Archiver Examples</td>
<td>6-6</td>
</tr>
</tbody>
</table>
6.1 Archiver Overview

The TMS320C54x archiver lets you combine several individual files into a single file called an archive or a library. Each file within the archive is called a member. Once you have created an archive, you can use the archiver to add, delete, or extract members.

You can build libraries from any type of files. Both the assembler and the linker accept archive libraries as input; the assembler can use libraries that contain individual source files, and the linker can use libraries that contain individual object files.

One of the most useful applications of the archiver is building libraries of object modules. For example, you can write several arithmetic routines, assemble them, and use the archiver to collect the object files into a single, logical group. You can then specify the object library as linker input. The linker will search the library and include members that resolve external references.

You can also use the archiver to build macro libraries. You can create several source files, each of which contains a single macro, and use the archiver to collect these macros into a single, functional group. The .mlib assembler directive lets you specify the name of a macro library; during the assembly process, the assembler will search the specified library for the macros that you call. Chapter 5, Macro Language, discusses macros and macro libraries in detail.
6.2 Archiver Development Flow

Figure 6–1 shows the archiver’s role in the assembly language development process. Both the assembler and the linker accept libraries as input.
6.3 Invoking the Archiver

To invoke the archiver, enter:

```
ar500 [-]command[option] libname [filename1 ... filenameN]
```

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Adds the specified files to the library. This command does not replace an existing member that has the same name as an added file; it simply appends new members to the end of the archive.</td>
</tr>
<tr>
<td>d</td>
<td>Deletes the specified members from the library.</td>
</tr>
<tr>
<td>r</td>
<td>Replaces the specified members in the library. If you don’t specify filenames, the archiver replaces the library members with files of the same name in the current directory. If the specified file is not found in the library, the archiver adds it instead of replacing it.</td>
</tr>
<tr>
<td>t</td>
<td>Prints a table of contents of the library. If you specify filenames, only those files are listed. If you don’t specify any filenames, the archiver lists all the members in the specified library.</td>
</tr>
<tr>
<td>x</td>
<td>Extracts the specified files. If you don’t specify member names, the archiver extracts all library members. When the archiver extracts a member, it simply copies the member into the current directory; it doesn’t remove it from the library.</td>
</tr>
</tbody>
</table>

ar500 is the command that invokes the archiver.

command tells the archiver how to manipulate the library members. A command can be preceded by an optional hyphen. You must use one of the following commands when you invoke the archiver, but you can use only one command per invocation. Valid archiver commands are:
**Invoking the Archiver**

`option` tells the archiver how to function. Specify as many of the following options as you want:

- `-q` (quiet) suppresses the banner and status messages.
- `-s` prints a list of the global symbols that are defined in the library. (This option is valid only with the `-a`, `-r`, and `-d` commands.)
- `-v` (verbose) provides a file-by-file description of the creation of a new library from an old library and its constituent members.

`libname` names an archive library. If you don’t specify an extension for `libname`, the archiver uses the default extension `.lib`.

`filename` names individual member files that are associated with the library. You must specify a complete filename including an extension, if applicable.

It is possible (but not desirable) for a library to contain several members with the same name. If you attempt to delete, replace, or extract a member, and the library contains more than one member with the specified name, then the archiver deletes, replaces, or extracts the first member with that name.
6.4 Archiver Examples

The following are some archiver examples:

- If you want to create a library called function.lib that contains the files sine.obj, cos.obj, and flt.obj, enter:

  ```sh
  ar500 -a function sine.obj cos.obj flt.obj
  ```

  The archiver makes a copy of the files and places them in the library called function.lib.

- You can print a table of contents of function.lib with the –t option:

  ```sh
  ar500 -t function
  ```

  This command prints a list of all the files in the library along with their size and dates.

- If you want to add new members to the library, enter:

  ```sh
  ar500 -as function atan.obj
  ```

  This command adds the new members to the library called function.lib.

- If you want to modify a library member, you can extract it, edit it, and replace it. In this example, assume there’s a library named macros.lib that contains the members push.asm, pop.asm, and swap.asm.

  ```sh
  ar500 -x macros push.asm
  ```

  This command extracts and edits the file, then replaces it in the library.

- If you want to modify a library member, you can extract it, edit it, and replace it. In this example, assume there’s a library named macros.lib that contains the members push.asm, pop.asm, and swap.asm.

  ```sh
  ar500 -r macros push.asm
  ```

  This command replaces the edited copy of push.asm back into the library.
The TMS320C54x™ linker creates executable modules by combining COFF object files. The concept of COFF sections is basic to linker operation. Chapter 2, *Introduction to Common Object File Format*, discusses the COFF format in detail.

### Chapter 7

**Linker Description**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1 Linker Overview</td>
<td>7-2</td>
</tr>
<tr>
<td>7.2 Linker Development Flow</td>
<td>7-3</td>
</tr>
<tr>
<td>7.3 Invoking the Linker</td>
<td>7-4</td>
</tr>
<tr>
<td>7.4 Linker Options</td>
<td>7-6</td>
</tr>
<tr>
<td>7.5 Linker Command Files</td>
<td>7-21</td>
</tr>
<tr>
<td>7.6 Object Libraries</td>
<td>7-25</td>
</tr>
<tr>
<td>7.7 The MEMORY Directive</td>
<td>7-27</td>
</tr>
<tr>
<td>7.8 The SECTIONS Directive</td>
<td>7-32</td>
</tr>
<tr>
<td>7.9 Specifying a Section’s Runtime Address</td>
<td>7-44</td>
</tr>
<tr>
<td>7.10 Using UNION and GROUP Statements</td>
<td>7-48</td>
</tr>
<tr>
<td>7.11 Overlay Pages</td>
<td>7-53</td>
</tr>
<tr>
<td>7.12 Default Allocation Algorithm</td>
<td>7-58</td>
</tr>
<tr>
<td>7.13 Special Section Types (DSECT, COPY, and NOLOAD)</td>
<td>7-61</td>
</tr>
<tr>
<td>7.14 Assigning Symbols at Link Time</td>
<td>7-62</td>
</tr>
<tr>
<td>7.15 Creating and Filling Holes</td>
<td>7-66</td>
</tr>
<tr>
<td>7.16 Partial (Incremental) Linking</td>
<td>7-70</td>
</tr>
<tr>
<td>7.17 Linking C/C++ Code</td>
<td>7-72</td>
</tr>
<tr>
<td>7.18 Linker Example</td>
<td>7-76</td>
</tr>
</tbody>
</table>
7.1 Linker Overview

The TMS320C54x linker allows you to configure system memory by allocating output sections efficiently into the memory map. As the linker combines object files, it performs the following tasks:

- Allocates sections into the target system's configured memory.
- Relocates symbols and sections to assign them to final addresses.
- Resolves undefined external references between input files.

The linker command language controls memory configuration, output section definition, and address binding. The language supports expression assignment and evaluation. You configure system memory by defining and creating a memory model that you design. Two powerful directives, MEMORY and SECTIONS, allow you to:

- Allocate sections into specific areas of memory.
- Combine object file sections.
- Define or redefine global symbols at link time.
7.2 Linker Development Flow

Figure 7–1 illustrates the linker’s role in the assembly language development process. The linker accepts several types of files as input, including object files, command files, libraries, and partially linked files. The linker creates an executable COFF object module that can be downloaded to one of several development tools or executed by a TMS320C54x device.

Figure 7–1. Linker Development Flow
7.3 Invoking the Linker

The general syntax for invoking the linker is:

\[ \text{lnk500 [–options ] filename}_1. \ldots \text{filename}_n \]

- **lnk500** is the command that invokes the linker.
- **options** can appear anywhere on the command line or in a linker command file. (Options are discussed in Section 7.4, Linker Options, on page 7-6.)
- **filenames** can be object files, linker command files, or archive libraries. The default extension for all input files is .obj; any other extension must be explicitly specified. The linker can determine whether the input file is an object or ASCII file that contains linker commands. The default output filename is *a.out*.

There are three methods for invoking the linker:

- Specify options and filenames on the command line. This example links two files, file1.obj and file2.obj, and creates an output module named link.out.

  \[ \text{lnk500 file1.obj file2.obj –o link.out} \]

- Enter the **lnk500** command with no filenames and no options; the linker prompts for them:

  - Command files :
  - Object files [.obj] :
  - Output file [a.out] :
  - Options :
    - For **command files**, enter one or more command filenames.
    - For **object files**, enter one or more object filenames. The default extension is .obj. Separate the filenames with spaces or commas; if the last character is a comma, the linker prompts for an additional line of object filenames.
    - The **output file** is the name of the linker output module. This overrides any –o options entered with any of the other prompts. If there are no –o options and you do not answer this prompt, the linker creates an object file with a default filename of *a.out*.
    - The **options** prompt is for additional options, although you can also enter them in a command file. Enter them with hyphens, just as you would on the command line.
Put filenames and options in a linker command file. For example, assume that the file linker.cmd contains the following lines:

```
-o link.out
file1.obj
file2.obj
```

Now you can invoke the linker from the command line; specify the command filename as an input file:

```
lnk500 linker.cmd
```

When you use a command file, you can also specify other options and files on the command line. For example, you could enter:

```
lnk500 -m link.map linker.cmd file3.obj
```

The linker reads and processes a command file as soon as it encounters the filename on the command line, so it links the files in this order: file1.obj, file2.obj, and file3.obj. This example creates an output file called link.out and a map file called link.map.
7.4 Linker Options

Linker options control linking operations. They can be placed on the command line or in a command file. Linker options must be preceded by a hyphen (–). The order in which options are specified is unimportant, except for the –l (lowercase L) and –i options. Options may be separated from arguments (if they have them) by an optional space. The following summarize the linker options:


- **–a**  
  Produce an absolute, executable module. This is the default; if neither –a nor –r is specified, the linker acts as if –a were specified.

- **–ar**  
  Produce a relocatable, executable object module.

- **–b**  
  Disable merge of symbolic debugging information.

- **–c**  
  Use linking conventions defined by the ROM autoinitialization model of the TMS320C54x C/C++ compiler.

- **–cr**  
  Use linking conventions defined by the RAM autoinitialization model of the TMS320C54x C/C++ compiler.

- **–e global_symbol**  
  Define a global_symbol that specifies the primary entry point for the output module.

- **–f fill_value**  
  Set the default fill value for holes within output sections; fill_value is a 16-bit constant.

- **–g global_symbol**  
  Keep a global_symbol global (overrides –h).

- **–h**  
  Make all global symbols static.

- **–help**  
  Display a listing of all available linker command line options.

- **–i**  
  Alter the library-search algorithm to look in dir before looking in the default location. This option must appear before the –l option. The directory or filename must follow operating system conventions.

- **–j**  
  Disable conditional linking.

- **–k**  
  Ignore alignment flags in input sections.
-l filename  Name an archive library file as linker input; `filename` is an archive library name. This option must appear after the `-i` option. The directory or filename must follow operating system conventions.

-m filename  Produce a map or listing of the input and output sections, including holes, and place the listing in `filename`.

-o filename  Name the executable output module. The default filename is `a.out`. The directory or filename must follow operating system conventions.

-q  Request a quiet run (suppress the banner).

-r  Produce a relocatable output module.

-s  Strip symbol table information and line number entries from the output module.

-stack size  Set C system stack size to `size` words and define a global symbol that specifies the stack size. The default size is 1K words.

-u symbol  Place an unresolved external `symbol` into the output module’s symbol table.

-vn  Specify the output COFF format, where `n` is 0, 1, or 2. The default format is COFF2.

-w  Displays a message when an undefined output section is created.

-x  Force rereading of libraries. Resolves back references.
7.4.1 Relocation Capabilities (–a and –r Options)

The linker performs relocation, which is the process of adjusting all references to a symbol when the symbol’s address changes. The linker supports two options (–a and –r) that allow you to produce an absolute or a relocatable output module. If neither –a nor –r is specified, the linker acts as if –a is specified by default.

Producing an Absolute Output Module (–a Option)

When you use the –a option without the –r option, the linker produces an absolute, executable output module. Absolute files contain no relocation information. Executable files contain the following:

- Special symbols defined by the linker (subsection 7.14.4, Symbols Defined by the Linker, on page 7-65 describes these symbols)
- An optional header that describes information such as the program entry point
- No unresolved references

The following example links file1.obj and file2.obj and creates an absolute output module called a.out:

```
lnk500 -a file1.obj file2.obj
```

Note: –a and –r Options

If you do not use the –a or the –r option, the linker acts as if you specified –a.
Producing a Relocatable Output Module (–r Option)

When you use the –r option without the –a option, the linker retains relocation entries in the output module. If the output module will be relocated (at load time) or relinked (by another linker execution), use –r to retain the relocation entries.

The linker produces a file that is not executable when you use the –r option without –a. A file that is not executable does not contain special linker symbols or an optional header. The file may contain unresolved references, but these references do not prevent creation of an output module.

The following example links file1.obj and file2.obj and creates a relocatable output module called a.out:

```
lnk500 –r file1.obj file2.obj
```

The output file a.out can be relinked with other object files or relocated at load time. (Linking a file that will be relinked with other files is called partial linking.) For more information, see Section 7.18, Linker Example, on page 7-76.

Producing an Executable Relocatable Output Module (–ar)

If you invoke the linker with both the –a and –r options, the linker produces an executable, relocatable object module. The output file contains the special linker symbols, an optional header, and all resolved symbol references; however, the relocation information is retained.

The following example links file1.obj and file2.obj and creates an executable, relocatable output module called xr.out:

```
lnk500 –ar file1.obj file2.obj –o xr.out
```

You can string the options together (lnk500 –ar) or enter them separately (lnk500 –a –r).

Relocating or Relinking an Absolute Output Module

The linker issues a warning message (but continues executing) when it encounters a file that contains no relocation or symbol table information. Relinking an absolute file can be successful only if each input file contains no information that needs to be relocated (that is, each file has no unresolved references and is bound to the same virtual address that it was bound to when the linker created it).
7.4.2 Disable Merge of Symbolic Debugging Information (–b Option)

By default, the linker eliminates duplicate entries of symbolic debugging information. Such duplicate information is commonly generated when a C program is compiled for debugging. For example:

```
- [ header.h ]-
typedef struct
 {<define some structure members>
 } XYZ;

- [ f1.c ]-
#include "header.h"
...

- [ f2.c ]-
#include "header.h"
...
```

When these files are compiled for debugging, both f1.obj and f2.obj will have symbolic debugging entries to describe type XYZ. For the final output file, only one set of these entries is necessary. The linker eliminates the duplicate entries automatically.

Use the –b option if you want the linker to keep such duplicate entries. Using the –b option has the effect of the linker running faster and using less machine memory.

7.4.3 C Language Options (–c and –cr Options)

The –c and –cr options cause the linker to use linking conventions that are required by the C/C++ compiler.

- The –c option tells the linker to use the ROM autoinitialization model.
- The –cr option tells the linker to use the RAM autoinitialization model.

For more information about linking C/C++ code, see Section 7.17, Linking C/C++ Code, on page 7-72 and subsection 7.17.5, The –c and –cr Linker Options, on page 7-75.
Linker Options

7.4.4 Define an Entry Point (–e global_symbol Option)

The memory address at which a program begins executing is called the entry point. When a loader loads a program into target memory, the program counter must be initialized to the entry point; the PC then points to the beginning of the program.

The linker can assign one of four possible values to the entry point. These values are listed below in the order in which the linker tries to use them. If you use one of the first three values, it must be an external symbol in the symbol table.

- The value specified by the –e option. The syntax is:
  
  \[ \text{–e global\_symbol} \]

  Where global\_symbol defines the entry point and must appear as an external symbol in one of the input files.

- The value of symbol _c_int00 (if present). _c_int00 must be the entry point if you are linking code produced by the C/C++ compiler.

- The value of symbol _main (if present).

- Zero (default value).

This example links file1.obj and file2.obj. The symbol begin is the entry point; begin must be defined as external in file1 or file2.

\[ \text{lnk500 –e begin file1.obj file2.obj} \]

7.4.5 Set Default Fill Value (–f cc Option)

The –f option fills the holes formed within output sections or initializes uninitialized sections when they are combined with initialized sections. This allows you to initialize memory areas during link time without reassembling a source file. The argument cc is a 16-bit constant (up to four hexadecimal digits). If you do not use –f, the linker uses 0 as the default fill value.

This example fills holes with the hexadecimal value ABCD.

\[ \text{lnk500 –f 0ABCDh file1.obj file2.obj} \]
7.4.6 Make a Symbol Global (–g global_symbol Option)

The –h option makes all global symbols static. If you have a symbol that you want to remain global and you use the –h option, you can use the –g option to declare that symbol to be global. The –g option overrides the effect of the –h option for the symbol that you specify. The syntax for the –g option is:

–g global_symbol

7.4.7 Make All Global Symbols Static (–h Option)

The –h option makes all global symbols defined with the .global assembler directive static. Static symbols are not visible to externally linked modules. By making global symbols static, global symbols are essentially hidden. This allows external symbols with the same name (in different files) to be treated as unique.

The –h option effectively nullifies all .global assembler directives. All symbols become local to the module in which they are defined, so no external references are possible. For example, assume that b1.obj, b2.obj, and b3.obj are related and reference a global variable GLOB. Also assume that d1.obj, d2.obj, and d3.obj are related and reference a separate global variable GLOB. By using the –h option and partial linking, you can link the related files without conflict.

    lnk500 –h –r b1.obj b2.obj b3.obj –o bpart.out
    lnk500 –h –r d1.obj d2.obj d3.obj –o dpart.out

The –h option guarantees that bpart.out and dpart.out do not have global symbols and therefore, that two distinct versions of GLOB exist. The –r option is used to allow bpart.out and dpart.out to retain their relocation entries. These two partially linked files can then be linked together safely with the following command:

    lnk500 bpart.out dpart.out –o system.out

7.4.8 Define Heap Size (–heap constant Option)

The C/C++ compiler uses an uninitialized section called .sysmem for the C runtime memory pool used by malloc(). You can set the size of this memory pool at link time by using the –heap option. Specify the size in words as a constant immediately after the option:

    lnk500 –heap 0x0400 /* defines a heap size */

The linker creates the .sysmem section only if there is a .sysmem section in one of the input files.
The linker also creates a global symbol _SYSMEM_SIZE and assigns it a value equal to the size of the heap. The default size is 1K words.

For more information about linking C code, see Section 7.17, Linking C Code, on page 7-72.

7.4.9 Alter the Library Search Algorithm (–l Option, –i Option, and C54X_C_DIR/C_DIR Environment Variables)

Usually, when you want to specify a library as linker input, you simply enter the library name as you would any other input filename; the linker looks for the library in the current directory. For example, suppose the current directory contains the library object.lib. Assume that this library defines symbols that are referenced in the file file1.obj. This is how you link the files:

    lnk500 file1.obj object.lib

If you want to use a library that is not in the current directory, use the –l (lowercase L) linker option. The syntax for this option is:

    –l filename

The filename is the name of an archive library; the space between –l and the filename is optional.

You can augment the linker’s directory search algorithm by using the –i linker option or the C_DIR or C54X_C_DIR environment variables. The linker searches for object libraries in the following order:

1) It searches directories named with the –i linker option.

2) It searches directories named with C_DIR and C54X_C_DIR.

3) If C_DIR and C54X_C_DIR are not set, it searches directories named with the assembler’s environment variables, C54X_A_DIR and A_DIR.

4) It searches the current directory.
7.4.9.1 Name an Alternate Library Directory (–i Option)

The –i option names an alternate directory that contains object libraries. The syntax for this option is:

–i dir

The dir names a directory that contains object libraries; the space between –i and the directory name is optional.

When the linker is searching for object libraries named with the –l option, it searches through directories named with –i first. Each –i option specifies only one directory, but you can use several –i options per invocation. When you use the –i option to name an alternate directory, it must precede the –l option on the command line or in a command file.

For example, assume that there are two archive libraries called r.lib and lib2.lib. The table below shows the directories that r.lib and lib2.lib reside in, how to set environment variable, and how to use both libraries during a link. Select the row for your operating system:

<table>
<thead>
<tr>
<th>Operating System</th>
<th>Pathname</th>
<th>Invocation Command</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOS</td>
<td>\ld and \ld2</td>
<td>lnk500 f1.obj f2.obj –i\ld –i\ld2 –lr.lib –llib2.lib</td>
</tr>
<tr>
<td>UNIX</td>
<td>/ld and /ld2</td>
<td>lnk500 f1.obj f2.obj –i/ld –i/ld2 –lr.lib –llib2.lib</td>
</tr>
</tbody>
</table>
7.4.9.2 Name an Alternate Library Directory (C_DIR Environment Variable)

An environment variable is a system symbol that you define and assign a string to. The linker uses environment variables named C_DIR and C54X_C_DIR to name alternate directories that contain object libraries. The commands for assigning the environment variable are:

<table>
<thead>
<tr>
<th>Operating System</th>
<th>Enter</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOS</td>
<td>set C_DIR= pathname;another pathname ...</td>
</tr>
<tr>
<td>UNIX</td>
<td>setenv C_DIR &quot;pathname;another pathname ...&quot;</td>
</tr>
</tbody>
</table>

The pathnames are directories that contain object libraries. Use the –l option on the command line or in a command file to tell the linker which libraries to search for.

In the example below, assume that two archive libraries called r.lib and lib2.lib reside in ld and ld2 directories. The table below shows the directories that r.lib and lib2.lib reside in, how to set the environment variable, and how to use both libraries during a link. Select the row for your operating system:

<table>
<thead>
<tr>
<th>Operating System</th>
<th>Pathname</th>
<th>Invocation Command</th>
</tr>
</thead>
</table>
| DOS              | \ld and \ld2| set C_DIR=\ld;\ld2
                  |              | lnk500 f1.obj f2.obj –l r.lib –l lib2.lib             |
| UNIX             | /ld and /ld2 | setenv C_DIR "/ld ;/ld2"
                  |              | lnk500 f1.obj f2.obj –l r.lib –l lib2.lib             |
Note that the environment variable remains set until you reboot the system or reset the variable by entering:

<table>
<thead>
<tr>
<th>Operating System</th>
<th>Enter</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOS</td>
<td>set C_DIR=</td>
</tr>
<tr>
<td>UNIX</td>
<td>unsetenv C_DIR</td>
</tr>
</tbody>
</table>

The assembler uses an environment variable named A_DIR to name alternative directories that contain copy/include files or macro libraries. If C_DIR is not set, the linker will search for object libraries in the directories named with A_DIR. Section 7.6, Object Libraries, on page 7-25 contains more information about object libraries.

7.4.10 Disable Conditional Linking (–j Option)

The –j option disables conditional linking that has been set up with the assembler .clink directive. By default, all sections are unconditionally linked.

7.4.11 Ignore Alignment Flags (–k Option)

The –k option forces the linker to ignore any SECTIONS directive alignment specifications. For more information on the SECTIONS directive, see Section 7.8, “The SECTIONS Directive”.

7.4.12 Create a Map File (–m filename Option)

The –m option creates a linker map listing and puts it in filename. The syntax for the –m option is:

–m filename

The linker map describes:

- Memory configuration
- Input and output section allocation
- The addresses of external symbols after they have been relocated

The map file contains the name of the output module and the entry point; it may also contain up to three tables:

- A table showing the new memory configuration if any non-default memory is specified
- A table showing the linked addresses of each output section and the input sections that make up the output sections
A table showing each external symbol and its address. This table has two columns: the left column contains the symbols sorted by name, and the right column contains the symbols sorted by address.

This example links file1.obj and file2.obj and creates a map file called file.map:

```
lnk500 file1.obj file2.obj -m file.map
```

Example 7–15 on page 7-78 shows an example of a map file.

### 7.4.13 Name an Output Module (–o filename Option)

The linker creates an output module when no errors are encountered. If you do not specify a filename for the output module, the linker gives it the default name a.out. If you want to write the output module to a different file, use the –o option. The syntax for the –o option is:

```plaintext
–o filename
```

The `filename` is the new output module name.

This example links file1.obj and file2.obj and creates an output module named run.out:

```
lnk500 –o run.out file1.obj file2.obj
```

### 7.4.14 Specify a Quiet Run (–q Option)

The –q option suppresses the linker’s banner when –q is the first option on the command line or in a command file. This option is useful for batch operation.

### 7.4.15 Strip Symbolic Information (–s Option)

The –s option creates a smaller output module by omitting symbol table information and line number entries. The –s option is useful for production applications when you must create the smallest possible output module.

This example links file1.obj and file2.obj and creates an output module, stripped of line numbers and symbol table information, named nosym.out:

```
lnk500 –o nosym.out –s file1.obj file2.obj
```

Using the –s option limits later use of a symbolic debugger and may prevent a file from being relinked.
7.4.16 Define Stack Size (–stack constant Option)

The TMS320C54x C/C++ compiler uses an uninitialized section, .stack, to allocate space for the runtime stack. You can set the size of the .stack section at link time with the –stack option. Specify the size in words as a constant immediately after the option:

```
lnk500 –stack 0x1000 /* defines a stack size */
```

If you specified a different stack size in an input section, the input section stack size is ignored. Any symbols defined in the input section remain valid; only the stack size will be different.

When the linker defines the .stack section, it also defines a global symbol, __STACK_SIZE, and assigns it a value equal to the size of the section. The default stack size is 1K words.

7.4.17 Introduce an Unresolved Symbol (–u symbol Option)

The –u option introduces an unresolved symbol into the linker’s symbol table. This forces the linker to search a library and include the member that defines the symbol. The linker must encounter the –u option before it links in the member that defines the symbol.

For example, suppose a library named rts.lib contains a member that defines the symbol symtab; none of the object files being linked reference symtab. However, suppose you plan to relink the output module, and you would like to include the library member that defines symtab in this link. Using the –u option as shown below forces the linker to search rts.lib for the member that defines symtab and to link in the member.

```
lnk500 –u symtab file1.obj file2.obj rts.lib
```

If you do not use –u, this member is not included because there is no explicit reference to it in file1.obj or file2.obj.
7.4.18 Specify a COFF Format (–v Option)

The –v option specifies the format the linker will use to create the COFF object file. The COFF object file is the output of the linker. The format specifies how information in the object file is arranged.

The linker can read and write COFF0, COFF1, and COFF2 formats. By default, the linker creates COFF2 files. To create a different output format, use the –v option where n is 0 for COFF0 or 1 for COFF1.

Chapter 2, *Introduction to Common Object File Format*, and Appendix A, *Common Object File Format*, provide further information on COFF.

7.4.19 Display a Message for Output Section Information (–w Option)

The –w option displays additional messages pertaining to the creation of memory sections. Additional messages are displayed in the following circumstances:

- In a linker command file, you can set up a SECTIONS directive that describes how input sections are combined into output sections. However, if the linker encounters one or more input sections that do not have a corresponding output section defined in the SECTIONS directive, the linker combines the input sections that have the same name into an output section with that name. By default, the linker does not display a message to tell you when this has occurred.

  If this situation occurs and you use the –w option, the linker displays a message when it creates a new output section.

- If you do not use the –heap and –stack options, the linker creates the .sysmem and .stack, respectively, sections for you. Each section has a default size of 0x400 words. You might not have enough memory available for one or both of these sections. In this case, the linker issues an error message saying a section could not be allocated.

  If you use the –w option, the linker displays another message with more details, which includes the name of the directive to allocate the .sysmem or .stack section yourself.

For more information about the SECTIONS directive, see Section 7.8, *The SECTIONS Directive*, on page 7-32. For more information about the default actions of the linker, see Section 7.12, *Default Allocation Algorithm*, on page 7-58.
7.4.20 Exhaustively Read Libraries (–x Option)

The linker normally reads input files, including archive libraries, only once when they are encountered on the command line or in the command file. When an archive is read, any members that resolve references to undefined symbols are included in the link. If an input file later references a symbol defined in a previously read archive library, the reference will not be resolved.

With the –x option, you can force the linker to reread all libraries. The linker rereads libraries until no more references can be resolved. Linking using the –x option may be slower, so you should use it only as needed. For example, if a.lib contains a reference to a symbol defined in b.lib, and b.lib contains a reference to a symbol defined in a.lib, you can resolve the mutual dependencies by listing one of the libraries twice, as in:

```
lnk500 -la.lib -lb.lib -la.lib
```

or you can force the linker to do it for you:

```
lnk500 -x -la.lib -lb.lib
```
7.5 Linker Command Files

Linker command files allow you to put linking information in a file; this is useful when you invoke the linker often with the same information. Linker command files are also useful because they allow you to use the MEMORY and SECTIONS directives to customize your application. You must use these directives in a command file; you cannot use them on the command line.

Linker command files are ASCII files that contain one or more of the following:

- Input filenames, which specify object files, archive libraries, or other command files.
- Linker options, which can be used in the command file in the same manner that they are used on the command line.
- The MEMORY and SECTIONS linker directives. The MEMORY directive defines the target memory configuration. The SECTIONS directive controls how sections are built and allocated.
- Assignment statements, which define and assign values to global symbols.

To invoke the linker with a command file, enter the `lnk500` command and follow it with the name of the command file:

```
lnk500 command_filename
```

The linker processes input files in the order that it encounters them. If the linker recognizes a file as an object file, it links it. Otherwise, it assumes that a file is a command file and begins reading and processing commands from it. Command filenames are case sensitive, regardless of the system used.
Example 7–1 shows a sample linker command file called link.cmd. (Subsection 2.4.2, *Placing Sections in the Memory Map*, on page 2-15 contains another example of a linker command file.)

**Example 7–1. Linker Command File**

```
 a.obj /* First input filename */
 b.obj /* Second input filename */
 -o prog.out /* Option to specify output file */
 -m prog.map /* Option to specify map file */
```

The sample file in Example 7–1 contains only filenames and options. You can place comments in a command file by delimiting them with /* and */. To invoke the linker with this command file, enter:

```
lnk500 link.cmd
```

You can place other parameters on the command line when you use a command file:

```
lnk500 -r link.cmd c.obj d.obj
```

The linker processes the command file as soon as it encounters it, so `a.obj` and `b.obj` are linked into the output module before `c.obj` and `d.obj`.

You can specify multiple command files. If, for example, you have a file called names.lst that contains filenames and another file called dir.cmd that contains linker directives, you could enter:

```
lnk500 names.lst dir.cmd
```

One command file can call another command file; this type of nesting is limited to 16 levels.

Blanks and blank lines are insignificant in a command file except as delimiters. This also applies to the format of linker directives in a command file.

**Note: Filenames and Option Parameters With Spaces or Hyphens**

Within the command file, filenames and option parameters containing embedded spaces or hyphens must be surrounded with quotation marks. For example: “this-file.obj”
Example 7–2 shows a sample command file that contains linker directives. (Linker directive formats are discussed in later sections.)

**Example 7–2. Command File With Linker Directives**

```plaintext
a.obj b.obj c.obj /* Input filenames */
-o prog.out -m prog.map /* Options */

MEMORY /* MEMORY directive */
{ RAM: origin = 100h length = 0100h
  ROM: origin = 01000h length = 0100h
}

SECTIONS /* SECTIONS directive */
{ .text: > ROM
  .data: > RAM
  .bss: > RAM
}
7.5.1 Reserved Names in Linker Command Files

The following names are reserved as keywords for linker directives. Do not use them as symbol or section names in a command file.

- align
- ALIGN
- attr
- ATTR
- block
- BLOCK
- COPY
- DSECT
- f
- fill
- FILL
- group

- GROUP
- ORIGIN
- len
- length
- LENGTH
- load
- LOAD
- MEMORY
- NOLOAD
- org
- spare
- TYPE
- origin
- ORIGIN
- page
- PAGE
- range
- run
- RUN
- SECTIONS
- spare
- TYPE
- UNION

7.5.2 Constants in Command Files

Constants can be specified with either of two syntax schemes: the scheme used for specifying decimal, octal, or hexadecimal constants used in the assembler (see Section 3.6, Constants, on page 3-15) or the scheme used for integer constants in C syntax.

Examples:

<table>
<thead>
<tr>
<th></th>
<th>Decimal</th>
<th>Octal</th>
<th>Hexadecimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembler Format:</td>
<td>32</td>
<td>40q</td>
<td>20h</td>
</tr>
<tr>
<td>C Format:</td>
<td>32</td>
<td>040</td>
<td>0x20</td>
</tr>
</tbody>
</table>
7.6 Object Libraries

An object library is a partitioned archive file that contains complete object files as members. Usually, a group of related modules are grouped together into a library. When you specify an object library as linker input, the linker includes any members of the library that define existing unresolved symbol references. You can use the archiver to build and maintain libraries. Chapter 6, Archiver Description, contains more information about the archiver.

Using object libraries can reduce link time and the size of the executable module. Normally, if an object file that contains a function is specified at link time, it is linked whether it is used or not; however, if that same function is placed in an archive library, it is included only if it is referenced.

The order in which libraries are specified is important because the linker includes only those members that resolve symbols that are undefined when the library is searched. The same library can be specified as often as necessary; it is searched each time it is included. Alternatively, the –x option can be used. A library has a table that lists all external symbols defined in the library; the linker searches through the table until it determines that it cannot use the library to resolve any more references.

The following examples link several files and libraries. Assume that:

- Input files f1.obj and f2.obj both reference an external function named clrscr
- Input file f1.obj references the symbol origin
- Input file f2.obj references the symbol fillclr
- Member 0 of library libc.lib contains a definition of origin
- Member 3 of library liba.lib contains a definition of fillclr
- Member 1 of both libraries defines clrscr

For example, if you enter the following, the references are resolved as shown:

```
lnk500 f1.obj liba.lib f2.obj libc.lib
```

- Member 1 of liba.lib satisfies both references to clrscr because the library is searched and clrscr is defined before f2.obj references it.
- Member 0 of libc.lib satisfies the reference to origin.
- Member 3 of liba.lib satisfies the reference to fillclr.
If, however, you enter the following, all the references to clrscr are satisfied by member 1 of libc.lib:

```
lnk500 f1.obj f2.obj libc.lib liba.lib
```

If none of the linked files reference symbols defined in a library, you can use the –u option to force the linker to include a library member. The next example creates an undefined symbol rout1 in the linker’s global symbol table:

```
lnk500 –u rout1 libc.lib
```

If any member of libc.lib define rout1, the linker includes those members.

It is not possible to control the allocation of individual library members; members are allocated according to the SECTIONS directive default allocation algorithm.

Subsection 7.4.9, Alter the Library Search Algorithm (–i dir Option/C_DIR), on page 7-13, describes methods for specifying directories that contain object libraries.
7.7 The MEMORY Directive

The linker determines where output sections should be allocated in memory; it must have a model of target memory to accomplish this task. The MEMORY directive allows you to specify a model of target memory so that you can define the types of memory your system contains and the address ranges they occupy. The linker maintains the model as it allocates output sections and uses it to determine which memory locations can be used for object code.

The memory configurations of TMS320C54x systems differ from application to application. The MEMORY directive allows you to specify a variety of configurations. After you use MEMORY to define a memory model, you can use the SECTIONS directive to allocate output sections into defined memory.

Refer to Section 2.4, How the Linker Handles Sections, on page 2-13 for details on how the linker handles sections. Refer to Section 2.5, Relocation, on page 2-16 for information on the relocation of sections.

7.7.1 Default Memory Model

The assembler enables you to assemble code for the TMS320C54x device. The assembler inserts a field in the output file’s header, identifying the device. The linker reads this information from the object file’s header. If you do not use the MEMORY directive, the linker uses a default memory model specific to the named device. For more information about the default memory model, see subsection 7.12.1, Allocation Algorithm, on page 7-58.

7.7.2 MEMORY Directive Syntax

The MEMORY directive identifies ranges of memory that are physically present in the target system and can be used by a program. Each memory range has a name, a starting address, and a length.

C54x devices have separate memory spaces that occupy the same address ranges. In the default model, one space is dedicated to program areas, while a second is dedicated to data (the number of separate address spaces depends on the customized configuration of your chip. See the TMS320C54x DSP Reference Set for more information).

The linker allows you to configure these address spaces separately by using the MEMORY directive’s PAGE option. In the default model, PAGE 0 refers to program memory, and PAGE 1 refers to data memory. The linker treats these two pages as completely separate memory spaces. The C54x supports as many as 255 PAGES, but the number available to you depends on the configuration you have chosen.
When you use the MEMORY directive, be sure to identify all the memory ranges that are available for object code. Memory defined by the MEMORY directive is configured memory; any memory that you do not explicitly account for with the MEMORY directive is unconfigured memory. The linker does not place any part of a program into unconfigured memory. You can represent nonexistent memory spaces by simply not including an address range in a MEMORY directive statement.

The MEMORY directive is specified in a command file by the word MEMORY (uppercase), followed by a list of memory range specifications enclosed in braces. The MEMORY directive in Example 7–3 defines a system that has 4K words of ROM at address C00h in program memory, 32 words of RAM at address 60h in data memory, and 4K words at address 80h in data memory.

Example 7–3. The MEMORY Directive

```
/**************************************************/
/* Sample command file with MEMORY directive */
/**************************************************/
file1.obj  file2.obj           /* Input files */
-o prog.out                        /* Options */
MEMORY
{ PAGE 0:   ROM:   origin = C00h, length = 1000h
  PAGE 1:   SCRATCH: origin = 60h, length = 20h
             ONCHIP: origin = 80h, length = 1000h
}
```
The general syntax for the MEMORY directive is:

```
MEMORY
{
    PAGE 0 : name 1 [(attr)] : origin = constant , length = constant;
    PAGE n : name n [(attr)] : origin = constant , length = constant;
}
```

PAGE identifies a memory space. You can specify up to 255 pages, depending on your configuration; usually, PAGE 0 specifies program memory, and PAGE 1 specifies data memory. If you do not specify a PAGE, the linker acts as if you specified PAGE 0. Each PAGE represents a completely independent address space. Configured memory on PAGE 0 can overlap configured memory on PAGE 1.

name Names a memory range. A memory name may be one to 64 characters; valid characters include A–Z, a–z, $, ., and _. The names have no special significance to the linker; they simply identify memory ranges. Memory range names are internal to the linker and are not retained in the output file or in the symbol table. Memory ranges on separate pages can have the same name; within a page, however, all memory ranges must have unique names and must not overlap.

attr Specifies one to four attributes associated with the named range. Attributes are optional; when used, they must be enclosed in parentheses. Attributes restrict the allocation of output sections into certain memory ranges. If you do not use any attributes, you can allocate any output section into any range with no restrictions. Any memory for which no attributes are specified (including all memory in the default model) has all four attributes. Valid attributes include:

- **R** specifies that the memory can be read
- **W** specifies that the memory can be written to
- **X** specifies that the memory can contain executable code
- **I** specifies that the memory can be initialized

origin Specifies the starting address of a memory range; enter as *origin*, *org*, or *o*. The value, specified in words, is a 16-bit constant and may be decimal, octal, or hexadecimal.
The MEMORY Directive

**length** Specifies the length of a memory range; enter as *length*, *len*, or *l*. The value, specified in words, is a 16-bit constant and may be decimal, octal, or hexadecimal.

**fill** Specifies a fill character for the memory range; enter as *fill* or *f*. Fills are optional. The value is a 2-byte integer constant and may be decimal, octal, or hexadecimal. The fill value will be used to fill areas of the memory range that are not allocated to a section.

**Note:** Filling Memory Ranges

If you specify fill values for large memory ranges, your output file will be very large because filling a memory range (even with 0s) causes raw data to be generated for all unallocated blocks of memory in the range.

The following example specifies a memory range with the R and W attributes and a fill constant of 0FFFFh:

```
MEMORY
{
    RFILE (RW) : o = 02h, l = 0FEh, f = 0FFFFh
}
```

You normally use the MEMORY directive in conjunction with the SECTIONS directive to control allocation of output sections. After you use the MEMORY directive to specify the target system’s memory model, you can use the SECTIONS directive to allocate output sections into specific named memory ranges or into memory that has specific attributes. For example, you could allocate the .text and .data sections into the area named ROM and allocate the .bss section into the area named ONCHIP.

Figure 7–2 illustrates the memory map shown in Example 7–3.
Figure 7–2. Memory Map Defined in Example 7–3

Data Memory

Program Memory

00000h
0005Fh
00060h
0007Fh
00080h
0107Fh
01080h
0FFFFFFh

00000h
00C00h
01C00h
0FFFFFFh

SCRATCH
ONCHIP
on-chip RAM
on-chip ROM
ROM

Data Memory

Program Memory

on-chip RAM
on-chip ROM
7.8 The SECTIONS Directive

The SECTIONS directive:

- Describes how input sections are combined into output sections
- Defines output sections in the executable program
- Specifies where output sections are placed in memory (in relation to each other and to the entire memory space)
- Permits renaming of output sections

Refer to Section 2.4, *How the Linker Handles Sections*, on page 2-13 for details on how the linker handles sections. Refer to Section 2.5, *Relocation*, on page 2-16 for information on the relocation of sections. Refer to subsection 2.3.4, *Subsections*, on page 2-9 for information on defining subsections; subsections allow you to manipulate sections with greater precision.

7.8.1 Default Configuration

If you do not specify a SECTIONS directive, the linker uses a default algorithm for combining and allocating the sections. Section 7.12, *Default Allocation Algorithm*, on page 7-58 describes this algorithm in detail.

7.8.2 SECTIONS Directive Syntax

The SECTIONS directive is specified in a command file by the word SECTIONS (uppercase), followed by a list of output section specifications enclosed in braces.

The general syntax for the SECTIONS directive is:

```
SECTIONS
{
    name : [property, property, property,...]
    name : [property, property, property,...]
    name : [property, property, property,...]
}
```
Each section specification, beginning with `name`, defines an output section. (An output section is a section in the output file.) After the section name is a list of properties that define the section’s contents and how the section is allocated. The properties may be separated by optional commas. Possible properties for a section are:

- **Load allocation**, which defines where in memory the section is to be loaded
  
  Syntax: `load = allocation` or `allocation` or `> allocation`

- **Run allocation**, which defines where in memory the section is to be run
  
  Syntax: `run = allocation` or `run > allocation`

- **Input sections**, which define the input sections that constitute the output section
  
  Syntax: `{ input_sections }

- **Section type**, which defines flags for special section types
  
  Syntax: `type = COPY` or `type = DSECT` or `type = NOLOAD`
  
  For more information on section types, see Section 7.13, *Special Section Types (DSECT, COPY, and NOLOAD)*, on page 7-61.

- **Fill value**, which defines the value used to fill uninitialized holes
  
  Syntax: `fill = value` or `name: ... { ... } = value`
  
  For more information on creating and filling holes, see Section 7.15, *Creating and Filling Holes*, on page 7-66.

Example 7–4 shows a SECTIONS directive in a sample linker command file. Figure 7–3 shows how these sections are allocated in memory.
Example 7–4. The SECTIONS Directive

```c
/******************** /
/* Sample command file with SECTIONS directive */
/******************** /
file1.obj  file2.obj /* Input files */
-o prog.out /* Options */
SECTIONS
{
  .text:     load = ROM, run = 800h
  .const:    load = ROM
  .bss:      load = RAM
  .vectors:  load = FF80h
    { 
      t1.obj(.intvec1)
      t2.obj(.intvec2)
      endvec = .;
    }
  .data:     align = 16
}
```

Figure 7–3 shows the five output sections defined by the sections directive in Example 7–4: .vectors, .text, .const, .bss, and .data.

**Figure 7–3. Section Allocation Defined by Example 7–4**

- **ROM**:
  - allocated at 0FF80h
  - bound at 0FF80h
  - allocated in ROM
  - allocated in ROM

- **.vectors**: bound at 0FF80h

- **.text**: combined from file1.obj and file2.obj. The linker combines all sections named .text into this section. The application must relocate the section to run at 0800h.

- **.const**: combined from file1.obj and file2.obj. The .const section combines the .const sections from file1.obj and file2.obj.

- **.bss**: combined from file1.obj and file2.obj. The .bss section combines the .bss sections from file1.obj and file2.obj.

- **.data**: aligned on a 16-word boundary and combined from file1.obj and file2.obj. The linker will place it anywhere there is space for it (in RAM in this illustration) and align it to a 16-word boundary.
7.8.3 Allocation

The linker assigns each output section two locations in target memory: the location where the section will be loaded and the location where it will be run. Usually, these are the same, and you can think of each section as having only a single address. In any case, the process of locating the output section in the target’s memory and assigning its address(es) is called allocation. For more information about using separate load and run allocation, see Section 7.9, *Specifying a Section’s Runtime Address*, on page 7-44.

If you do not tell the linker how a section is to be allocated, it uses a default algorithm to allocate the section. Generally, the linker puts sections wherever they fit into configured memory. You can override this default allocation for a section by defining it within a SECTIONS directive and providing instructions on how to allocate it.

You control allocation by specifying one or more allocation parameters. Each parameter consists of a keyword, an optional equal sign or greater-than sign, and a value optionally enclosed in parentheses. If load and run allocation is separate, all parameters following the keyword LOAD apply to load allocation, and those following RUN apply to run allocation. Possible allocation parameters are:

- **Binding**
  - allocates a section at a specific address.
  
  `.text: load = 0x1000`

- **Memory**
  - allocates the section into a range defined in the MEMORY directive with the specified name (like ROM) or attributes.
  
  `.text: load > ROM`

- **Alignment**
  - uses the align keyword to specify that the section should start on an address boundary.
  
  `.text: align = 0x80`

  To force the output section containing the assignment to also be aligned, assign . (dot) with an align expression. For example, the following will align bar.obj, and it will force outsect to align on a 0x40 word boundary:

  ```
  SECTIONS
  {
    outsect: { bar.obj(.bss)
               . = align(0x40);
    }
  }
  ```
The SECTIONS Directive

Blocking uses the block keyword to specify that the section must fit between two address boundaries: if the section is too big, it will start on an address boundary.

```
.text: block(0x80)
```

Page specifies the memory page to be used (see Section 7.11, Overlay Pages, on page 7-53).

```
.text: PAGE 0
```

For the load (usually the only) allocation, you may simply use a greater-than sign and omit the load keyword:

```
.text: > ROM
.text: {...} > ROM
.text: > 0x1000
```

If more than one parameter is used, you can string them together as follows:

```
.text: > ROM align 16 PAGE 2
```

Or, if you prefer, use parentheses for readability:

```
.text: load = (ROM align(16) page (2))
```

7.8.3.1 Binding

You can supply a specific starting address for an output section by following the section name with an address:

```
.text: 0x1000
```

This example specifies that the .text section must begin at word location 1000h. The binding address must be a 16-bit constant.

Output sections can be bound anywhere in configured memory (assuming there is enough space), but they cannot overlap. If there is not enough space to bind a section to a specified address, the linker issues an error message.

---

**Note:** Binding and Alignment or Named Memory are Incompatible

You cannot bind a section to an address if you use alignment or named memory. If you try to do so, the linker issues an error message.
7.8.3.2 Named memory

You can allocate a section into a memory range that is defined by the MEMORY directive. This example names ranges and links sections into them:

MEMORY
{
    ROM (RIX) : origin = 0C00h, length = 1000h
    RAM (RWIX): origin = 0080h, length = 1000h
}

SECTIONS
{
    .text       : > ROM
    .data ALIGN(128): > RAM
    .bss        : > RAM

In this example, the linker places .text into the area called ROM. The .data and .bss output sections are allocated into RAM. You can align a section within a named memory range; the .data section is aligned on a 128-word boundary within the RAM range.

Similarly, you can link a section into an area of memory that has particular attributes. To do this, specify a set of attributes (enclosed in parentheses) instead of a memory name. Using the same MEMORY directive declaration, you can specify:

SECTIONS
{
    .text: > (X) /* .text --> executable memory */
    .data: > (RI) /* .data --> read or init memory */
    .bss : > (RW) /* .bss --> read or write memory */
}

In this example, the .text output section can be linked into either the ROM or RAM area because both areas have the X attribute. The .data section can also go into either ROM or RAM because both areas have the R and I attributes. The .bss output section, however, must go into the RAM area because only RAM is declared with the W attribute.

You cannot control where in a named memory range a section is allocated, although the linker uses lower memory addresses first and avoids fragmentation when possible. In the preceding examples, assuming that no conflicting assignments exist, the .text section would start at address 0. If a section must start on a specific address, use binding instead of named memory.
7.8.3.3 Alignment and blocking

You can tell the linker to place an output section at an address that falls on an n-word boundary, where n is a power of 2. For example:

```
.text: load = align(128)
```

allocates .text so that it falls on a 128-word boundary.

Blocking is a weaker form of alignment that allocates a section anywhere within a block of size n. If the section is larger than the block size, the section will begin on that boundary. As with alignment, n must be a power of 2. For example:

```
bss: load = block(0x80)
```

allocates .bss so that the section either is contained in a single 128-word page or begins on a page.

You can use alignment or blocking alone or in conjunction with a memory area, but alignment and blocking cannot be used together.

7.8.3.4 Specifying input sections

An input section specification identifies the sections from input files that are combined to form an output section. The size of an output section is the sum of the sizes of the input sections that comprise it. The linker combines input sections by concatenating them in the order in which they are specified, unless alignment or blocking is specified for any of the input sections.

If alignment or blocking is specified for any input section, the input sections within an output section are ordered as follows:

1) all aligned sections, from largest to smallest, followed by
2) all blocked sections, from largest to smallest, followed by
3) all other input sections from largest to smallest

Example 7–5 shows the most common type of section specification; note that no input sections are listed.

Example 7–5. The Most Common Method of Specifying Section Contents

```
SECTIONS
{
   .text:
   .data:
   .bss:
}
```
In Example 7–5 the linker takes all the .text sections from the input files and combines them into the .text output section. The linker concatenates the .text input sections in the order that it encounters them in the input files. The linker performs similar operations with the .data and .bss sections. You can use this type of specification for any output section.

You can explicitly specify the input sections that form an output section. Each input section is identified by its filename and section name:

```
SECTIONS
{
  .text : /* Build .text output section */
  {                                               
    f1.obj(.text) /* Link .text section from f1.obj */  
    f2.obj(secl) /* Link secl section from f2.obj */ 
    f3.obj /* Link ALL sections from f3.obj */       
    f4.obj(.text,sec2) /* Link .text and sec2 from f4.obj */ 
  }                                               
}
```

It is not necessary for input sections to have the same name as each other or as the output section they become part of. If a file is listed with no sections, *all* of its sections are included in the output section. If any additional input sections have the same name as an output section, but are not explicitly specified by the SECTIONS directive, they are automatically linked in at the end of the output section. For example, if the linker found more .text sections in the preceding example, and these .text sections were not specified anywhere in the SECTIONS directive, the linker would concatenate these extra sections after f4.obj(secl).

The specifications in Example 7–5 are actually a shorthand method for the following:

```
SECTIONS
{
  .text: { *(.text) }
  .data: { *(.data) }
  .bss: { *(.bss) }
}
```

The specification *(.text) means *the unallocated .text sections from all the input files*. This format is useful when:

- You want the output section to contain all input sections that have a specified name, but the output section name is different than the input sections’ name.
- You want the linker to allocate the input sections before it processes additional input sections or commands within the braces.
The following example illustrates the two purposes above:

```plaintext
SECTIONS
{
  .text : {
    abc.obj(xqt)
    *(.text)
  }
  .data : {
    *(.data)
    fil.obj(table)
  }
}
```

In this example, the .text output section contains a named section xqt from file abc.obj, which is followed by all the .text input sections. The .data section contains all the .data input sections, followed by a named section table from the file fil.obj. This method includes all the unallocated sections. For example, if one of the .text input sections was already included in another output section when the linker encountered *(.text), the linker could not include that first .text input section in the second output section.

### 7.8.3.5 Allocation Using Multiple Memory Ranges

The linker allows you to specify an explicit list of memory ranges into which an output section can be allocated. Consider the following example:

```plaintext
MEMORY
{
  P_MEM1 : origin = 02000h, length = 01000h
  P_MEM2 : origin = 04000h, length = 01000h
  P_MEM3 : origin = 06000h, length = 01000h
  P_MEM4 : origin = 08000h, length = 01000h
}

SECTIONS
{
  .text : { } > P_MEM1 | P_MEM2 | P_MEM4
}
```

The "|" operator is used to specify the multiple memory ranges. The .text output section will be allocated as a whole into the first memory range in which it fits. The memory ranges are accessed in the order specified. In this example, the linker will first try to allocate the section in P_MEM1. If that attempt fails, the linker will try to place the section into P_MEM2, and so on. If the output section is not successfully allocated in any of the named memory ranges, the linker issues an error message.

With this type of SECTIONS directive specification, the linker can seamlessly handle an output section that grows beyond the available space of the memory range in which it is originally allocated. Instead of modifying the linker command file, you can let the linker move the section into one of the other areas.
7.8.3.6 Automatic Splitting of Output Sections Among Non-Contiguous Memory Ranges

The linker can split output sections among multiple memory ranges to achieve an efficient allocation. Use the >> operator to indicate that an output section can be split, if necessary, into the specified memory ranges. For example:

```
MEMORY
{
    P_MEM1 : origin = 02000h, length = 01000h
    P_MEM2 : origin = 04000h, length = 01000h
    P_MEM3 : origin = 06000h, length = 01000h
    P_MEM4 : origin = 08000h, length = 01000h
}
SECTIONS
{
    .text: { *(.text) } >> P_MEM1 | P_MEM2 | P_MEM3 | P_MEM4
}
```

In this example, the >> operator indicates that the .text output section can be split among any of the listed memory areas. If the .text section grows beyond the available memory in P_MEM1, it is split on an input section boundary, and the remainder of the output section is allocated to P_MEM2 | P_MEM3 | P_MEM4.

The "|" operator is used to specify the list of multiple memory ranges.

You can also use the >> operator to indicate that an output section can be split within a single memory range. This functionality is useful when several output sections must be allocated into the same memory range, but the restrictions of one output section cause the memory range to be partitioned. Consider the following example:

```
MEMORY
{
    RAM : origin = 01000h, length = 08000h
}
SECTIONS
{
    .special: { f1.obj(.text) } = 04000h
    .text: { *(.text) } >> RAM
}
```

The .special output section is allocated near the middle of the RAM memory range. This leaves two unused areas in RAM: from 01000h to 04000h, and from the end of f1.obj(.text) to 08000h. The specification for the .text section allows the linker to split the .text section around the .special section and use the available space in RAM on either side of .special.
The \texttt{SECTIONS} Directive

The \texttt{>>} operator can also be used to split an output section among all memory ranges that match a specified attribute combination. For example:

\begin{verbatim}
MEMORY
\{
    P_MEM1 (RWX) : origin = 01000h, length = 02000h
    P_MEM2 (RWI) : origin = 04000h, length = 01000h
\}
SECTIONS
\{
    .text: \{ *(.text) \} >> (RN)
\}
\end{verbatim}

The linker will attempt to allocate all or part of the output section into any memory range whose attributes match the attributes specified in the \texttt{SECTIONS} directive.

This \texttt{SECTIONS} directive has the same effect as:

\begin{verbatim}
SECTIONS
\{
    .text: \{ *(.text) \} >> P_MEM1 | P_MEM2
\}
\end{verbatim}

Certain output sections should not be split:

- \texttt{.cinit}, which contains the autoinitialization table for C/C++ programs
- \texttt{.pinit}, which contains the list of global constructors for C++ programs
- An output section with separate load and run allocations. The code that copies the output section from its load-time allocation to its run-time location cannot accommodate a split in the output section.
- An output section with an input section specification that includes an expression to be evaluated. The expression may define a symbol that is used in the program to manage the output section at run-time.

If you use the \texttt{>>} operator on any of these sections, the linker will issue a warning and ignore the operator.
### 7.8.3.7 Allocating an Archive Member to an Output Section

The linker allows you to allocate one or more members of an archive library into a specific output section. The syntax for such an allocation is:

```
SECTIONS
{
  .output_sec
  {
    [-l] lib_name<obj1 [obj2...objn]> (.sec_name)
  }
}
```

In this syntax, the `lib_name` is the archive library. The `–l` is optional, since the library search algorithm is always used to search for the archive. For more information on the `–l` option, see Section 7.4.9, *Alter the Library Search Algorithm*, on page 7-13. Brackets (`<>`) are used to specify the archive member(s). The brackets may contain one or more object files, separated by a space. The `sec_name` is the archive section to be allocated.

For example:

```
SECTIONS
{
  .boot > BOOT1
  {
    -l rts.lib<boot.obj exit.obj strcpy.obj> (.text)
  }
  .rts > BOOT2
  {
    -l rts.lib (.text)
  }
  .text > RAM
  {
    * (.text)
  }
}
```

In the specification above, the .text sections of boot.obj, exit.obj, and strcpy.obj from rts.lib will be placed in the .boot section.

The remainder of the .text sections from rts.lib will be placed in the .rts section.

All other unallocated .text sections will be placed in the .text section.
7.9 Specifying a Section’s Runtime Address

At times, you may want to load code into one area of memory and run it in another. For example, you may have performance-critical code in a ROM-based system. The code must be loaded into ROM, but it would run faster in RAM.

The linker provides a simple way to accomplish this. You can use the SECTIONS directive to direct the linker to allocate a section twice: once to set its load address and again to set its run address. For example:

```
.fir: load = ROM, run = RAM
```

Use the load keyword for the load address and the run keyword for the run address.

Refer to Section 2.6, Runtime Relocation, on page 2-19 for an overview on runtime relocation.

7.9.1 Specifying Load and Run Addresses

The load address determines where a loader will place the raw data for the section. All references to the section (such as labels in it) refer to its run address. The application must copy the section from its load address to its run address; this does not happen automatically when you specify a separate run address.

If you provide only one allocation (either load or run) for a section, the section is allocated only once and will load and run at the same address. If you provide both allocations, the section is allocated as if it were two sections of the same size. This means that both allocations occupy space in the memory map and cannot overlay each other or other sections. (The UNION directive provides a way to overlay sections; see subsection 7.10.1, Overlaying Sections With the UNION Statement, on page 7-48.)

If either the load or run address has additional parameters, such as alignment or blocking, list them after the appropriate keyword. Everything related to allocation after the keyword load affects the load address until the keyword run is seen, after which, everything affects the run address. The load and run allocations are completely independent, so any qualification of one (such as alignment) has no effect on the other. You may also specify run first, then load. Use parentheses to improve readability.
The examples below specify load and run addresses:

.data: load = ROM, align = 32, run = RAM

(align applies only to load )

.data: load = (ROM align 32), run = RAM

(identical to previous example)

.data: run = RAM, align 32,
       load = align 16

(align 32 in RAM for run; align 16 anywhere for load)

7.9.2 Uninitialized Sections

Uninitialized sections (such as .bss) are not loaded, so their only significant address is the run address. The linker allocates uninitialized sections only once: if you specify both run and load addresses, the linker warns you and ignores the load address. Otherwise, if you specify only one address, the linker treats it as a run address, regardless of whether you call it load or run. The example below specifies load and run addresses for an uninitialized section:

.bss: load = 0x1000, run = RAM

A warning is issued, load is ignored, and space is allocated in RAM. All of the following examples have the same effect. The .bss section is allocated in RAM.

.bss: load = RAM
.bss: run = RAM
.bss: > RAM

7.9.3 Referring to the Load Address by Using the .label Directive

Normally, any reference to a symbol in a section refers to its runtime address. However, it may be necessary at runtime to refer to a load-time address. Specifically, the code that copies a section from its load address to its run address must have access to the load address. The .label directive defines a special symbol that refers to the section's load address. Thus, whereas normal symbols are relocated with respect to the run address, .label symbols are relocated with respect to the load address. For more information on the .label directive, see page 4-60.

Example 7–6 shows the use of the .label directive.
Example 7–6. Copying a Section From ROM to RAM

```metal
; define a section to be copied from ROM to RAM
.sect "fir"
.label fir_src    ; load address of section
fir:             ; run address of section
<code here>      ; code for the section
.label fir_end    ; load address of section end

; copy .fir section from ROM into RAM
.text
STM fir_src, AR1  ; get load address
RPT #(fir_end – fir_src – 1)
MVDP *AR1+, fir   ; copy address to program memory

; jump to section, now in RAM
CALL fir
```

Linker Command File

```plaintext
/**********************************************************/
/* PARTIAL LINKER COMMAND FILE FOR FIR EXAMPLE */
/**********************************************************/
MEMORY
{
    PAGE 0 : ONCHIP : origin = 0800h, length = 02400h
    PAGE 0 : PROG : origin = 02C00h, length = 0D200h
    PAGE 1 : DATA : origin = 0800h, length = 0F800h
}
SECTIONS
{
    .text: load = PROG PAGE 0
    .fir: load = DATA PAGE 1, run ONCHIP PAGE 0
}
```
Figure 7–4 illustrates the runtime execution of this example.

Figure 7–4. Runtime Execution of Example 7–6
7.10 Using UNION and GROUP Statements

Two SECTIONS statements allow you to conserve memory: GROUP and UNION. Unioning sections causes the linker to allocate them to the same run address. Grouping sections causes the linker to allocate them contiguously in memory.

7.10.1 Overlaying Sections With the UNION Statement

For some applications, you may want to allocate more than one section to run at the same address. For example, you may have several routines you want in on-chip RAM at various stages of execution. Or you may want several data objects that will not be active at the same time to share a block of memory. The UNION statement within the SECTIONS directive provides a way to allocate several sections at the same runtime address.

In Example 7–7, the .bss sections from file1.obj and file2.obj are allocated at the same address in RAM. In the memory map, the union occupies as much space as its largest component. The components of a union remain independent sections; they are simply allocated together as a unit.

Example 7–7. The UNION Statement

```
SECTIONS
{
  .text: load = ROM
  UNION: run = RAM
  {
    .bss1: { file1.obj(.bss) }
    .bss2: { file2.obj(.bss) }
  }
  .bss3: run = RAM { globals.obj(.bss) }
}
```

Allocation of a section as part of a union affects only its run address. Under no circumstances can sections be overlaid for loading. If an initialized section is a union member (an initialized section has raw data, such as .text), its load allocation must be separately specified. For example:

Example 7–8. Separate Load Addresses for UNION Sections

```
UNION: run = RAM
{
  .text1: load = ROM, { file1.obj(.text) }
  .text2: load = ROM, { file2.obj(.text) }
}
```
Since the .text sections contain data, they cannot load as a union, although they can be run as a union. Therefore, each requires its own load address. If you fail to provide a load allocation for an initialized section within a union, the linker issues a warning and allocates load space anywhere it fits in configured memory.

Uninitialized sections are not loaded and do not require load addresses.

The UNION statement applies only to allocation of run addresses, so it is redundant to specify a load address for the union itself. For purposes of allocation, the union is treated as an uninitialized section: any one allocation specified is considered a run address, and, if both are specified, the linker issues a warning and ignores the load address.

The alignment and block attributes of a union are the maximum alignment and block attributes of any of its members.
Note: UNION and Overlay Page Are Not the Same

The UNION capability and the overlay page capability (see Section 7.11, Overlay Pages, on page 7-53) may sound similar because they both deal with overlays. They are, in fact, quite different. UNION allows multiple sections to be overlaid within the same memory space. Overlay pages, on the other hand, define multiple memory spaces. It is possible to use the page facility to approximate the function of UNION, but this is cumbersome.

7.10.2 Grouping Output Sections Together

The SECTIONS directive has a GROUP option that forces several output sections to be allocated contiguously. For example, assume that a section named term_rec contains a termination record for a table in the .data section. You can force the linker to allocate .data and term_rec together:

Example 7–9. Allocate Sections Together

```plaintext
SECTIONS
{
  .text     /* Normal output section */
  .bss      /* Normal output section */
  GROUP 1000h : /* Specify a group of sections */
  {         /* Specify a group of sections */
    .data   /* First section in the group */
    term_rec /* Allocated immediately after .data */
  }
}
```

You can use binding, alignment, or named memory to allocate a GROUP in the same manner as a single output section. In the preceding example, the GROUP is bound to word address 1000h. This means that .data is allocated at word 1000h, and term_rec follows it in memory.

The alignment and block attributes of a GROUP are the maximum alignment and block attributes of any of its members.

An allocator for a GROUP is subject to the consistency checking rules listed in Section 7.10.4.
7.10.3 Nesting UNIONs and GROUPs

The linker allows arbitrary nesting of GROUP and UNION statements with the SECTIONS directive. By nesting GROUP and UNION statements, you can express hierarchical overlays and groupings of sections. Example 7–10 shows how two overlays of sections can be grouped together.

Example 7–10. Nesting GROUP and UNION statements

```
SECTIONS
{
    GROUP 1000h : run = RAM
    {
        UNION:
        {
            mysect1: load = ROM
            mysect2: load = ROM
        }
        UNION:
        {
            mysect3: load = ROM
            mysect4: load = ROM
        }
    }
}
```

Given the example linker control file above, the linker performs the following allocations:

- The four sections (mysect1, mysect2, mysect3, mysect4) are assigned unique, non-overlapping load addresses in the ROM memory region. This assignment is determined by the particular load allocations given for each section.
- Sections mysect1 and mysect2 are assigned the same run address in RAM.
- Sections mysect3 and mysect4 are assigned the same run address in RAM.
- The run addresses of mysect1/mysect2 and mysect3/mysect4 are allocated contiguously, as directed by the GROUP statement (subject to alignment and blocking restrictions).

To refer to groups and unions, linker diagnostic messages use the notation:

```
GROUP_n
UNION_n
```

In this notation, \( n \) is a sequential number (beginning at 1) that represents the lexical ordering of the group or union in the linker control file, without regard to nesting. Groups and unions each have their own counter.
7.10.4 Checking the Consistency of Allocators

The linker checks the consistency of load and run allocations specified for unions, groups, and sections. The following rules are used:

- Run allocations are only allowed for top-level sections, groups, or unions (sections, groups, or unions that are not nested under any other groups or unions). The linker uses the run address of the top-level structure to compute the run addresses of the components within groups and unions.

- As discussed in Section 7.10.1, the linker does not accept a load allocation for UNIONS.

- As discussed in Section 7.10.1, the linker does not accept a load allocation for uninitialized sections.

- In most cases, you must provide a load allocation for an initialized section. However, the linker does not accept a load allocation for an initialized section that is located within a group that already defines a load allocator.

- As a shortcut, you can specify a load allocation for an entire group, to determine the load allocations for every initialized section or subgroup nested within the group. However, a load allocation is accepted for an entire group only if all of the following conditions are true:
  - The group is initialized (i.e., it has at least one initialized member).
  - The group is not nested inside another group that has a load allocator.
  - The group does not contain a union containing initialized sections.

If the group contains a union with initialized sections, it is necessary to specify the load allocation for each initialized section nested within the group. Consider the following example:

```
SECTIONS
{    
  GROUP: load = ROM, run = ROM
  {    
    .text1:
    UNION:
    {    
      .text2:
      .text3:
    }
  }
}
```

The load allocator given for the group does not uniquely specify the load allocation for the elements within the union: .text2 and .text3. In this case, the linker will issue a diagnostic message to request that these load allocations be specified explicitly.
7.11 Overlay Pages

Some target systems use a memory configuration in which all or part of the memory space is overlaid by shadow memory. This allows the system to map different banks of physical memory into and out of a single address range in response to hardware selection signals. In other words, multiple banks of physical memory overlay each other at one address range. You may want the linker to load various output sections into each of these banks or into banks that are not mapped at load time.

The linker supports this feature by providing overlay pages. Each page represents an address range that must be configured separately with the MEMORY directive. You can then use the SECTIONS directive to specify the sections to be mapped into various pages.

7.11.1 Using the MEMORY Directive to Define Overlay Pages

To the linker, each overlay page represents a completely separate memory comprising the full 24-bit range of addressable locations. This allows you to link two or more sections at the same (or overlapping) addresses if they are on different pages.

Pages are numbered sequentially, beginning with 0. If you do not use the PAGE option, the linker allocates initialized sections into PAGE 0 (program memory) and uninitialized sections into PAGE 1 (data memory).

For example, assume that your system can select between two banks of physical memory for data memory space: address range A00h to FFFFh for PAGE 1 and 0A00h to 2BFF for PAGE 2. Although only one bank can be selected at a time, you can initialize each bank with different data. This is how you use the MEMORY directive to obtain this configuration:

Example 7–11. Memory Directive With Overlay Pages

```
MEMORY
{
    PAGE 0 : ONCHIP : origin = 0800h, length = 0240h
              : PROG  : origin = 02C00h, length = 0D200h
    PAGE 1 : OVR_MEM : origin = 0A00h, length = 02200h
              : DATA  : origin = 02C00h, length = 0D400h
    PAGE 2 : OVR_MEM : origin = 0A00h, length = 02200h
}
```
Example 7–11 defines three separate address spaces. PAGE 0 defines an area of on-chip program memory and the rest of program memory space. PAGE 1 defines the first overlay memory area and the rest of data memory space. PAGE 2 defines another area of overlay memory for data space. Both OVR_MEM ranges cover the same address range. This is possible because each range is on a different page and therefore represents a different memory space.

Figure 7–6 shows overlay pages defined by the MEMORY directive in Example 7–11 and the SECTIONS directive in Example 7–12.

Figure 7–6. Overlay Pages Defined by Example 7–11 and Example 7–12
7.11.2 Using Overlay Pages With the SECTIONS Directive

Assume that you are using the MEMORY directive as shown in Example 7–11. Further assume that your code consists of, besides the usual sections, four modules of code that you want to load in data memory space but that you intend to run in the on-chip RAM in program memory space. Example 7–12 shows how to use the SECTIONS directive overlays accordingly.

Example 7–12. SECTIONS Directive Definition for Overlays in Figure 7–6

```assembly
SECTIONS
{
  UNION :  run = ONCHIP
  {
    S1 :  load = OVR_MEM PAGE 1
    {
      s1_load = 0A00h;
      s1_start = .;
      f1.obj (.text)
      f2.obj (.text)
      s1_length = . - s1_start;
    }
    S2 :  load = OVR_MEM PAGE 2
    {
      s2_load = 0A00h;
      s2_start = .;
      f3.obj (.text)
      f4.obj (.text)
      s2_length = . - s2_start;
    }
  }
  .text: load = PROG PAGE 0
  .data: load = PROG PAGE 0
  .bss : load = DATA PAGE 1
}
```

The four modules of code are f1, f2, f3, and f4. The modules f1 and f2 are combined into output section S1, and f3 and f4 are combined into output section S2. The PAGE specifications for S1 and S2 tell the linker to link these sections into the corresponding pages. As a result, they are both linked to load address A00h, but in different memory spaces. When the program is loaded, a loader can configure hardware so that each section is loaded into the appropriate memory bank.

Output sections S1 and S2 are placed in a union that has a run address in on-chip RAM. The application must move these sections at runtime before executing them. You can use the symbols s1_load and s1_length to move section S1, and s2_load and s2_length to move section S2. The special symbol "." refers to the current run address, not the current load address.
Within a page, you can bind output sections or use named memory areas in the usual way. In Example 7–12, S1 could have been allocated:

\[ S1 : \text{load} = 01200h, \text{page} = 1 \]  

This binds S1 at address 1200h in page 1. You can also use page as a qualifier on the address. For example:

\[ S1 : \text{load} = (01200h \text{ PAGE} 1) \]

If you do not specify any binding or named memory range for the section, the linker allocates the section into the page wherever it can (just as it normally does with a single memory space). For example, S2 could also be specified as:

\[ S2 : \text{PAGE} 2 \]

Because OVR_MEM is the only memory on page 2, it is not necessary (but acceptable) to specify \(=\) OVR_MEM for the section.

### 7.11.3 Page Definition Syntax

To specify overlay pages as illustrated in Example 7–11 and Example 7–12, use the following syntax for the MEMORY directive:

```
MEMORY
{
    PAGE 0 : name 1 [(attr)] : origin = constant , length = constant;
    PAGE n : name n [(attr)] : origin = constant , length = constant;
}
```

Each page is introduced by the keyword PAGE and a page number, followed by a colon and a list of memory ranges the page contains. **Bold** portions must be entered as shown. Memory ranges are specified in the normal way. You can define up to 255 overlay pages.

Because each page represents a completely independent address space, memory ranges on different pages can have the same name. Configured memory on any page can overlap configured memory on any other page. Within a single page, however, all memory ranges must have unique names and must not overlap.
Memory ranges listed outside the scope of a PAGE specification default to PAGE 0. Consider the following example:

```
MEMORY
{          ROM   : org = 0h     len = 1000h
  EPROM : org = 1000h  len = 1000h
  RAM  : org = 2000h  len = 0E000h
  PAGE1:  XROM  : org = 0h     len = 1000h
           XRAM  : org = 2000h  len = 0E000h
}
```

The memory ranges ROM, EPROM, and RAM are all on PAGE 0 (since no page is specified). XROM and XRAM are on PAGE 1. Note that XROM on PAGE 1 overlays ROM on PAGE 0, and XRAM on PAGE 1 overlays RAM on PAGE 0.

In the output link map (obtained with the –m linker option), the listing of the memory model is keyed by pages. This provides an easy method of verifying that you specified the memory model correctly. Also, the listing of output sections has a PAGE column that identifies the memory space into which each section will be loaded.
7.12 Default Allocation Algorithm

The MEMORY and SECTIONS directives provide flexible methods for building, combining, and allocating sections. However, any memory locations or sections that you choose not to specify must still be handled by the linker. The linker uses default algorithms to build and allocate sections within the specifications you supply. Subsections 7.12.1, Allocation Algorithm, and 7.12.2, General Rules for Output Sections, describe default allocation.

7.12.1 Allocation Algorithm

If you do not use the MEMORY and SECTIONS directives, the linker allocates output sections as though the following definitions are specified.

Example 7–13. Default Allocation for TMS320C54x Devices

```
MEMORY
{
    PAGE 0: PROG: origin = 0x0080 length = 0xFF00
    PAGE 1: DATA: origin = 0x0080 length = 0xFF80
}

SECTIONS
{
    .text: PAGE = 0
    .data: PAGE = 0
    .cinit: PAGE = 0 ;cflag option only
    .bss: PAGE = 1
}
```

All .text input sections are concatenated to form a .text output section in the executable output file, and all .data input sections are combined to form a .data output section. The .text and .data sections are allocated into configured memory on PAGE 0, which is the program memory space. All .bss sections are combined to form a .bss output section. The .bss section is allocated into configured memory on PAGE 1, which is the data memory space.

If the input files contain initialized named sections, the linker allocates them into program memory following the .data section. If the input files contain uninitialized named sections, the linker allocates them into data memory following the .bss section. You can override this by specifying an explicit PAGE in the SECTIONS directive.

If you use a SECTIONS directive, the linker performs no part of the default allocation. Allocation is performed according to the rules specified by the SECTIONS directive and the general algorithm described in subsection 7.12.2, General Rules for Output Sections.
7.12.2 General Rules for Output Sections

An output section can be formed in one of two ways:

**Rule 1**  As the result of a SECTIONS directive definition.

**Rule 2**  By combining input sections with the same names into an output section that is not defined in a SECTIONS directive.

If an output section is formed as a result of a SECTIONS directive (rule 1), this definition completely determines the section’s contents. (See Section 7.8, The \textit{SECTIONS Directive}, on page 7-32 for examples of how to define an output section’s content.)

An output section can also be formed when input sections are not specified by a SECTIONS directive (rule 2). In this case, the linker combines all such input sections that have the same name into an output section with that name. For example, suppose the files f1.obj and f2.obj both contain named sections called Vectors and that the SECTIONS directive does not define an output section for them. The linker combines the two Vectors sections from the input files into a single output section named Vectors, allocates it into memory, and includes it in the output file.

After the linker determines the composition of all output sections, it must allocate them into configured memory. The MEMORY directive specifies which portions of memory are configured; if there is no MEMORY directive, the linker uses the default configuration.

The linker’s allocation algorithm attempts to minimize memory fragmentation. This allows memory to be used more efficiently and increases the probability that your program will fit into memory. This is the algorithm:

1) Output sections for which you have supplied a specific binding address are placed in memory at that address.

2) Output sections that are included in a specific, named memory range or that have memory attribute restrictions are allocated. Each output section is placed into the first available space within the named area, considering alignment where necessary.
3) Any remaining sections are allocated in the order in which they are defined. Sections not defined in a SECTIONS directive are allocated in the order in which they are encountered. Each output section is placed into the first available memory space, considering alignment where necessary.

Note: The PAGE Option

If you do not use the PAGE option to explicitly specify a memory space for an output section, the linker allocates the section into PAGE 0. This occurs even if PAGE 0 has no room and other pages do. To use a page other than PAGE 0, you must specify the page with the SECTIONS directive.
7.13 Special Section Types (DSECT, COPY, and NOLOAD)

You can assign three special type designations to output sections: DSECT, COPY, and NOLOAD. These types affect the way that the program is treated when it is linked and loaded. You can assign a type to a section by placing the type (enclosed in parentheses) after the section definition. For example:

```
SECTIONS
{
  sec1 2000h  (DSECT)   : {f1.obj}
  sec2 4000h  (COPY)    : {f2.obj}
  sec3 6000h  (NOLOAD)  : {f3.obj}
}
```

- The DSECT type creates a dummy section with the following qualities:
  - It is not included in the output section memory allocation. It takes up no memory and is not included in the memory map listing.
  - It can overlay other output sections, other DSECTs, and unconfigured memory.
  - Global symbols defined in a dummy section are relocated normally. They appear in the output module's symbol table with the same value they would have if the DSECT had actually been loaded. These symbols can be referenced by other input sections.
  - Undefined external symbols found in a DSECT cause specified archive libraries to be searched.
  - The section's contents, relocation information, and line number information are not placed in the output module.

In the preceding example, none of the sections from f1.obj are allocated, but all of the symbols are relocated as though the sections were linked at word address 2000h. The other sections can refer to any of the global symbols in sec1.

- A COPY section is similar to a DSECT section, except that its contents and associated information are written to the output module. The .cinit section that contains initialization tables for the TMS320C54x C compiler has this attribute under the RAM model. The .comment section created by pragma IDENT is a COPY section.

- A NOLOAD section differs from a normal output section in one respect: the section's contents, relocation information, and line number information are not placed in the output module. The linker allocates space for it, and it appears in the memory map listing.
7.14 Assigning Symbols at Link Time

Linker assignment statements allow you to define external (global) symbols and assign values to them at link time. You can use this feature to initialize a variable or pointer to an allocation-dependent value.

7.14.1 Syntax of Assignment Statements

The syntax of assignment statements in the linker is similar to that of assignment statements in the C language:

\[
\begin{align*}
\text{symbol} & = \text{expression}; & \text{assigns the value of expression to symbol} \\
\text{symbol} & += \text{expression}; & \text{adds the value of expression to symbol} \\
\text{symbol} & -= \text{expression}; & \text{subtracts the value of expression from symbol} \\
\text{symbol} & *= \text{expression}; & \text{multiplies symbol by expression} \\
\text{symbol} & /= \text{expression}; & \text{divides symbol by expression}
\end{align*}
\]

The symbol should be defined externally. If it is not, the linker defines a new symbol and enters it into the symbol table. The expression must follow the rules defined in subsection 7.14.3, Assignment Expressions. Assignment statements must terminate with a semicolon.

The linker processes assignment statements after it allocates all the output sections. Therefore, if an expression contains a symbol, the address used for that symbol reflects the symbol's address in the executable output file.

For example, suppose a program reads data from one of two tables identified by two external symbols, Table1 and Table2. The program uses the symbol cur_tab as the address of the current table. cur_tab must point to either Table1 or Table2. You could accomplish this in the assembly code, but you would need to reassemble the program to change tables. Instead, you can use a linker assignment statement to assign cur_tab at link time:

\[
\begin{align*}
\text{prog.obj} & /* Input file */ \\
\text{cur_tab} & = \text{Table1}; & /* Assign cur_tab to one of the tables */
\end{align*}
\]
7.14.2 Assigning the SPC to a Symbol

A special symbol, denoted by a dot (.), represents the current value of the SPC during allocation. The linker’s “.” symbol is analogous to the assembler’s $ symbol. The “.” symbol can be used only in assignment statements within a SECTIONS directive because “.” is meaningful only during allocation, and SECTIONS controls the allocation process. (See Section 7.8, The SECTIONS Directive, on page 7-32.) Note that the “.” symbol cannot be used outside of the braces that define a single output section.

The “.” symbol refers to the current run address, not the current load address, of the section.

For example, suppose a program needs to know the address of the beginning of the .data section. By using the .global directive, you can create an external undefined variable called Dstart in the program. Then assign the value of “.” to Dstart:

```c
SECTIONS
{
    .text:   {}
    .data:   { Dstart = .; }
    .bss:    {}
}
```

This defines Dstart to be the first linked address of the .data section. (Dstart is assigned before .data is allocated.) The linker will relocate all references to Dstart.

A special type of assignment assigns a value to the “.” symbol. This adjusts the SPC within an output section and creates a hole between two input sections. Any value assigned to “.” to create a hole is relative to the beginning of the section, not to the address actually represented by “.”. Assignments to “.” and holes are described in Section 7.15, Creating and Filling Holes, on page 7-66.

7.14.3 Assignment Expressions

These rules apply to linker expressions:

- Expressions can contain global symbols, constants, and the C language operators listed in Table 7–1.
- All numbers are treated as long (32-bit) integers.
- Constants are identified by the linker in the same way as by the assembler. That is, numbers are recognized as decimal unless they have a suffix (H
or h for hexadecimal and Q or q for octal). C language prefixes are also recognized (0 for octal and 0x for hex). Hexadecimal constants must begin with a digit. No binary constants are allowed.

- Symbols within an expression have only the value of the symbol’s address. No type-checking is performed.

- Linker expressions can be absolute or relocatable. If an expression contains *any* relocatable symbols (and zero or more constants or absolute symbols), it is relocatable. Otherwise, the expression is absolute. If a symbol is assigned the value of a relocatable expression, it is relocatable; if it is assigned the value of an absolute expression, it is absolute.

The linker supports the C language operators listed in Table 7–1 in order of precedence. Operators in the same group have the same precedence. Besides the operators listed in Table 7–1, the linker also has an align operator that allows a symbol to be aligned on an n-word boundary within an output section (n is a power of 2). For example, the expression

```
. = align(16);
```

aligns the SPC within the current section on the next 16-word boundary. Because the align operator is a function of the current SPC, it can be used only in the same context as “.” —that is, within a SECTIONS directive.

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Operators</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>+, −, ~</td>
<td>Unary plus, minus, 1s complement</td>
<td>Right to left</td>
</tr>
<tr>
<td>* / %</td>
<td>Multiplication, division, modulo</td>
<td>Left to right</td>
</tr>
<tr>
<td>+, −</td>
<td>Addition, subtraction</td>
<td>Left to right</td>
</tr>
<tr>
<td>&lt;&lt;, &gt;&gt;</td>
<td>Left shift, right shift</td>
<td>Left to right</td>
</tr>
<tr>
<td>&lt;, ≤, &gt;, ≥</td>
<td>Less than, LT or equal, greater than, GT or equal</td>
<td>Left to right</td>
</tr>
<tr>
<td>!=, =, [=]</td>
<td>Not equal to, equal to</td>
<td>Left to right</td>
</tr>
<tr>
<td>&amp;</td>
<td>Bitwise AND</td>
<td>Left to right</td>
</tr>
<tr>
<td>^</td>
<td>Bitwise exclusive OR</td>
<td>Left to right</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bitwise OR</td>
</tr>
</tbody>
</table>

**Note:** Unary +, −, and * have higher precedence than the binary forms.
7.14.4 Symbols Defined by the Linker

The linker automatically defines several symbols that a program can use at runtime to determine where a section is linked. These symbols are external, so they appear in the link map. They can be accessed in any assembly language module if they are declared with a .global directive. Values are assigned to these symbols as follows:

.text is assigned the first address of the .text output section.
(It marks the beginning of executable code.)

.ettex is assigned the first address following the .text output section.
(It marks the end of executable code.)

.data is assigned the first address of the .data output section.
(It marks the beginning of initialized data tables.)

.edata is assigned the first address following the .data output section.
(It marks the end of initialized data tables.)

.bss is assigned the first address of the .bss output section.
(It marks the beginning of uninitialized data.)

.end is assigned the first address following the .bss output section.
(It marks the end of uninitialized data.)

7.14.5 Symbols Defined Only For C Support (–c or –cr Option)

__STACK_SIZE is assigned the size of the .stack section.

__SYSMEM_SIZE is assigned the size of the .sysmem section.
7.15 Creating and Filling Holes

The linker provides you with the ability to create areas within output sections that have nothing linked into them. These areas are called holes. In special cases, uninitialized sections can also be treated as holes. The following text describes how the linker handles such holes and how you can fill holes (and uninitialized sections) with a value.

7.15.1 Initialized and Uninitialized Sections

An output section contains one of the following:

- Raw data for the entire section
- No raw data

A section that has raw data is referred to as initialized. This means that the object file contains the actual memory image contents of the section. When the section is loaded, this image is loaded into memory at the section’s specified starting address. The .text and .data sections always have raw data if anything was assembled into them. Named sections defined with the .sect assembler directive also have raw data.

By default, the .bss section and sections defined with the .usect directive have no raw data (they are uninitialized). They occupy space in the memory map but have no actual contents. Uninitialized sections typically reserve space in RAM for variables. In the object file, an uninitialized section has a normal section header and may have symbols defined in it; however, no memory image is stored in the section.

7.15.2 Creating Holes

You can create a hole in an initialized output section. A hole is created when you force the linker to leave extra space between input sections within an output section. When such a hole is created, the linker must follow the first guideline above and supply raw data for the hole.

Holes can be created only within output sections. Space can exist between output sections, but such space is not holes. There is no way to fill or initialize the space between output sections with the SECTIONS directive.

To create a hole in an output section, you must use a special type of linker assignment statement within an output section definition. The assignment statement modifies the SPC (denoted by ".") by adding to it, assigning a greater value to it, or aligning it on an address boundary. The operators, expressions, and syntaxes of assignment statements are described in Section 7.14, Assigning Symbols at Link Time, on page 7-62.
The following example uses assignment statements to create holes in output sections:

```
SECTIONS
{
  outsect:
    {
      file1.obj(.text)
        . += 100h; /* Create a hole with size 100h words */
      file2.obj(.text)
        . = align(16); /* Create a hole to align the SPC */
      file3.obj(.text)
    }
}
```

The output section outsect is built as follows:

- The `.text` section from file1.obj is linked in.
- The linker creates a 256-word hole.
- The `.text` section from file2.obj is linked in after the hole.
- The linker creates another hole by aligning the SPC on a 16-word boundary.
- Finally, the `.text` section from file3.obj is linked in.

All values assigned to the `.` symbol within a section refer to the relative address within the section. The linker handles assignments to the `.` symbol as if the section started at address 0 (even if you have specified a binding address). Consider the statement `. = align(16)` in the example. This statement effectively aligns file3.obj `.text` to start on a 16-word boundary within outsect. If outsect is ultimately allocated to start on an address that is not aligned, file3.obj `.text` will not be aligned either.

Note that the `.` symbol refers to the current run address, not the current load address, of the section.

Expressions that decrement `.` are illegal. For example, it is invalid to use the `-=` operator in an assignment to `.`. The most common operators used in assignments to `.` are `+=` and `align`.

If an output section contains all input sections of a certain type (such as `.text`), you can use the following statements to create a hole at the beginning or end of the output section:

```
.text:  { . += 100h; } /* Hole at the beginning */
.data:  {
      *(.data)
        . += 100h; } /* Hole at the end */
```
Another way to create a hole in an output section is to combine an uninitialized section with an initialized section to form a single output section. *In this case, the linker treats the uninitialized section as a hole and supplies data for it.* The following example illustrates this method:

```
SECTIONS
{
   outsect:
   {
      file1.obj(.text)
      file1.obj(.bss)  /* This becomes a hole */
   }
}
```

Because the .text section has raw data, all of outsect must also contain raw data (rule 1). Therefore, the uninitialized .bss section becomes a hole.

Uninitialized sections become holes only when they are combined with initialized sections. If several uninitialized sections are linked together, the resulting output section is also uninitialized.

### 7.15.3 Filling Holes

When a hole exists in an initialized output section, the linker must supply raw data to fill it. The linker fills holes with a 16-bit fill value that is replicated through memory until it fills the hole. The linker determines the fill value as follows:

1) If the hole is formed by combining an uninitialized section with an initialized section, you can specify a fill value for the uninitialized section. Follow the section name with an = sign and a 16-bit constant:

```
SECTIONS
{
   outsect:
   {
      file1.obj(.text)
      file2.obj(.bss) = 00FFh /* Fill this hole */
      /* with 0FFh */
   }
}
```

2) You can also specify a fill value for all the holes in an output section by supplying the fill value after the section definition:

```
SECTIONS
{
   outsect:fill = 0FF00h /* fills holes with 0FF00h */
   {
      . += 10h; /* This creates a hole */
      file1.obj(.text)
      file1.obj(.bss) /* This creates another hole*/
   }
}
```
3) If you do not specify an initialization value for a hole, the linker fills the hole with the value specified by the –f option. For example, suppose the command file link.cmd contains the following SECTIONS directive:

```
SECTIONS
{
  .text: { .= 100; } /* Create a 100-word hole */
}
```

Now invoke the linker with the –f option:

```
lk500 -f OFFFFh link.cmd
```

This fills the hole with OFFFFh.

4) If you do not invoke the linker with the –f option, the linker fills holes with 0s.

Whenever a hole is created and filled in an initialized output section, the hole is identified in the link map along with the value the linker uses to fill it.

### 7.15.4 Explicit Initialization of Uninitialized Sections

An uninitialized section becomes a hole only when it is combined with an initialized section. When uninitialized sections are combined with each other, the resulting output section remains uninitialized.

However, you can force the linker to initialize an uninitialized section by specifying an explicit fill value for it in the SECTIONS directive. This causes the entire section to have raw data (the fill value). For example:

```
SECTIONS
{
  .bss: fill = 1234h /* Fills .bss with 1234h */
}
```

---

**Note: Filling Sections**

Because filling a section (even with 0s) causes raw data to be generated for the entire section in the output file, your output file will be very large if you specify fill values for large sections or holes.
7.16 Partial (Incremental) Linking

An output file that has been linked can be linked again with additional modules. This is known as *partial linking* or incremental linking. Partial linking allows you to partition large applications, link each part separately, and then link all the parts together to create the final executable program.

Follow these guidelines for producing a file that you will relink:

- Intermediate files *must* have relocation information. Use the \(-r\) option when you link the file the first time.

- Intermediate files *must* have symbolic information. By default, the linker retains symbolic information in its output. Do not use the \(-s\) option if you plan to relink a file, because \(-s\) strips symbolic information from the output module.

- Intermediate link steps should be concerned only with the formation of output sections and not with allocation. All allocation, binding, and MEMORY directives should be performed in the final link step.

- If the intermediate files have global symbols that have the same name as global symbols in other files and you wish them to be treated as static (visible only within the intermediate file), you must link the files with the \(-h\) option (See subsection 7.4.7, Make All Global Symbols Static \((-h\) and \(-g\) global_symbol Options), on page 7-12.)

- If you are linking C code, don’t use \(-c\) or \(-cr\) until the final link step. Every time you invoke the linker with the \(-c\) or \(-cr\) option the linker will attempt to create an entry point.

The following example shows how you can use partial linking:

**Step 1:** Link the file file1.com; use the \(-r\) option to retain relocation information in the output file tempout1.out.

```
lnk500 -r -o tempout1 file1.com
```

**`file1.com` contains:**

```plaintext
SECTIONS
{
  ss1: {  
    f1.obj
    f2.obj
    ...
    fn.obj
  }
}
```

7-70
**Step 2:** Link the file file2.com; use the \(-r\) option to retain relocation information in the output file tempout2.out.

```
lnk500 -r -o tempout2 file2.com
```

file2.com contains:

```
SECTIONS
{
  ss2: {
    g1.obj
    g2.obj
    ...
    gn.obj
  }
}
```

**Step 3:** Link tempout1.out and tempout2.out:

```
lnk500 -m final.map -o final.out tempout1.out tempout2.out
```
7.17 Linking C/C++ Code

The TMS320C54x C/C++ compiler produces assembly language source code that can be assembled and linked. For example, a C/C++ program consisting of modules prog1, prog2, etc., can be assembled and then linked to produce an executable file called prog.out:

```
lnk500 -c -o prog.out prog1.obj prog2.obj ... rts.lib
```

The --c option tells the linker to use special conventions that are defined by the C/C++ environment. The runtime library contains C/C++ runtime-support functions.

For more information about C/C++, including the runtime environment and runtime-support functions, see the TMS320C54x Optimizing C/C++ Compiler User’s Guide.

7.17.1 Runtime Initialization

All C/C++ programs must be linked with an object module called boot.obj. When a program begins running, it executes boot.obj first. boot.obj contains code and data for initializing the runtime environment. The module performs the following tasks:

- Sets up the system stack
- Processes the runtime initialization table and autoinitializes global variables (in the ROM model)
- Disables interrupts and calls _main

The runtime-support object library, rts.lib, contains boot.obj. You can:

- Use the archiver to extract boot.obj from the library and then link the module in directly.
- Include rts.lib as an input file (the linker automatically extracts boot.obj when you use the --c or --cr option).

7.17.2 Object Libraries and Runtime Support

The TMS320C54x Optimizing C Compiler User’s Guide describes additional runtime-support functions that are included in rts.lib. If your program uses any of these functions, you must link rts.lib with your object files.

You can also create your own object libraries and link them. The linker includes and links only those library members that resolve undefined references.
7.17.3 Setting the Size of the Stack and Heap Sections

C uses two uninitialized sections called .sysmem and .stack for the memory pool used by the malloc() functions and the runtime stack, respectively. You can set the size of these by using the –heap option or –stack option and specifying the size of the section as a constant immediately after the option. The default size for both is 1K words.

For more information, see subsection 7.4.8, Define Heap Size (–heap constant Option), on page 7-12, or subsection 7.4.16, Define Stack Size (–stack constant Option), on page 7-18.

7.17.4 Automainitization (ROM and RAM Models)

The C/C++ compiler produces tables of data for automainitization global variables. These are in a named section called .cinit. The initialization tables can be used in either of two ways:

- **RAM Model (–cr option)**

  Variables are initialized at load time. This enhances performance by reducing boot time and by saving memory used by the initialization tables. You must use a smart loader (i.e., one capable of initializing variables) to take advantage of the RAM model of automainitization.

  When you use –cr, the linker marks the .cinit section with a special attribute. This attribute tells the linker not to load the .cinit section into memory. The linker also sets the cinit symbol to –1; this tells the C/C++ boot routine that initialization tables are not present in memory. Thus, no runtime initialization is performed at boot time.

  When the program is loaded, the loader must be able to:

  - Detect the presence of the .cinit section in the object file
  - Detect the presence of the attribute that tells it not to copy the .cinit section
  - Understand the format of the initialization tables. (This format is described in the TMS320C54x Optimizing C/C++ Compiler User’s Guide.)

  The loader then uses the initialization tables directly from the object file to initialize variables in .bss.
Figure 7–7 illustrates the RAM autoinitialization model.

**Figure 7–7. RAM Model of Autoinitialization**

[Diagram of RAM model]

- **ROM Model** (–c option)

  Variables are initialized at runtime. The .cinit section is loaded into memory along with all the other sections. The linker defines a special symbol called cinit that points to the beginning of the tables in memory. When the program begins running, the C/C++ boot routine copies data from the tables into the specified variables in the .bss section. This allows initialization data to be stored in ROM and copied to RAM each time the program is started.

  Figure 7–8 illustrates the ROM autoinitialization model.

**Figure 7–8. ROM Model of Autoinitialization**

[Diagram of ROM model]
7.17.5 The –c and –cr Linker Options

The following list outlines what happens when you invoke the linker with the –c or –cr option.

- The symbol `_c_int00` is defined as the program entry point. `_c_int00` is the start of the C/C++ boot routine in boot.obj; referencing `_c_int00` ensures that boot.obj is automatically linked in from the runtime-support library rts.lib.

- The .cinit output section is padded with a termination record to designate to the boot routine (ROM model) or the loader (RAM model) when to stop reading the initialization tables.

- In the ROM model (–c option), the linker defines the symbol cinit as the starting address of the .cinit section. The C/C++ boot routine uses this symbol as the starting point for autoinitialization.

- In the RAM model (–cr option):
  - The linker sets the symbol cinit to −1. This indicates that the initialization tables are not in memory, so no initialization is performed at runtime.
  - The STYP_COPY flag (0010h) is set in the .cinit section header. STYP_COPY is the special attribute that tells the loader to perform autoinitialization directly and not to load the .cinit section into memory. The linker does not allocate space in memory for the .cinit section.
7.18 Linker Example

This example links three object files named demo.obj, fft.obj, and tables.obj and creates a program called demo.out. The symbol SETUP is the program entry point.

Assume that target memory has the following configuration:

**Program Memory**

<table>
<thead>
<tr>
<th>Address Range</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>0080 to 7000</td>
<td>On-chip RAM_PG</td>
</tr>
<tr>
<td>C000 to FF80</td>
<td>On-chip ROM</td>
</tr>
</tbody>
</table>

**Data Memory**

<table>
<thead>
<tr>
<th>Address Range</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>0080 to 0FFF</td>
<td>RAM block ONCHIP</td>
</tr>
<tr>
<td>0060 to FFFF</td>
<td>Mapped external addresses EXT</td>
</tr>
</tbody>
</table>

The output sections are constructed from the following input sections:

- Executable code, contained in the .text sections of demo.obj, fft.obj, and tables.obj must be linked into program ROM.

- Variables, contained in the var_defs section of demo.obj, must be linked into data memory in block ONCHIP.

- Tables of coefficients in the .data sections of demo.obj, tables.obj and fft.obj must be linked into RAM block ONCHIP in data memory. A hole is created with a length of 100 words and a fill value of 07A1Ch. The remainder of block ONCHIP must be initialized to the value 07A1Ch.

- The .bss sections from demo.obj, tables.obj, and fft.obj, which contain variables, must be linked into block RAM_PG of program RAM. The unused part of this RAM must be initialized to 0FFFFh.

- The xy section from demo.obj, which contains buffers and variables, will have the default linking into block ONCHIP of data RAM, since it was not explicitly linked.

Example 7–14 shows the linker command file for this example. Example 7–15 shows the map file.
Example 7–14. Linker Command File, demo.cmd

```plaintext
/**************************************************************
/***                 Specify Linker Options                  ***/
**************************************************************
–e coeff                     /* Define the program entry point */
–o demo.out                  /* Name the output file */
–m demo.map                  /* Create an output map */

/**************************************************************
/***                  Specify the Input Files                ***/
**************************************************************
demo.obj
fft.obj
tables.obj

/**************************************************************
/***            Specify the Memory Configurations            ***/
**************************************************************
MEMORY
{
  PAGE 0: RAM_PG: origin=00080h length=06F80h
            ROM: origin=0C000h length=03F80h
  PAGE 1: ONCHIP: origin=00080h length=0F7Fh
            EXT: origin=01000h length=0EFFFh
}

/**************************************************************
/***              Specify the Output Sections                 ***/
**************************************************************
SECTIONS
{
  .text: load = ROM, page = 0 /* link .text into ROM */
  var_defs: load = ONCHIP, page=1 /* defs in RAM */
  .data: fill = 07A1Ch, load=ONCHIP, page=1
    { tables.obj(.data) /* .data input */
        fft.obj(.data) /* .data input */
        . = 100h; /* create hole, fill with 07A1Ch */
    } /* and link with ONCHIP */
  .bss: load=RAM_PG,page=0,fill=0FFFFh /* Remaining .bss; fill and link */
}

/**************************************************************
/***                  End of Command File                    ***/
**************************************************************
```
Invoke the linker with the following command:

```
lnk500 demo.cmd
```

This creates the map file shown in Example 7–15 and an output file called demo.out that can be run on a TMS320C54x.

**Example 7–15. Output Map File, demo.map**

```
OUTPUT FILE NAME:  <demo.out>
ENTRY POINT SYMBOL:  0

MEMORY CONFIGURATION

<table>
<thead>
<tr>
<th>name</th>
<th>origin</th>
<th>length</th>
<th>used</th>
<th>attributes</th>
<th>fill</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAGE 0: RAM_PG</td>
<td>00000080</td>
<td>000006f80</td>
<td>00000002</td>
<td>RWIX</td>
<td></td>
</tr>
<tr>
<td>ROM</td>
<td>0000c000</td>
<td>00003f80</td>
<td>00000011</td>
<td>RWIX</td>
<td></td>
</tr>
<tr>
<td>PAGE 1: ONCHIP</td>
<td>00000080</td>
<td>00000ff7f</td>
<td>00000105</td>
<td>RWIX</td>
<td></td>
</tr>
<tr>
<td>EXT</td>
<td>00001000</td>
<td>00000efff</td>
<td>00000000</td>
<td>RWIX</td>
<td></td>
</tr>
</tbody>
</table>

SECTION ALLOCATION MAP

<table>
<thead>
<tr>
<th>section</th>
<th>page</th>
<th>origin</th>
<th>length</th>
<th>input sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>.text</td>
<td>0</td>
<td>0000c000</td>
<td>00000111</td>
<td>demo.obj (.text)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0000c000</td>
<td>00000008</td>
<td>fft.obj (.text)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0000c008</td>
<td>0000004</td>
<td>tables.obj (.text)</td>
</tr>
<tr>
<td>var_defs</td>
<td>1</td>
<td>00000080</td>
<td>00000002</td>
<td>demo.obj (var_defs)</td>
</tr>
<tr>
<td>.data</td>
<td>1</td>
<td>00000082</td>
<td>00000100</td>
<td>tables.obj (.data)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>00000083</td>
<td>00000004</td>
<td>fft.obj (.data)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>00000087</td>
<td>000000f8b</td>
<td>--HOLE-- [fill = 7a1c]</td>
</tr>
<tr>
<td>.bss</td>
<td>0</td>
<td>00000080</td>
<td>00000002</td>
<td>demo.obj (.bss) [fill=ffff]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>00000082</td>
<td>00000000</td>
<td>tables.obj (.bss)</td>
</tr>
<tr>
<td>xy</td>
<td>1</td>
<td>00000182</td>
<td>00000003</td>
<td>UNINITIALIZED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>00000182</td>
<td>00000003</td>
<td>demo.obj (xy)</td>
</tr>
</tbody>
</table>

GLOBAL SYMBOLS

<table>
<thead>
<tr>
<th>address</th>
<th>name</th>
<th>address</th>
<th>name</th>
</tr>
</thead>
<tbody>
<tr>
<td>00000080</td>
<td>.bss</td>
<td>00000080</td>
<td>.bss</td>
</tr>
<tr>
<td>00000082</td>
<td>.data</td>
<td>00000082</td>
<td>.data</td>
</tr>
<tr>
<td>0000c000</td>
<td>.text</td>
<td>00000082</td>
<td>TEMP</td>
</tr>
<tr>
<td>0000c002</td>
<td>ARRAY</td>
<td>00000082</td>
<td>ARRAY</td>
</tr>
<tr>
<td>00000082</td>
<td>TEMP</td>
<td>00000182</td>
<td>end</td>
</tr>
<tr>
<td>00000182</td>
<td>edata</td>
<td>0000018a</td>
<td>edata</td>
</tr>
<tr>
<td>00000082</td>
<td>end</td>
<td>0000c000</td>
<td>.text</td>
</tr>
<tr>
<td>0000c011</td>
<td>etext</td>
<td>0000c011</td>
<td>etext</td>
</tr>
</tbody>
</table>

[8 symbols]

7-78
The absolute lister is a debugging tool that accepts linked object files as input and creates .abs files as output. These .abs files can be assembled to produce a listing that shows the absolute addresses of object code. Manually, this could be a tedious process requiring many operations; however, the absolute lister utility performs these operations automatically.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1 Producing an Absolute Listing</td>
<td>8-2</td>
</tr>
<tr>
<td>8.2 Invoking the Absolute Lister</td>
<td>8-3</td>
</tr>
<tr>
<td>8.3 Absolute Lister Example</td>
<td>8-5</td>
</tr>
</tbody>
</table>
8.1 Producing an Absolute Listing

Figure 8–1 illustrates the steps required to produce an absolute listing.

*Figure 8–1. Absolute Lister Development Flow*

1. **Step 1:** First, assemble a source file.
   - Assembler
   - Assembler source file

2. **Step 2:** Link the resulting object file.
   - Linker
   - Linked object file

3. **Step 3:** Invoke the absolute lister; use the linked object file as input. This creates a file with an .abs extension.
   - Absolute lister
   - .abs file

4. **Step 4:** Finally, assemble the .abs file; you must invoke the assembler with the –a option. This produces a listing file that contains absolute addresses.
   - Assembler
   - Absolute listing
8.2 Invoking the Absolute Lister

The syntax for invoking the absolute lister is:

\[
\text{abs500} \ [\text{–options}] \ \text{input file}
\]

\textbf{abs500} is the command that invokes the absolute lister.

\textbf{options} identifies the absolute lister options that you want to use. Options are not case sensitive and can appear anywhere on the command line following the command. Precede each option with a hyphen (–). The absolute lister options are as follows:

- \textbf{–e} enables you to change the default naming conventions for filename extensions on assembly files, C source files, and C header files. The three options are listed below.
  - \textbf{–ea} [.]asmext for assembly files (default is .asm)
  - \textbf{–ec} [.]cext for C source files (default is .c)
  - \textbf{–eh} [.]hext for C header files (default is .h)

  The “.” in the extensions and the space between the option and the extension are optional.

- \textbf{–q} (quiet) suppresses the banner and all progress information.

\textbf{input file} names the linked object file. If you do not supply an extension, the absolute lister assumes that the input file has the default extension .out. If you do not supply an input filename when you invoke the absolute lister, the absolute lister will prompt you for one.

The absolute lister produces an output file for each file that was linked. These files are named with the input filenames and an extension of .abs. Header files, however, do not generate a corresponding .abs file.

Assemble these files with the \textbf{–a} assembler option as follows to create the absolute listing:

\[
\text{asm500} \ \text{–a} \ \text{filename.abs}
\]

The \textbf{–e} options affect both the interpretation of filenames on the command line and the names of the output files. They should always precede any filename on the command line.
The –e options are useful when the linked object file was created from C files compiled with the debugging option (–g compiler option). When the debugging option is set, the resulting linked object file contains the name of the source files used to build it. In this case, the absolute lister will not generate a corresponding .abs file for the C header files. Also, the .abs file corresponding to a C source file will use the assembly file generated from the C source file rather than the C source file itself.

For example, suppose the C source file hello.csr is compiled with debugging set; this generates the assembly file hello.s. hello.csr also includes hello.hsr. Assuming the executable file created is called hello.out, the following command will generate the proper .abs file:

```
abs500 –ea s –ec csr –eh hsr hello.out
```

An .abs file will not be created for hello.hsr (the header file), and hello.abs will include the assembly file hello.s, not the C source file hello.csr.
8.3 Absolute Lister Example

This example uses three source files. module1.asm and module2.asm both include the file globals.def.

**module1.asm**

```assembly
.text
.bss   array, 100
.bss   dflag, 2
.copy  globals.def
ld     #offset, A
ld     dflag, A
```

**module2.asm**

```assembly
.bss   offset, 2
.copy  globals.def
ld     #offset, A
ld     #array, A
```

**globals.def**

```assembly
.global dflag
.global array
.global offset
```

The following steps create absolute listings for the files module1.asm and module2.asm:

**Step 1:** First, assemble module1.asm and module2.asm:

```bash
asm500 module1
asm500 module2
```

This creates two object files called module1.obj and module2.obj.
**Step 2:** Next, link module1.obj and module2.obj using the following linker command file, called bttest.cmd:

```
/************************************************/
/* File bttest.cmd -- COFF linker command file */
/* for linking TMS320C54x modules */
/************************************************/
-o bttest.out /* Name the output file */
-m bttest.map /* Create an output map */

/**********************************************************/
/* Specify the Input Files */
/**********************************************************/
module1.obj
module2.obj

/**********************************************************/
/* Specify the Memory Configurations */
/**********************************************************/
MEMORY
{
    PAGE 0:   ROM: origin=2000h   length=2000h
    PAGE 1:   RAM: origin=8000h   length=8000h
}

/**********************************************************/
/* Specify the Output Sections */
/**********************************************************/
SECTIONS
{
    .data: >RAM PAGE 1
    .text: >ROM PAGE 0
    .bss: >RAM PAGE 1
}
```

Invoke the linker:

```
lnk500 bttest.cmd
```

This creates an executable object file called bttest.out; use this new file as input for the absolute lister.
Step 3:  Now, invoke the absolute lister:

```bash
abs500 bttest.out
```

This creates two files called module1.abs and module2.abs:

**module1.abs:**

```asm
.nolist
array .setsym 08000h
dflag  .setsym 08064h
offset .setsym 08066h
.data   .setsym 08000h
edata   .setsym 08000h
.text   .setsym 02000h
etext   .setsym 02007h
.bss    .setsym 08000h
end     .setsym 08068h
.setsect ".text",02000h
.setsect ".data",08000h
.setsect ".bss",08000h
.list
.text
.copy   "module1.asm"
```

**module2.abs:**

```asm
.nolist
array .setsym 08000h
dflag  .setsym 08064h
offset .setsym 08066h
.data   .setsym 08000h
edata   .setsym 08000h
.text   .setsym 02003h
etext   .setsym 02007h
.bss    .setsym 08000h
end     .setsym 08068h
.setsect ".text",02003h
.setsect ".data",08000h
.setsect ".bss",08066h
.list
.text
.copy   "module2.asm"
```
These files contain the following information that the assembler needs when you invoke it in step 4:

- They contain .setsym directives, which equate values to global symbols. Both files contain global equates for the symbol dflag. The symbol dflag was defined in the file globals.def, which was included in module1.asm and module2.asm.

- They contain .setsect directives, which define the absolute addresses for sections.

- They contain .copy directives, which tell the assembler which assembly language source file to include.

The .setsym and .setsect directives are not useful in normal assembly; they are useful only for creating absolute listings.

**Step 4:** Finally, assemble the .abs files created by the absolute lister (remember that you must use the –a option when you invoke the assembler):

```
asm500  -a  module1.abs
asm500  -a  module2.abs
```

This creates two listing files called module1.lst and module2.lst; no object code is produced. These listing files are similar to normal listing files; however, the addresses shown are absolute addresses.

The absolute listing files created are module1.lst (see Figure 8–2) and module2.lst (see Figure 8–3).
Figure 8–2. module1.lst

```
TMS320C54x COFF Assembler       Version x.xx     Wed Oct 16 12:00:05 2001
Copyright (c) 2001    Texas Instruments Incorporated
module1.abs                                                          PAGE    1
22 002000 .text
23 .copy       "module1.asm"
A  1 002000 .text
A  2 008000 .bss   array, 100
A  3 008064 .bss   dflag, 2
A  4 .copy  globals.def
B  1 .global dflag
B  2 .global array
B  3 .global offset
A  5 002000 F020 ld     #offset, A
     002001 8066–
A  6 002002 1064– ld     dflag, A
No Errors, No Warnings
```

Figure 8–3. module2.lst

```
TMS320C54x COFF Assembler       Version x.xx     Wed Oct 16 12:00:17 2001
Copyright (c) 2001    Texas Instruments Incorporated
module2.abs                                                          PAGE    1
22 002003 .text
23 .copy       "module2.asm"
A  1 008066 .bss   offset, 2
A  2 .copy  globals.def
B  1 .global dflag
B  2 .global array
B  3 .global offset
A  3 002003 F020 ld     #offset, A
     002004 8066–
A  4 002005 F020 ld     #array, A
     002006 8000!
No Errors, No Warnings
```
Cross-Reference Lister Description

The cross-reference lister is a debugging tool. This utility accepts linked object files as input and produces a cross-reference listing as output. This listing shows symbols, their definitions, and their references in the linked source files.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.1 Producing a Cross-Reference Listing</td>
<td>9-2</td>
</tr>
<tr>
<td>9.2 Invoking the Cross-Reference Lister</td>
<td>9-3</td>
</tr>
<tr>
<td>9.3 Cross-Reference Listing Example</td>
<td>9-4</td>
</tr>
</tbody>
</table>
9.1 Producing a Cross-Reference Listing

Figure 9–1. Cross-Reference Lister Development Flow

**Figure 9–1. Cross-Reference Lister Development Flow**

<table>
<thead>
<tr>
<th>Step 1:</th>
<th>Step 2:</th>
<th>Step 3:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembler source file</td>
<td>Link the object file (.obj) to obtain an executable object file (.out).</td>
<td>Invoke the cross-reference lister. The following section provides the command syntax for invoking the cross-reference lister utility.</td>
</tr>
<tr>
<td>Assembler</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Object file</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linked object file</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross-reference lister</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross-reference listing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

First, invoke the assembler with the –x option. This option produces a cross-reference table in the listing file and adds to the object file cross-reference information. By default, the assembler cross-references only global symbols. If you use the –s option when invoking the assembler, it will cross-reference local variables as well.
9.2 Invoking the Cross-Reference Lister

To use the cross-reference utility, the file must be assembled with the correct options and then linked into an executable file. Assemble the assembly language files with the –x option. This option creates a cross-reference listing and adds cross-reference information to the object file.

By default, the assembler cross-references only global symbols, but if assembler is invoked with the –s option, local symbols are also added. Link the object files to obtain an executable file.

To invoke the cross-reference lister, enter the following:

```
xref500 [–options] [input filename [output filename]]
```

--xref500 is the command that invokes the cross-reference utility.

- `options` identifies the cross-reference lister options you want to use. Options are not case sensitive and can appear anywhere on the command line following the command. Precede each option with a hyphen (–). The cross-reference lister options are as follows:

- `–l` (lowercase L) specifies the number of lines per page for the output file. The format of the –l option is –lnum, where num is a decimal constant. For example, –l30 sets the number of lines per page in the output file to 30. The space between the option and the decimal constant is optional. The default is 60 lines per page.

- `–q` (quiet) suppresses the banner and all progress information.

- `input filename` is a linked object file. If you omit the input filename, the utility prompts for a filename.

- `output filename` is the name of the cross-reference listing file. If you omit the output filename, the default filename will be the input filename with an .xrf extension.
# Cross-Reference Listing Example

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Filename</th>
<th>RTYP</th>
<th>AsmVal</th>
<th>LnkVal</th>
<th>DefLn</th>
<th>RefLn</th>
<th>RefLn</th>
<th>RefLn</th>
</tr>
</thead>
<tbody>
<tr>
<td>INIT</td>
<td>file1.asm</td>
<td>EDEF</td>
<td>'000000</td>
<td>000080</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>file2.asm</td>
<td>EREF</td>
<td>000000</td>
<td>000080</td>
<td>2</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>file1.asm</td>
<td>EREF</td>
<td>000000</td>
<td>000001</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>file2.asm</td>
<td>EDEF</td>
<td>000001</td>
<td>000001</td>
<td></td>
<td></td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Y</td>
<td>file2.asm</td>
<td>EDEF</td>
<td>-000000</td>
<td>000080</td>
<td>9</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z</td>
<td>file2.asm</td>
<td>EDEF</td>
<td>000003</td>
<td>000003</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The terms defined below appear in the preceding cross-reference listing:

<table>
<thead>
<tr>
<th>Symbol Name</th>
<th>Name of the symbol listed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filename</td>
<td>Name of the file where the symbol appears</td>
</tr>
<tr>
<td>RTYP</td>
<td>The symbol’s reference type in this file. The possible reference types are:</td>
</tr>
<tr>
<td></td>
<td>STAT The symbol is defined in this file and is not declared as global.</td>
</tr>
<tr>
<td></td>
<td>EDEF The symbol is defined in this file and is declared as global.</td>
</tr>
<tr>
<td></td>
<td>EREF The symbol is not defined in this file but is referenced as a global.</td>
</tr>
<tr>
<td></td>
<td>UNDF The symbol is not defined in this file and is not declared as global.</td>
</tr>
<tr>
<td>AsmVal</td>
<td>This hexadecimal number is the value assigned to the symbol at assembly time. A value may also be preceded by a character that describes the symbol’s attributes. Table 9–1 lists these characters and names.</td>
</tr>
<tr>
<td>LnkVal</td>
<td>This hexadecimal number is the value assigned to the symbol after linking.</td>
</tr>
<tr>
<td>DefLn</td>
<td>The statement number where the symbol is defined.</td>
</tr>
<tr>
<td>RefLn</td>
<td>The line number where the symbol is referenced. If the line number is followed by an asterisk (*), then that reference may modify the contents of the object. If the line number is followed by a letter (such as A, B, or C), the symbol is referenced in a file specified by a .include directive in the assembly source. “A” is assigned to the first file specified by a .include directive; “B” is assigned to the second file, etc. A blank in this column indicates that the symbol was never used.</td>
</tr>
</tbody>
</table>
Cross-Reference Listing Example

Table 9–1. Symbol Attributes

<table>
<thead>
<tr>
<th>Character</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>'</td>
<td>Symbol defined in a .text section</td>
</tr>
<tr>
<td>&quot;</td>
<td>Symbol defined in a .data section</td>
</tr>
<tr>
<td>+</td>
<td>Symbol defined in a .sect section</td>
</tr>
<tr>
<td>–</td>
<td>Symbol defined in a .bss or .usect section</td>
</tr>
<tr>
<td>=</td>
<td>Symbol defined in a .reg section</td>
</tr>
</tbody>
</table>
Hex Conversion Utility Description

The TMS320C54x™ assembler and linker create object files that are in common object file format (COFF). COFF is a binary object file format that encourages modular programming and provides more powerful and flexible methods for managing code segments and target system memory.

Most EPROM programmers do not accept COFF object files as input. The hex conversion utility converts a COFF object file into one of several standard ASCII hexadecimal formats, suitable for loading into an EPROM programmer. The utility is also useful in other applications requiring hexadecimal conversion of a COFF object file (for example, when using debuggers and loaders). This utility also supports the on-chip boot loader built into the target device, automating the code creation process for the C54x.

The hex conversion utility can produce these output file formats:

- ASCII-Hex, supporting 16-bit addresses
- Extended Tektronix (Tektronix)
- Intel MCS-86 (Intel)
- Motorola Exorciser (Motorola-S), supporting 16-bit, 24-bit, and 32-bit addresses
- Texas Instruments SDSMAC (TI-Tagged), supporting 16-bit addresses

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.1 Hex Conversion Utility Development Flow</td>
<td>10-2</td>
</tr>
<tr>
<td>10.2 Invoking the Hex Conversion Utility</td>
<td>10-3</td>
</tr>
<tr>
<td>10.3 Command File</td>
<td>10-7</td>
</tr>
<tr>
<td>10.4 Understanding Memory Widths</td>
<td>10-9</td>
</tr>
<tr>
<td>10.5 The ROMS Directive</td>
<td>10-16</td>
</tr>
<tr>
<td>10.6 The SECTIONS Directive</td>
<td>10-22</td>
</tr>
<tr>
<td>10.7 Output Filenames</td>
<td>10-24</td>
</tr>
<tr>
<td>10.8 Image Mode and the –fill Option</td>
<td>10-26</td>
</tr>
<tr>
<td>10.9 Building a Table for an On-Chip Boot Loader</td>
<td>10-28</td>
</tr>
<tr>
<td>10.10 Controlling the ROM Device Address</td>
<td>10-35</td>
</tr>
<tr>
<td>10.11 Description of the Object Formats</td>
<td>10-39</td>
</tr>
<tr>
<td>10.12 Hex Conversion Utility Error Messages</td>
<td>10-45</td>
</tr>
</tbody>
</table>
10.1 Hex Conversion Utility Development Flow

Figure 10–1 highlights the role of the hex conversion utility in the assembly language development process.

*Figure 10–1. Hex Conversion Utility Development Flow*
10.2 Invoking the Hex Conversion Utility

There are two basic methods for invoking the hex conversion utility:

- **Specify the options and filenames on the command line.** The following example converts the file firmware.out into TI-Tagged format, producing two output files, firm.lsb and firm.msb.

  ```
  hex500 -t firmware -o firm.lsb -o firm.msb
  ```

- **Specify the options and filenames in a command file.** You can create a batch file that stores command line options and filenames for invoking the hex conversion utility. The following example invokes the utility using a command file called hexutil.cmd:

  ```
  hex500 hexutil.cmd
  ```

In addition to regular command line information, you can use the hex conversion utility ROMS and SECTIONS directives in a command file.

To invoke the hex conversion utility, enter:

```
hex500 [–options] filename
```

- **hex500** is the command that invokes the hex conversion utility.
- **–options** supplies additional information that controls the hex conversion process. You can use options on the command line or in a command file.
  - All options are preceded by a dash and are not case sensitive.
  - Several options have an additional parameter that must be separated from the option by at least one space.
  - Options with multicharacter names must be spelled exactly as shown in this document; no abbreviations are allowed.
  - Options are not affected by the order in which they are used. The exception to this rule is the –q option, which must be used before any other options.
- **filename** names a COFF object file or a command file (for more information on command files, see Section 10.3, Command Files, on page 10-7).
Table 10–1.  *Hex Conversion Utility Options*

(a) *General options*

The general options control the overall operation of the hex conversion utility.

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>–byte</td>
<td>Number bytes sequentially</td>
<td>10-37</td>
</tr>
<tr>
<td>–map filename</td>
<td>Generate a map file</td>
<td>10-21</td>
</tr>
<tr>
<td>–o filename</td>
<td>Specify an output filename</td>
<td>10-24</td>
</tr>
<tr>
<td>–q</td>
<td>Run quietly (when used, it must appear before other options)</td>
<td>10-7</td>
</tr>
</tbody>
</table>

(b) *Image options*

The image options create a continuous image of a range of target memory.

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>–fill value</td>
<td>Fill holes with <em>value</em></td>
<td>10-27</td>
</tr>
<tr>
<td>–image</td>
<td>Specify image mode</td>
<td>10-26</td>
</tr>
<tr>
<td>–zero</td>
<td>Reset the address origin to zero</td>
<td>10-36</td>
</tr>
</tbody>
</table>

(c) *Memory options*

The memory options configure the memory widths for your output files.

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>–memwidth value</td>
<td>Define the system memory word width (default 16 bits)</td>
<td>10-10</td>
</tr>
<tr>
<td>–order (LS</td>
<td>MS)</td>
<td>Specify the memory word ordering</td>
</tr>
<tr>
<td>–romwidth value</td>
<td>Specify the ROM device width (default depends on format used)</td>
<td>10-11</td>
</tr>
</tbody>
</table>
Table 10–1. *Hex Conversion Utility Options (Continued)*

*(d) Output formats*

The output formats specify the format of the output file.

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>–a</td>
<td>Select ASCII-Hex</td>
<td>10-40</td>
</tr>
<tr>
<td>–i</td>
<td>Select Intel</td>
<td>10-41</td>
</tr>
<tr>
<td>–m1</td>
<td>Select Motorola–S1</td>
<td>10-42</td>
</tr>
<tr>
<td>–m2 or –m</td>
<td>Select Motorola–S2 (default)</td>
<td>10-42</td>
</tr>
<tr>
<td>–m3</td>
<td>Select Motorola–S3</td>
<td>10-42</td>
</tr>
<tr>
<td>–t</td>
<td>Select TI-Tagged</td>
<td>10-43</td>
</tr>
<tr>
<td>–x</td>
<td>Select Tektronix</td>
<td>10-44</td>
</tr>
</tbody>
</table>

*(e) Boot-loader options for all C54x devices*

The boot-loader options for all C54x devices control how the hex conversion utility builds the boot table.

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>–boot</td>
<td>Convert all sections into bootable form (use instead of a SECTIONS directive)</td>
<td>10-30</td>
</tr>
<tr>
<td>–bootorg PARALLEL</td>
<td>Specify the source of the boot loader table as the parallel port</td>
<td>10-29</td>
</tr>
<tr>
<td>–bootorg SERIAL</td>
<td>Specify the source of the boot loader table as the serial port</td>
<td>10-29</td>
</tr>
<tr>
<td>–bootorg value</td>
<td>Specify the source address of the boot loader table</td>
<td>10-30</td>
</tr>
<tr>
<td>–bootpage value</td>
<td>Specify the target page number of the boot loader table</td>
<td>10-30</td>
</tr>
<tr>
<td>–e value</td>
<td>Specify the entry point at which to begin execution after boot loading. The value can be an address or a global symbol.</td>
<td>10-29</td>
</tr>
</tbody>
</table>
### Table 10–1. Hex Conversion Utility Options (Continued)

*(f) Boot-loader options for the C54x LP devices only*

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>–bootorg WARM</td>
<td>Specify the source of the boot loader table as the table currently in memory</td>
<td>10-29</td>
</tr>
<tr>
<td>or –warm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>–bootorg COMM</td>
<td>Specify the source of the boot loader table as the communications port</td>
<td>10-29</td>
</tr>
<tr>
<td>–spc value</td>
<td>Set the serial port control register value</td>
<td>10-29</td>
</tr>
<tr>
<td>–spce value</td>
<td>Set the serial port control extension register value</td>
<td>10-29</td>
</tr>
<tr>
<td>–arr value</td>
<td>Set the ABU receive address register value</td>
<td>10-29</td>
</tr>
<tr>
<td>–bkr value</td>
<td>Set the ABU transmit buffer size register value</td>
<td>10-29</td>
</tr>
<tr>
<td>–tcsr value</td>
<td>Set the TDM serial port channel select register value</td>
<td>10-29</td>
</tr>
<tr>
<td>–trta value</td>
<td>Set the TDM serial port receive/transmit address register value</td>
<td>10-29</td>
</tr>
<tr>
<td>–swwsr value</td>
<td>Set the Software Wait State Reg value for PARALLEL/WARM boot mode</td>
<td>10-29</td>
</tr>
<tr>
<td>–bscr value</td>
<td>Set the Bank-Switch Control Reg value for PARALLEL/WARM boot mode</td>
<td>10-29</td>
</tr>
</tbody>
</table>
10.3 Command File

A command file is useful if you plan to invoke the utility more than once with the same input files and options. It is also useful if you want to use the ROMS and SECTIONS hex conversion utility directives to customize the conversion process.

Command files are ASCII files that contain one or more of the following:

- **Options and filenames.** These are specified in a command file in exactly the same manner as on the command line.

- **ROMS directive.** The ROMS directive defines the physical memory configuration of your system as a list of address-range parameters. (For more information about the ROMS directive, see Section 10.5, *The ROMS Directive*, on page 10-16.)

- **SECTIONS directive.** The SECTIONS directive specifies which sections from the COFF object file should be selected. (For more information about the SECTIONS directive, see Section 10.6, *The SECTIONS Directive*, on page 10-22.)

  You can also use this directive to identify specific sections that will be initialized by an on-chip boot loader. (For more information on the on-chip boot loader, see Section 10.9.3, *Building a Table for an On-Chip Boot Loader*, on page 10-29.)

- **Comments.** You can add comments to your command file by using the /* and */ delimiters. For example:

  
  /* This is a comment */

To invoke the utility and use the options you defined in a command file, enter:

```
hex500 command_filename
```

You can also specify other options and files on the command line. For example, you could invoke the utility by using both a command file and command line options:

```
hex500 firmware.cmd -map firmware.mxp
```

The order in which these options and file names appear is not important. The utility reads all input from the command line and all information from the command file before starting the conversion process. However, if you are using the –q option, *it must appear as the first option on the command line or in a command file.*

The –q option suppresses the utility’s normal banner and progress information.
10.3.1 Examples of Command Files

Assume that a command file named firmware.cmd contains these lines:

```plaintext
firmware.out /* input file */
-t /* TI-Tagged */
-o firm.lsb /* output file 1, LSBs of ROM */
-o firm.msb /* output file 2, MSBs of ROM*/
```

You can invoke the hex conversion utility by entering:
```
hex500 firmware.cmd
```

This example converts a file called appl.out into four hex files in Intel format. Each output file is one byte wide and 16K bytes long. The .text section is converted to boot loader format.
```plaintext
appl.out /* input file */
-l /* Intel format */
-map appl.mxp /* map file */
```

```plaintext
ROMS
{    
    ROW1: origin=01000h len=04000h romwidth=8
        files={ appl.u0 appl.u1 }
    ROW2: origin 05000h len=04000h romwidth=8
        files={ appl.u2 appl.u3 }
}
```

```plaintext
SECTIONS
{    
    .text: BOOT
    .data, .cinit, .sect1, .vectors, .const:
}
```
10.4 Understanding Memory Widths

The hex conversion utility makes your memory architecture more flexible by allowing you to specify memory and ROM widths. In order to use the hex conversion utility, you must understand how the utility treats word widths. Four widths are important in the conversion process: target width, data width, memory width, and ROM width. The terms target word, data word, memory word, and ROM word refer to a word of such a width.

Figure 10–2 illustrates the three separate and distinct phases of the hex conversion utility’s process flow.

Figure 10–2. Hex Conversion Utility Process Flow

Raw data in COFF files is represented in target-width-sized words. For C54x, this is 16 bits. The target width is fixed and cannot be changed.

Phase I
The raw data in the COFF file is truncated to the size specified by the default data width (16 bits).

Phase II
The data-width-sized internal representation is divided into words according to size specified by the –memwidth option.

Phase III
The memwidth-sized words are broken up according to the size specified by the –romwidth option and are written to a file(s) according to the specified format (i.e. Intel, Tektronix, etc.).

Output file(s)
10.4.1 Target Width

Target width is the unit size (in bits) of raw data fields in the COFF file. This corresponds to the size of an opcode on the target processor. The width is fixed for each target and cannot be changed. The C54x targets have a width of 16 bits.

10.4.2 Data Width

Data width is the logical width (in bits) of the data words stored in a particular section of a COFF file. Usually, the logical data width is the same as the target width. The data width is fixed at 16 bits for the TMS320C54x and cannot be changed.

10.4.3 Memory Width

Memory width is the physical width (in bits) of the memory system. Usually, the memory system is physically the same width as the target processor width: a 16-bit processor has a 16-bit memory architecture. However, some applications require target words to be broken up into multiple, consecutive, narrower memory words. Moreover, with certain processors like the C54x, the memory width can be narrower than the target width.

The hex conversion utility defaults memory width to the target width (in this case, 16 bits).

You can change the memory width by:

- Using the –memwidth option. This changes the memory width value for the entire file.

- Setting the memwidth parameter of the ROMS directive. This changes the memory width value for the address range specified in the ROMS directive and overrides the –memwidth option for that range. See Section 10.5, The ROMS Directive, on page 10-16.

For both methods, use a value that is a power of 2 greater than or equal to 8.

You should change the memory width default value of 16 only in exceptional situations: for example, when you need to break single target words into consecutive, narrower memory words. Situations in which memory words are narrower than target words are most common when you use an on-chip boot loader that supports booting from narrower memory. For example, a 16-bit TMS320C54x can be booted from 8-bit memory or an 8-bit serial port, with each 16-bit value occupying two memory locations (this would be specified as –memwidth 8).
Understanding Memory Widths

Figure 10–3 demonstrates how the memory width is related to the data width.

Figure 10–3. Data and Memory Widths

Data after phase I of hex utility

Source file

```plaintext
.word 0AABBh
.word 01122h
```

Data width = 16 (fixed)

```
0AABBh
01122h
```

Data after phase II of hex utility

Memory widths (variable)

data width = 16

```
AABB
1122
...
```

−memwidth 16 (default)

```
BB
AA
22
11
```

−memwidth 8

```
...
```

10.4.4 ROM Width

ROM width specifies the physical width (in bits) of each ROM device and corresponding output file (usually one byte or eight bits). The ROM width determines how the hex conversion utility partitions the data into output files. After the target words are mapped to the memory words, the memory words are broken into one or more output files. The number of output files per address range is determined by the following formula, where memory width ≥ ROM width:

\[
\text{number of files} = \frac{\text{memory width}}{\text{ROM width}}
\]

For example, for a memory width of 16, you could specify a ROM width of 16 and get a single output file containing 16-bit words. Or you can use a ROM width value of 8 to get two files, each containing 8 bits of each word.

For more information on calculating the number of files per address range, see Section 10.5, The ROMS Directive, on page 10-16.
The default ROM width that the hex conversion utility uses depends on the output format:

- All hex formats except TI-Tagged are configured as lists of 8-bit bytes; the default ROM width for these formats is 8 bits.
- TI-Tagged is a 16-bit format; the default ROM width for TI-Tagged is 16 bits.

**Note:** The TI-Tagged Format Is 16 Bits Wide

You cannot change the ROM width of the TI-Tagged format. The TI-Tagged format supports a 16-bit ROM width only.

You can change ROM width (except for TI-Tagged) by:

- Using the \texttt{–romwidth} option. This changes the ROM width value for the entire COFF file.
- Setting the \texttt{romwidth} parameter of the ROMS directive. This changes the ROM width value for a specific ROM address range and overrides the \texttt{–romwidth} option for that range. See Section 10.5, The ROMS Directive, on page 10-16.

For both methods, use a \textit{value} that is a power of 2 greater than or equal to 8.

If you select a ROM width that is wider than the natural size of the output format (16 bits for TI-Tagged or 8 bits for all others), the utility simply writes multibyte fields into the file.

Figure 10–4 illustrates how the target, memory, and ROM widths are related to one another.
Figure 10–4. Data, Memory, and ROM Widths

<table>
<thead>
<tr>
<th>Source file</th>
</tr>
</thead>
<tbody>
<tr>
<td>.word 0AABBCDDh</td>
</tr>
<tr>
<td>.word 01122344h</td>
</tr>
<tr>
<td>. . .</td>
</tr>
</tbody>
</table>

Data width = 16 (fixed)

<table>
<thead>
<tr>
<th>Data after phase I of hex utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>0AABBh</td>
</tr>
<tr>
<td>0112h</td>
</tr>
<tr>
<td>. . .</td>
</tr>
</tbody>
</table>

Memory widths (variable)

<table>
<thead>
<tr>
<th>Data after phase II of hex utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>AABB</td>
</tr>
<tr>
<td>1122</td>
</tr>
<tr>
<td>. . .</td>
</tr>
<tr>
<td>BB</td>
</tr>
<tr>
<td>AA</td>
</tr>
<tr>
<td>22</td>
</tr>
<tr>
<td>11</td>
</tr>
<tr>
<td>. . .</td>
</tr>
</tbody>
</table>

Output files

<table>
<thead>
<tr>
<th>Data after phase III of hex utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>–romwidth 16 –o file.wrd AABB1122 . . .</td>
</tr>
<tr>
<td>–romwidth 8 –o file.b0 BB 22 . . .</td>
</tr>
<tr>
<td>–o file.b1 AA 11 . . .</td>
</tr>
<tr>
<td>–romwidth 8 –o file.byt BBAAB2111 . . .</td>
</tr>
</tbody>
</table>
10.4.5 A Memory Configuration Example

Figure 10–5 shows a typical memory configuration example. This memory system consists of two 128K × 8-bit ROM devices.

**Figure 10–5. C54x Memory Configuration Example**

![Diagram of memory configuration example]

- Data width = 16 bits
- Lower 8 bits (data)
- Upper 8 bits (data)
- Source file word AABBh
- CPU
- ROM width 8 bits
- ROM1
- ROM0
- 128K x 8
- System memory width 16 bits

10.4.6 Specifying Word Order for Output Words

When memory words are narrower than target words (memory width < 16), target words are split into multiple consecutive memory words. There are two ways to split a wide word into consecutive memory locations in the same hex conversion utility output file:

- **–order MS** specifies *big-endian* ordering, in which the most significant part of the wide word occupies the first of the consecutive locations

- **–order LS** specifies *little-endian* ordering, in which the least significant part of the wide word occupies the first of the consecutive locations

By default, the utility uses little-endian format because the C54x boot loaders expect the data in this order. Unless you are using your own boot loader program, avoid using –order MS.
Note: When the –order Option Applies

- This option applies only when you use a memory width with a value less than 16. Otherwise, –order is ignored.
- This option does not affect the way memory words are split into output files. Think of the files as a set: the set contains a least significant file and a most significant file, but there is no ordering over the set. When you list filenames for a set of files, you always list the least significant first, regardless of the –order option.

Figure 10–6 demonstrates how –order affects the conversion process. This figure, and the previous figure, Figure 10–4, explain the condition of the data in the hex conversion utility output files.

Figure 10–6. Varying the Word Order

<table>
<thead>
<tr>
<th>Source file</th>
<th>Target width = 16 (fixed)</th>
<th>Memory widths (variable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.word 0AABBh</td>
<td></td>
<td>–memwidth 8</td>
</tr>
<tr>
<td>.word 01122h</td>
<td></td>
<td>–order LS (default)</td>
</tr>
<tr>
<td>. . .</td>
<td></td>
<td>–memwidth 8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>–order MS</td>
</tr>
<tr>
<td>0AABBh</td>
<td></td>
<td>BB</td>
</tr>
<tr>
<td>01122h</td>
<td></td>
<td>AA</td>
</tr>
<tr>
<td>. . .</td>
<td></td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>. . .</td>
</tr>
<tr>
<td></td>
<td></td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>. . .</td>
</tr>
</tbody>
</table>
10.5 The ROMS Directive

The ROMS directive specifies the physical memory configuration of your system as a list of address-range parameters.

Each address range produces one set of files containing the hex conversion utility output data that corresponds to that address range. Each file can be used to program one single ROM device.

If you do not use a ROMS directive, the utility defines a default memory configuration that includes two address spaces (PAGE 0 and PAGE 1). Each address space contains a single address range. PAGE 0 contains a default range of the entire program address space, and PAGE 1 contains a default range of the entire data address space.

The ROMS directive is similar to the MEMORY directive of the TMS320C54x linker: both define the memory map of the target address space. Each line entry in the ROMS directive defines a specific address range. The general syntax is:

```
ROMS
{
[PAGE n:
  romname: [origin=value,] [length=value,] [romwidth=value,]
  [memwidth=value,] [fill=value,]
  [files={filename1, filename2, ...}]
  romname: [origin=value,] [length=value,] [romwidth=value,]
  [memwidth=value,] [fill=value,]
  [files={filename1, filename2, ...}]
  ...
}
```

ROMS begins the directive definition.

PAGE identifies a memory space for targets that use program- and data-address spaces. If your program has been linked normally, PAGE 0 specifies program memory and PAGE 1 specifies data memory. Each memory range after the PAGE command belongs to that page until you specify another PAGE. If you don’t include PAGE, all ranges belong to page 0.

romname identifies a memory range. The name of the memory range may be one to eight characters in length. The name has no significance to the program; it simply identifies the range. (Duplicate memory range names are allowed.)
origin specifies the starting address of a memory range. It can be entered as origin, org, or o. The associated value must be a decimal, octal, or hexadecimal constant. If you omit the origin value, the origin defaults to 0.

The following table summarizes the notation you can use to specify a decimal, octal, or hexadecimal constant:

<table>
<thead>
<tr>
<th>Constant</th>
<th>Notation</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hexadecimal</td>
<td>0x prefix or h suffix</td>
<td>0x77 or 077h</td>
</tr>
<tr>
<td>Octal</td>
<td>0 prefix</td>
<td>077</td>
</tr>
<tr>
<td>Decimal</td>
<td>No prefix or suffix</td>
<td>77</td>
</tr>
</tbody>
</table>

length specifies the length of a memory range as the physical length of the ROM device. It can be entered as length, len, or l. The value must be a decimal, octal, or hexadecimal constant. If you omit the length value, it defaults to the length of the entire address space.

romwidth specifies the physical ROM width of the range in bits (see subsection 10.4.4, ROM Width, on page 10-11). Any value you specify here overrides the –romwidth option. The value must be a decimal, octal, or hexadecimal constant that is a power of 2 greater than or equal to 8.

memwidth specifies the memory width of the range in bits (see subsection 10.4.3, Memory Width, on page 10-10). Any value you specify here overrides the –memwidth option. The value must be a decimal, octal, or hexadecimal constant that is a power of 2 greater than or equal to 8. When using the memwidth parameter, you must also specify the paddr parameter for each section in the SECTIONS directive.

fill specifies a fill value to use for the range. In image mode, the hex conversion utility uses this value to fill any holes between sections in a range. The value must be a decimal, octal, or hexadecimal constant with a width equal to the target width. Any value you specify here overrides the –fill option. When using fill, you must also use the –image command line option. See subsection 10.8.2, Specifying a Fill Value, on page 10-27.
files identifies the names of the output files that correspond to this range. Enclose the list of names in curly braces and order them from least significant to most significant output file.

The number of file names should equal the number of output files that the range will generate. To calculate the number of output files, refer to Section 10.4.4, ROM Width, on page 10-11. The utility warns you if you list too many or too few file-names.

Unless you are using the –image option, all of the parameters defining a range are optional; the commas and equals signs are also optional. A range with no origin or length defines the entire address space. In image mode, an origin and length are required for all ranges.

Ranges on the same page must not overlap and must be listed in order of ascending address.

### 10.5.1 When to Use the ROMS Directive

If you do not use a ROMS directive, the utility defines a default memory configuration that includes two address spaces (PAGE 0 and PAGE 1). Each address space contains a single address range. PAGE 0 contains a default range of the entire program address space, and PAGE 1 contains a default range of the entire data address space. If nothing is loaded into a particular page, no output is created for that page.

Use the ROMS directive when you want to:

- **Program large amounts of data into fixed-size ROMs.** When you specify memory ranges corresponding to the length of your ROMs, the utility automatically breaks the output into blocks that fit into the ROMs.

- **Restrict output to certain segments.** You can also use the ROMS directive to restrict the conversion to a certain segment or segments of the target address space. The utility does not convert the data that falls outside of the ranges defined by the ROMS directive. Sections can span range boundaries; the utility splits them at the boundary into multiple ranges. If a section falls completely outside any of the ranges you define, the utility does not convert that section and issues no messages or warnings. In this way, you can exclude sections without listing them by name with the SECTIONS directive. However, if a section falls partially in a range and partially in unconfigured memory, the utility issues a warning and converts only the part within the range.

- **Use image mode.** When you use the –image option, you must use a ROMS directive. Each range is filled completely so that each output file in
a range contains data for the whole range. Gaps before, between, or after sections are filled with the fill value from the ROMS directive, with the value specified with the –fill option, or with the default value of 0.

### 10.5.2 An Example of the ROMS Directive

The ROMS directive in Example 10–1 shows how 16K words of 16-bit memory could be partitioned for four 8K × 8-bit EPROMs.

**Example 10–1. A ROMS Directive Example**

```plaintext
ingfile.out
   -image
   -memwidth 16

ROMS
{
   EPROM1: org = 04000h, len = 02000h, romwidth = 8
            files = { rom4000.b0, rom4000.b1 }
   EPROM2: org = 06000h, len = 02000h, romwidth = 8,
            fill = 0FFh,
            files = { rom6000.b0, rom6000.b1 }
}
```

In this example, EPROM1 defines the address range from 4000h through 5FFFh. The range contains the following sections:

<table>
<thead>
<tr>
<th>This section</th>
<th>Has this range</th>
</tr>
</thead>
<tbody>
<tr>
<td>.text</td>
<td>4000h through 487Fh</td>
</tr>
<tr>
<td>.data</td>
<td>5B80H through 5FFFh</td>
</tr>
</tbody>
</table>

The rest of the range is filled with 0h (the default fill value). The data from this range is converted into two output files:

- rom4000.b0 contains bits 0 through 7
- rom4000.b1 contains bits 8 through 15

EPROM2 defines the address range from 6000h through 7FFFh. The range contains the following sections:

<table>
<thead>
<tr>
<th>This section</th>
<th>Has this range</th>
</tr>
</thead>
<tbody>
<tr>
<td>.data</td>
<td>6000h through 633Fh</td>
</tr>
<tr>
<td>.table</td>
<td>6700h through 7C7Fh</td>
</tr>
</tbody>
</table>
The ROMS Directive

The rest of the range is filled with 0FFh (from the specified fill value). The data from this range is converted into two output files:

- rom6000.b0 contains bits 0 through 7
- rom6000.b1 contains bits 8 through 15

Figure 10–7 shows how the ROMS directive partitions the infile.out file into four output files.

**Figure 10–7. The infile.out File From Example 10–1 Partitioned Into Four Output Files**
10.5.3 Creating a Map File of the ROMS Directive

The map file (specified with the –map option) is advantageous when you use the ROMS directive with multiple ranges. The map file shows each range, its parameters, names of associated output files, and a list of contents (section names and fill values) broken down by address. Following is a segment of the map file resulting from the example in Example 10–1.

**Example 10–2. Map File Output From Example 10–1 Showing Memory Ranges**

```
00004000..00005fff  Page=0  Width=8  "EPROM1"

OUTPUT FILES: rom4000.b0 [b0..b7]
               rom4000.b1 [b8..b15]

CONTENTS: 00004000..0000487f .text
           00004880..00005b7f FILL = 00000000
           00005b80..00005fff .data

00006000..00007fff  Page=0  Width=8  "EPROM2"

OUTPUT FILES: rom6000.b0 [b0..b7]
               rom6000.b1 [b8..b15]

CONTENTS: 00006000..0000633f .data
           00006340..000066ff FILL = 000000ff
           00006700..00007c7f .table
           00007c80..00007fff FILL = 000000ff
```
10.6 The SECTIONS Directive

You can convert specific sections of the COFF file by name with the SECTIONS directive. You can also specify those sections you want the utility to configure for loading from an on-chip boot loader, and those sections that you want to locate in ROM at a different address than the load address specified in the linker command file:

- If you use a SECTIONS directive, the utility converts only the sections that you list in the directive and ignores all other sections in the COFF file.

- If you don’t use a SECTIONS directive, the utility converts all initialized sections that fall within the configured memory. The TMS320C54x compiler-generated initialized sections include: .text, .const, .cinit, and .switch.

Uninitialized sections are never converted, whether or not you specify them in a SECTIONS directive.

**Note: Sections Generated by the C/C++ Compiler**

The TMS320C54x C/C++ compiler automatically generates these sections:

- **Initialized sections**: .text, .const, .cinit, and .switch.
- **Uninitialized sections**: .bss, .stack, and .sysmem.

Use the SECTIONS directive in a command file. (For more information about using a command file, see Section 10.3, *Command Files*, on page 10-7.) The general syntax for the SECTIONS directive is:

```
SECTIONS
{
    sname: [paddr=value]
    sname: [paddr=boot]
    sname: [= boot],
    ...
}
```
The SECTIONS Directive

SECTIONS begins the directive definition.

sname identifies a section in the COFF input file. If you specify a section that doesn’t exist, the utility issues a warning and ignores the name.

paddr specifies the physical ROM address at which this section should be located. This value overrides the section load address given by the linker. (See Section 10.10, Controlling the ROM Device Address, on page 10-35). This value must be a decimal, octal, or hexadecimal constant. It can also be the word boot (to indicate a boot table section for use with the on-chip boot loader). If your file contains multiple sections, and if one section uses a paddr parameter, then all sections must use a paddr parameter.

= boot configures a section for loading by the on-chip boot loader. This is equivalent to using paddr=boot. Boot sections have a physical address determined both by the target processor type and by the various boot-loader-specific command line options.

The commas separating section names are optional. For more similarity with the linker’s SECTIONS directive, you can use colons after the section names (in place of the equal sign on the boot keyboard). For example, the following statements are equivalent:

SECTIONS { .text: .data: boot }

SECTIONS { .text, .data = boot }

In the example below, the COFF file contains six initialized sections: .text, .data, .const, .vectors, .coeff, and .tables. Suppose you want only .text and .data to be converted. Use a SECTIONS directive to specify this:

SECTIONS { .text, .data }

To configure both of these sections for boot loading, add the boot keyword:

SECTIONS { .text = boot, .data = boot }

**Note:** Using the –boot Option and the SECTIONS Directive

When you use the SECTIONS directive with the on-chip boot loader, the –boot option is ignored. You must explicitly specify any boot sections in the SECTIONS directive. For more information about –boot and other command line options associated with the on-chip boot loader, see Table 10–2, page 10-29.
10.7 Output Filenames

When the hex conversion utility translates your COFF object file into a data format, it partitions the data into one or more output files. When multiple files are formed by splitting data into byte-wide or word-wide files, filenames are always assigned in order from least to most significant. This is true, regardless of target or COFF endian ordering, or of any –order option.

10.7.1 Assigning Output Filenames

The hex conversion utility follows this sequence when assigning output filenames:

1) It looks for the ROMS directive. If a file is associated with a range in the ROMS directive and you have included a list of files (files = { . . . }) on that range, the utility takes the filename from the list.

   For example, assume that the target data is 16-bit words being converted to two files, each eight bits wide. To name the output files using the ROMS directive, you could specify:

   ROMS
   {
   RANGE1: romwidth=8, files={ xyz.b0 xyz.b1 }
   }

   The utility creates the output files by writing the least significant bits (LSBs) to xyz.b0 and the most significant bits (MSBs) to xyz.b1.

2) It looks for the –o options. You can specify names for the output files by using the –o option. If no filenames are listed in the ROMS directive and you use –o options, the utility takes the filename from the list of –o options. The following line has the same effect as the example above using the ROMS directive:

   –o xyz.b0 –o xyz.b1

   Note that if both the ROMS directive and –o options are used together, the ROMS directive overrides the –o options.
3) **It assigns a default filename.** If you specify no filenames or fewer names than output files, the utility assigns a default filename. A default filename consists of the base name from the COFF input file plus a 2- to 3-character extension (e.g., filename.abc). The extension has three parts:

a) A format character, based on the output format:
   - **a** for ASCII-Hex
   - **i** for Intel
   - **t** for TI-Tagged
   - **m** for Motorola-S
   - **x** for Tektronix

b) The range number in the ROMS directive. Ranges are numbered starting with 0. If there is no ROMS directive, or only one range, the utility omits this character.

c) The file number in the set of files for the range, starting with 0 for the least significant file.

For example, assume coff.out is for a 16-bit target processor and you are creating Intel format output. With no output filenames specified, the utility produces two output files named coff.i00 and coff.i01.

If you include the following ROMS directive when you invoke the hex conversion utility, you would have two output files:

```plaintext
ROMS
  {range1: o = 1000h l = 1000h
   range2: o = 2000h l = 1000h
  }
```

<table>
<thead>
<tr>
<th>These Output Files</th>
<th>Contain This Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>coff.i00</td>
<td>1000h through 1FFFh</td>
</tr>
<tr>
<td>coff.i10</td>
<td>2000h through 2FFFh</td>
</tr>
</tbody>
</table>
10.8 Image Mode and the –fill Option

This section points out the advantages of operating in image mode and describes how to produce output files with a precise, continuous image of a target memory range.

10.8.1 The –image Option

With the –image option, the utility generates a memory image by completely filling all of the mapped ranges specified in the ROMS directive.

A COFF file consists of blocks of memory (sections) with assigned memory locations. Typically, all sections are not adjacent: there are gaps between sections in the address space for which there is no data. When such a file is converted without the use of image mode, the hex conversion utility bridges these gaps by using the address records in the output file to skip ahead to the start of the next section. In other words, there may be discontinuities in the output file addresses. Some EPROM programmers do not support address discontinuities.

In image mode, there are no discontinuities. Each output file contains a continuous stream of data that corresponds exactly to an address range in target memory. Any gaps before, between, or after sections are filled with a fill value that you supply.

An output file converted by using image mode still has address records because many of the hexadecimal formats require an address on each line. However, in image mode, these addresses will always be contiguous.

Note: Defining the Ranges of Target Memory

If you use image mode, you must also use a ROMS directive. In image mode, each output file corresponds directly to a range of target memory. You must define the ranges. If you don’t supply the ranges of target memory, the utility tries to build a memory image of the entire target processor address space—potentially a huge amount of output data. To prevent this situation, the utility requires you to explicitly restrict the address space with the ROMS directive.
10.8.2 Specifying a Fill Value

The –fill option specifies a value for filling the holes between sections. The fill value must be specified as an integer constant following the –fill option. The width of the constant is assumed to be that of a word on the target processor. For example, for the C54x, specifying –fill 0FFh results in a fill pattern of 00FFh. The constant value is not sign extended.

The hex conversion utility uses a default fill value of zero if you don’t specify a value with the fill option. The –fill option is valid only when you use –image; otherwise, it is ignored.

10.8.3 Steps to Follow in Image Mode

Step 1: Define the ranges of target memory with a ROMS directive. See Section 10.5, The ROMS Directive, on page 10-16 for details.

Step 2: Invoke the hex conversion utility with the –image option. To number the bytes sequentially, use the –byte option; to reset the address origin to zero for each output file, use the –zero option. See subsection 10.10.3, The –byte Option, on page 10-37 for details on the –byte option, and page 10-36 for details on the –zero option. If you don’t specify a fill value with the ROMS directive and you want a value other than the default of zero, use the –fill option.
10.9 Building a Table for an On-Chip Boot Loader

Some DSP devices, such as the C54x, have a built-in boot loader that initializes memory with one or more blocks of code or data. The boot loader uses a special table (a boot table) stored in memory (such as EPROM) or loaded from a device peripheral (such as a serial or communications port) to initialize the code or data. The hex conversion utility supports the boot loader by automatically building the boot table.

10.9.1 Description of the Boot Table

The input for a boot loader is the boot table. The boot table contains records that instruct the on-chip loader to copy blocks of data contained in the table to specified destination addresses. Some boot tables also contain values for initializing various processor control registers. The boot table can be stored in memory or read in through a device peripheral.

The hex conversion utility automatically builds the boot table for the boot loader. Using the utility, you specify the COFF sections you want the boot loader to initialize, the table location, and the values for any control registers. The hex conversion utility identifies the target device type from the COFF file, builds a complete image of the table according to the format required by that device, and converts it into hexadecimal in the output files. Then, you can burn the table into ROM or load it by other means.

The boot loader supports loading from memory that is narrower than the normal width of memory. For example, you can boot a 16-bit TMS320C54x from a single 8-bit EPROM by using the –memwidth option to configure the width of the boot table. The hex conversion utility automatically adjusts the table’s format and length. See the boot loader example in the TMS320C54x DSP Reference Set for an illustration of a boot table.

10.9.2 The Boot Table Format

The boot table format is simple. Typically, there is a header record containing values for various control registers. Each subsequent block has a header containing the size and destination address of the block followed by data for the block. Multiple blocks can be entered; a termination block follows the last block. Finally, the table can have a footer containing more control register values. See the boot loader section in the TMS320C54x DSP Reference Set for more information.
10.9.3 How to Build the Boot Table

Table 10–2 summarizes the hex conversion utility options available for the boot loader.

Table 10–2. Boot-Loader Options

(a) Options for all C54x devices

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>–boot</td>
<td>Convert all sections into bootable form (use instead of a SECTIONS directive)</td>
</tr>
<tr>
<td>–bootorg PARALLEL</td>
<td>Specify the source of the boot loader table as the parallel port</td>
</tr>
<tr>
<td>–bootorg SERIAL</td>
<td>Specify the source of the boot loader table as the serial port</td>
</tr>
<tr>
<td>–bootorg value</td>
<td>Specify the source address of the boot loader table</td>
</tr>
<tr>
<td>–bootpage value</td>
<td>Specify the target page number of the boot loader table</td>
</tr>
<tr>
<td>–e value</td>
<td>Specify the entry point at which to begin execution after boot loading. The value can be an address or a global symbol.</td>
</tr>
</tbody>
</table>

(b) Options for C54x LP devices only

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>–bootorg WARM or –warm</td>
<td>Specify the source of the boot loader table as the table currently in memory</td>
</tr>
<tr>
<td>–bootorg COMM</td>
<td>Specify the source of the boot loader table as the communications port</td>
</tr>
<tr>
<td>–spc value</td>
<td>Set the serial port control register value</td>
</tr>
<tr>
<td>–spce value</td>
<td>Set the serial port control extension register value</td>
</tr>
<tr>
<td>–arr value</td>
<td>Set the ABU receive address register value</td>
</tr>
<tr>
<td>–bkr value</td>
<td>Set the ABU transmit buffer size register value</td>
</tr>
<tr>
<td>–tcsr value</td>
<td>Set the TDM serial port channel select register value</td>
</tr>
<tr>
<td>–trta value</td>
<td>Set the TDM serial port receive/transmit address register value</td>
</tr>
<tr>
<td>–swwwsr value</td>
<td>Set the software wait state register value for PARALLEL/WARM boot mode</td>
</tr>
<tr>
<td>–bscr value</td>
<td>Set the bank-switch control register value for PARALLEL/WARM boot mode</td>
</tr>
</tbody>
</table>
10.9.3.1 Building the Boot Table

To build the boot table, follow these steps:

**Step 1:** Link the file. Each block of the boot table data corresponds to an initialized section in the COFF file. Uninitialized sections are not converted by the hex conversion utility (see Section 10.6, *The SECTIONS Directive*, on page 10-22).

When you select a section for placement in a boot-loader table, the hex conversion utility places the section’s *load address* in the destination address field for the block in the boot table. The section content is then treated as raw data for that block.
The hex conversion utility does not use the section run address. When linking, you need not worry about the ROM address or the construction of the boot table—the hex conversion utility handles this.

**Step 2:** **Identify the bootable sections.** You can use the –boot option to tell the hex conversion utility to configure all sections for boot loading. Or, you can use a SECTIONS directive to select specific sections to be configured (see Section 10.6, The SECTIONS Directive, on page 10-22). Note that if you use a SECTIONS directive, the –boot option is ignored.

**Step 3:** **Set the ROM address of the boot table.** Use the –bootorg option to set the source address of the complete table. For example, if you are using the C54x and booting from memory location 8000h, specify –bootorg 8000h. The address field in the the hex conversion utility output file will then start at 8000h.

If you use –bootorg SERIAL or –bootorg PARALLEL, or if you do not use the –bootorg option at all, the utility places the table at the origin of the first memory range in a ROMS directive. If you do not use a ROMS directive, the table will start at the first section load address. There is also a –bootpage option for starting the table somewhere other than page 0.

**Step 4:** **Set boot-loader-specific options.** Set such options as entry point and memory control registers as needed.

**Step 5:** **Describe your system memory configuration.** See Section 10.4, Understanding Memory Widths, on page 10-9 and Section 10.5, The ROMS Directive, on page 10-16 for details.

10.9.3.2 **Leaving Room for the Boot Table**

The complete boot table is similar to a single section containing all of the header records and data for the boot loader. The address of this “section” is the boot table origin. As part of the normal conversion process, the hex conversion utility converts the boot table to hexadecimal format and maps it into the output files like any other section.

Be sure to leave room in your system memory for the boot table, especially when you are using the ROMS directive. The boot table cannot overlap other nonboot sections or unconfigured memory. Usually, this is not a problem; typically, a portion of memory in your system is reserved for the boot table. Simply configure this memory as one or more ranges in the ROMS directive, and use the –bootorg option to specify the starting address.
10.9.4 Booting From a Device Peripheral

You can choose to boot from a serial or parallel port by using the SERIAL or PARALLEL keyword with the –bootorg option. Your selection of a keyword depends on the target device and the channel you want to use. For example, to boot a C54x from its serial port, specify –bootorg SERIAL on the command line or in a command file. To boot a C54x from one of its parallel ports, specify –bootorg PARALLEL.

Note: On-Chip Boot Loader Concerns

- Possible memory conflicts. When you boot from a device peripheral, the boot table is not actually in memory; it is being received through the device peripheral. However, as explained in Step 3 on page 10-31, a memory address is assigned.

  If the table conflicts with a nonboot section, put the boot table on a different page. Use the ROMS directive to define a range on an unused page and the –bootpage option to place the boot table on that page. The boot table will then appear to be at location 0 on the dummy page.

- Why the System Might Require an EPROM Format for a Peripheral Boot Loader Address. In a typical system, a parent processor boots a child processor through that child’s peripheral. The boot loader table itself may occupy space in the memory map of the parent processor. The EPROM format and ROMS directive address correspond to those used by the parent processor, not those that are used by the child.

10.9.5 Setting the Entry Point for the Boot Table

After completing the boot load process, execution starts at the default entry point specified by the linker and contained in the COFF file. By using the –e option with the hex conversion utility, you can set the entry point to a different address.

For example, if you want your program to start running at address 0123h after loading, specify –e 0123h on the command line or in a command file. You can determine the –e address by looking at the map file that the linker generates.

Note: Valid Entry Points

The value can be a constant, or it can be a symbol that is externally defined (for example, with a .global) in the assembly source.
When you use the –e option, the utility builds a dummy block of length 1 and data value 0 that loads at the specified address. Your blocks follow this dummy block. Since the dummy block is loaded first, the dummy value of 0 is overwritten by the subsequent blocks. Then, the boot loader jumps to the –e option address after the boot load is completed.

When using the –bootorg WARM option, the –e option sets the address of where the boot table is loaded in ROM.

### 10.9.6 Using the C54x Boot Loader

This subsection explains and gives an example on using the hex conversion utility with the boot loader for C54x devices.

The C54x boot loader has several different modes. You can select these modes by using the –bootorg and –memwidth options:

<table>
<thead>
<tr>
<th>Mode</th>
<th>–bootorg Setting</th>
<th>–memwidth Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-bit parallel I/O</td>
<td>–bootorg PARALLEL</td>
<td>–memwidth 8</td>
</tr>
<tr>
<td>16-bit parallel I/O</td>
<td>–bootorg PARALLEL</td>
<td>–memwidth 16</td>
</tr>
<tr>
<td>8-bit serial RS232</td>
<td>–bootorg SERIAL</td>
<td>–memwidth 8</td>
</tr>
<tr>
<td>16-bit serial RS232</td>
<td>–bootorg SERIAL</td>
<td>–memwidth 16</td>
</tr>
<tr>
<td>8-bit parallel EPROM</td>
<td>–bootorg 0x8000</td>
<td>–memwidth 8</td>
</tr>
<tr>
<td>16-bit parallel EPROM</td>
<td>–bootorg 0x8000</td>
<td>–memwidth 16</td>
</tr>
<tr>
<td>8-bit parallel</td>
<td>–bootorg WARM</td>
<td>–memwidth 8</td>
</tr>
<tr>
<td>16-bit parallel</td>
<td>–bootorg WARM</td>
<td>–memwidth 16</td>
</tr>
<tr>
<td>8-bit I/O</td>
<td>–bootorg COMM</td>
<td>–memwidth 8</td>
</tr>
</tbody>
</table>

You should set the –romwidth equal to the –memwidth unless you want to have multiple output files.

The C54x can boot through either the serial or parallel interface with either 8- or 16-bit data. The format is the same for any combination: the boot table consists of a field containing the destination address, a field containing the length, and a block containing the data.

You can boot only one section. If you are booting from an 8-bit channel, 16-bit words are stored in the table with the MSBs first; the hex conversion utility automatically builds the table in the correct format.

- To boot from a serial port, specify –bootorg SERIAL when invoking the utility. Use either –memwidth 8 or –memwidth 16.
Building a Table for an On-Chip Boot Loader

- To load from a parallel I/O port, invoke the utility by specifying `–bootorg PARALLEL`. Use either `–memwidth 8` or `–memwidth 16`.

- To boot from external memory (EPROM), specify the source address of the boot memory by using the `–bootorg` option. Use either `–memwidth 8` or `–memwidth 16`.

For example, the command file in Figure 10–8 allows you to boot the .text section of abc.out from a byte-wide EPROM at location 0x8000.

**Figure 10–8. Sample Command File for Booting From a C54x EPROM**

```
abc.out    /* input file   */
-o abc.i   /* output file */
-i         /* Intel format */
-memwidth 8 /* 8-bit memory */
-romwidth 8 /* outfile is bytes, not words */
-bootorg 0x8000 /* external memory boot */

SECTIONS { .text: BOOT }
```
10.10 Controlling the ROM Device Address

The hex conversion utility output address field corresponds to the ROM device address. The EPROM programmer burns the data into the location specified by the hex conversion utility output file address field. The hex conversion utility offers some mechanisms to control the starting address in ROM of each section and/or to control the address index used to increment the address field. However, many EPROM programmers offer direct control of the location in ROM in which the data is burned.

10.10.1 Controlling the Starting Address

Depending on whether or not you are using the boot loader, the hex conversion utility output file controlling mechanisms are different.

Non-boot loader mode. The address field of the hex conversion utility output file is controlled by the following mechanisms listed from low to high priority:

1) The linker command file. By default, the address field of the hex conversion utility output file is a function of the load address (as given in the linker command file) and the hex conversion utility parameter values. The relationship is summarized as follows:

\[
\text{out\_file\_addr} = \text{load\_addr} \times (\text{data\_width} \div \text{mem\_width})
\]

out\_file\_addr is the address of the output file.
load\_addr is the linker-assigned load address.
data\_width is specified as 16 bits for the TMS320C54x devices. See subsection 10.4.2, Data Width, on page 10-10.
mem\_width is the memory width of the memory system. You can specify the memory width by the –memwidth option or by the memwidth parameter inside the ROMS directive. See subsection 10.4.3, Memory Width, on page 10-10.

† If paddr is not specified

The value of data width divided by memory width is a correction factor for address generation. When data width is larger than memory width, the correction factor expands the address space. For example, if the load address is 0 and data width divided by memory width is 2, the output file address field would be 0×2. The data is split into two consecutive locations the size of the memory width.

2) The paddr parameter of the SECTIONS directive. When the paddr parameter is specified for a section, the hex conversion utility bypasses
the section load address and places the section in the address specified by paddr. The relationship between the hex conversion utility output file address field and the paddr parameter can be summarized as follows:

\[
\text{out\_file\_addr} = \text{paddr\_val} + (\text{load\_addr} - \text{sect\_beg\_load\_addr}) \times (\text{data\_width} \div \text{mem\_width})
\]

- **out\_file\_addr** is the address of the output file.
- **paddr\_val** is the value supplied with the paddr parameter inside the SECTIONS directive.
- **sec\_beg\_load\_addr** is the section load address assigned by the linker.

† If paddr is not specified

The value of data width divided by memory width is a correction factor for address generation. The section beginning load address factor subtracted from the load address is an offset from the beginning of the section.

3) **The –zero option.** When you use the –zero option, the utility resets the address origin to 0 for each output file. Since each file starts at 0 and counts upward, any address records represent offsets from the beginning of the file (the address within the ROM) rather than actual target addresses of the data.

   You must use the –zero option in conjunction with the –image option to force the starting address in each output file to be zero. If you specify the –zero option without the –image option, the utility issues a warning and ignores the –zero option.

**Boot-Loader Mode.** When the boot loader is used, the hex conversion utility places the different COFF sections that are in the boot table into consecutive memory locations. Each COFF section becomes a boot table block whose destination address is equal to the linker-assigned section load address.

In a boot table, the address field of the hex conversion utility output file is not related to the section load addresses assigned by the linker. The address fields of the boot table are simply offsets to the beginning of the table, multiplied by the correction factor (data width divided by memory width). The section load addresses assigned by the linker will be encoded into the boot table along with the size of the section and the data contained within the section. These addresses will be used to store the data into memory during the boot load process.

The beginning of the boot table defaults to the linked load address of the first bootable section in the COFF input file, unless you use one of the following mechanisms, listed here from low to high priority. Higher priority mechanisms override the values set by low priority options in an overlapping range.
1) **The ROM origin specified in the ROMS directive.** The hex conversion utility places the boot table at the origin of the first memory range in a ROMS directive.

2) **The –bootorg option.** The hex conversion utility places the boot table at the address specified by the –bootorg option if you select boot loading from memory.

3) **The –bootorg option.** The hex conversion utility places the boot table at the address specified by the –bootorg option if you select boot loading from memory. Neither –bootorg PARALLEL nor –bootorg SERIAL affect the address field.

### 10.10.2 Controlling the Address Increment Index

By default, the hex conversion utility increments the output file address field according to the memory width value. If memory width equals 16, the address increments on the basis of how many 16-bit words are present in each line of the output file.

### 10.10.3 The –byte Option

Some EPROM programmers may require the output file address field to contain a byte count rather than a word count. If you use the –byte option, the output file address increments once for each byte. For example, if the starting address is 0h, the first line contains eight words, and you use no –byte option, the second line would start at address 8 (8h). If the starting address is 0h, the first line contains eight words, and you use the –byte option, the second line would start at address 16 (010h). The data in both examples are the same; –byte affects only the calculation of the output file address field, not the actual target processor address of the converted data.

The –byte option causes the address records in an output file to refer to byte locations within the file, whether the target processor is byte-addressable or not.

### 10.10.4 Dealing With Address Holes

When memory width is different from data width, the automatic multiplication of the load address by the correction factor might create holes at the beginning of a section or between sections.

For example, assume you want to load a COFF section (.sec1) at address 0x0100 of an 8-bit EPROM. If you specify the load address in the linker com-
Controlling the ROM Device Address

A command file at location 0x0100, the hex conversion utility will multiply the address by 2 (data width divided by memory width = 16/8 = 2), giving the output file a starting address of 0x0200. Unless you control the starting address of the EPROM with your EPROM programmer, you could create holes within the EPROM. The programmer will burn the data starting at location 0x0200 instead of 0x0100. To solve this, you can:

- Use the paddr parameter of the SECTIONS directive. This forces a section to start at the specified value. Figure 10–9 shows a command file that can be used to avoid the hole at the beginning of .sec1.

**Figure 10–9. Hex Command File for Avoiding a Hole at the Beginning of a Section**

```
-i
a.out
-map a.map

ROMS
{
  ROM : org = 0x0100, length = 0x200, romwidth = 8,
       memwidth = 8
}

SECTIONS
{
  sec1: paddr = 0x100
}
```

Note: If your file contains multiple sections, and, if one section uses a paddr parameter, then all sections must use the paddr parameter.

- Use the –bootorg option or use the ROMS origin parameter (for boot loading only). As described on page 10-36, when you are boot loading, the EPROM address of the entire boot-loader table can be controlled by the –bootorg option or by the ROMS directive origin.

- For another example, see Section C.4, Example 3: Generating a Boot Table for Non-LP Core Devices, on page C-10.
10.11 Description of the Object Formats

The hex conversion utility converts a COFF object file into one of five object formats that most EPROM programmers accept as input: ASCII-Hex, Intel MCS-86, Motorola-S, Extended Tektronix, or TI-Tagged.

Table 10–3 specifies the format options.

- If you use more than one of these options, the last one you list overrides the others.
- The default format is Tektronix (–x option).

Table 10–3. Options for Specifying Hex Conversion Formats

<table>
<thead>
<tr>
<th>Option</th>
<th>Format</th>
<th>Address Bits</th>
<th>Default Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>–a</td>
<td>ASCII-Hex</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>–i</td>
<td>Intel</td>
<td>32</td>
<td>8</td>
</tr>
<tr>
<td>–m1</td>
<td>Motorola-S1</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>–m2 or –m</td>
<td>Motorola-S2</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td>–m3</td>
<td>Motorola-S3</td>
<td>32</td>
<td>8</td>
</tr>
<tr>
<td>–t</td>
<td>TI-Tagged</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>–x</td>
<td>Tektronix</td>
<td>32</td>
<td>8</td>
</tr>
</tbody>
</table>

Address bits determine how many bits of the address information the format supports. Formats with 16-bit addresses support addresses up to 64K only. The utility truncates target addresses to fit in the number of available bits.

The default width determines the default output width. You can change the default width by using the –romwidth option or by using the romwidth parameter in the ROMS directive. You cannot change the default width of the TI-Tagged format, which supports a 16-bit width only.
10.11.1 ASCII-Hex Object Format (–a Option)

The ASCII-Hex object format supports 16-bit addresses. The format consists of a byte stream with bytes separated by spaces. Figure 10–10 illustrates the ASCII-Hex format.

Figure 10–10. ASCII-Hex Object Format

The file begins with an ASCII STX character (ctrl-B, 02h) and ends with an ASCII ETX character (ctrl-C, 03h). Address records are indicated with $AXXXX, in which XXXX is a 4-digit (16-bit) hexadecimal address. The address records are present only in the following situations:

- When discontinuities occur
- When the byte stream does not begin at address 0

You can avoid all discontinuities and any address records by using the –image and –zero options. The output created is a list of byte values.
10.11.2 Intel MCS-86 Object Format (–i Option)

The Intel object format supports 16-bit addresses and 32-bit extended addresses. Intel format consists of a 9-character (4-field) prefix—which defines the start of record, byte count, load address, and record type—the data, and a 2-character checksum suffix.

The 9-character prefix represents three record types:

<table>
<thead>
<tr>
<th>Record Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>Data record</td>
</tr>
<tr>
<td>01</td>
<td>End-of-file record</td>
</tr>
<tr>
<td>04</td>
<td>Extended linear address record</td>
</tr>
</tbody>
</table>

Record type 00, the data record, begins with a colon (:) and is followed by the byte count, the address of the first data byte, the record type (00), and the checksum. Note that the address is the least significant 16 bits of a 32-bit address; this value is concatenated with the value from the most recent 04 (extended linear address) record to create a full 32-bit address. The checksum is the 2s complement (in binary form) of the preceding bytes in the record, including byte count, address, and data bytes.

Record type 01, the end-of-file record, also begins with a colon (:) followed by the byte count, the address, the record type (01), and the checksum.

Record type 04, the extended linear address record, specifies the upper 16 address bits. It begins with a colon (:) followed by the byte count, a dummy address of 0h, the record type (04), the most significant 16 bits of the address, and the checksum. The subsequent address fields in the data records contain the least significant bits of the address.

Figure 10–11 illustrates the Intel hexadecimal object format.

![Figure 10–11. Intel Hex Object Format](image)
10.11.3 Motorola Exorciser Object Format (–m1, –m2, –m3 Options)

The Motorola S1, S2, and S3 formats support 16-bit, 24-bit, and 32-bit addresses, respectively. The formats consist of a start-of-file (header) record, data records, and an end-of-file (termination) record. Each record is made up of five fields: record type, byte count, address, data, and checksum. The record types are:

<table>
<thead>
<tr>
<th>Record Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>S0</td>
<td>Header record</td>
</tr>
<tr>
<td>S1</td>
<td>Code/data record for 16-bit addresses (S1 format)</td>
</tr>
<tr>
<td>S2</td>
<td>Code/data record for 24-bit addresses (S2 format)</td>
</tr>
<tr>
<td>S3</td>
<td>Code/data record for 32-bit addresses (S3 format)</td>
</tr>
<tr>
<td>S7</td>
<td>Termination record for 32-bit addresses (S3 format)</td>
</tr>
<tr>
<td>S8</td>
<td>Termination record for 24-bit addresses (S2 format)</td>
</tr>
<tr>
<td>S9</td>
<td>Termination record for 16-bit addresses (S1 format)</td>
</tr>
</tbody>
</table>

The byte count is the character pair count in the record, excluding the type and byte count itself.

The checksum is the least significant byte of the 1s complement of the sum of the values represented by the pairs of characters making up the byte count, address, and the code/data fields.

Figure 10–12 illustrates the Motorola-S object format.

Figure 10–12. Motorola-S Format
10.11.4 Texas Instruments SDSMAC Object Format (–t Option)

The TI-Tagged object format supports 16-bit addresses. It consists of a start-of-file record, data records, and end-of-file record. Each of the data records is made up of a series of small fields and is signified by a tag character. The significant tag characters are:

<table>
<thead>
<tr>
<th>Tag Character</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>followed by the program identifier</td>
</tr>
<tr>
<td>7</td>
<td>followed by a checksum</td>
</tr>
<tr>
<td>8</td>
<td>followed by a dummy checksum (ignored)</td>
</tr>
<tr>
<td>9</td>
<td>followed by a 16-bit load address</td>
</tr>
<tr>
<td>B</td>
<td>followed by a data word (four characters)</td>
</tr>
<tr>
<td>F</td>
<td>identifies the end of a data record</td>
</tr>
<tr>
<td>*</td>
<td>followed by a data byte (two characters)</td>
</tr>
</tbody>
</table>

Figure 10–13 illustrates the tag characters and fields in TI-Tagged object format.

Figure 10–13. TI-Tagged Object Format

If any data fields appear before the first address, the first field is assigned address 0000h. Address fields may be expressed for any data byte, but none is required. The checksum field, which is preceded by the tag character 7, is a 2s complement of the sum of the 8-bit ASCII values of characters, beginning with the first tag character and ending with the checksum tag character (7 or 8). The end-of-file record is a colon ( : ).
10.11.5 Extended Tektronix Object Format (–x Option)

The Tektronix object format supports 32-bit addresses and has two types of records:

- **data record** contains the header field, the load address, and the object code.
- **termination record** signifies the end of a module.

The header field in the data record contains the following information:

<table>
<thead>
<tr>
<th>Item</th>
<th>Number of ASCII Characters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>1</td>
<td>Data type is Tektronix format</td>
</tr>
<tr>
<td>Block length</td>
<td>2</td>
<td>Number of characters in the record, minus the %</td>
</tr>
<tr>
<td>Block type</td>
<td>1</td>
<td>6 = data record</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8 = termination record</td>
</tr>
<tr>
<td>Checksum</td>
<td>2</td>
<td>A 2-digit hex sum modulo 256 of all values in the record except the % and the checksum itself.</td>
</tr>
</tbody>
</table>

The load address in the data record specifies where the object code will be located. The first digit specifies the address length; this is always 8. The remaining characters of the data record contain the object code, two characters per byte.

Figure 10–14 illustrates the Tektronix object format.

*Figure 10–14. Extended Tektronix Object Format*
10.12 Hex Conversion Utility Error Messages

section mapped to reserved memory message
Description A section or a boot-loader table is mapped into a reserved memory area listed in the processor memory map.
Action Correct the section or boot-loader address. Refer to the TMS320C54x DSP Reference Set for valid memory locations.

sections overlapping
Description Two or more COFF section load addresses overlap or a boot table address overlaps another section.
Action This problem may be caused by an incorrect translation from load address to hex output file address that is performed by the hex conversion utility when memory width is less than data width. See Section 10.4, Understanding Memory Widths, on page 10-9 and Section 10.10, Controlling the ROM Device Address, on page 10-35.

unconfigured memory error
Description This error could have one of two causes:

- The COFF file contains a section whose load address falls outside the memory range defined in the ROMS directive.
- The boot-loader table address is not within the memory range defined by the ROMS directive.

Action Correct the ROM range as defined by the ROMS directive to cover the memory range as needed, or modify the section load address or boot-loader table address. Remember that if the ROMS directive is not used, the memory range defaults to the entire processor address space. For this reason, removing the ROMS directive could also be a workaround.
Mnemonic-to-Algebraic Translator Description

The TMS320C54x mnemonic-to-algebraic translator utility converts assembly code written in the mnemonic instruction set to code written in the algebraic instruction set.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.1 Translator Overview</td>
<td>11-2</td>
</tr>
<tr>
<td>11.2 Translator Development Flow</td>
<td>11-3</td>
</tr>
<tr>
<td>11.3 Invoking the Translator</td>
<td>11-4</td>
</tr>
<tr>
<td>11.4 Translation Modes</td>
<td>11-5</td>
</tr>
<tr>
<td>11.5 How the Translator Works With Macros</td>
<td>11-8</td>
</tr>
</tbody>
</table>
11.1 Translator Overview

The TMS320C54x mnemonic-to-algebraic translator utility converts mnemonic assembly instructions into algebraic assembly instructions. Mnemonic instructions usually consist of a keyword and operands. Algebraic instructions usually consist of operands and operators. Algebraic instructions resemble higher-level programming language instructions.

The translator requires error-free code. When the translator encounters unrecognized instructions or macro invocations, it prints a message to standard output and does not translate the line of code.

The translator accepts assembly code source files containing mnemonic instructions and produces assembly code source files containing algebraic instructions. The input file can have no extension or an extension of asm. The output file will have the same name as the input file with an extension of cnv.

11.1.1 What the Translator Does

The translator accomplishes the following:

- Replaces a mnemonic with an algebraic representation of what the instruction does as defined by the language specifications. The algebraic representation might consist of more than one line of code.

- Reformats mnemonic instruction operands into algebraic syntax as described in the language specifications. This reformatting includes the following:
  - Data memory address (dma) accesses are prefixed with a @ symbol.
  - The mnemonic indirect shorthand * is replaced with *AR0.
  - When necessary, constants are prefixed with a # symbol.
  - Algebraic expressions that are used as a single operand and have more than one term are enclosed in parentheses.

11.1.2 What the Translator Does Not Do

The translator has the following limitations:

- The translator cannot convert macro definitions. It ignores them. Optionally, the translator replaces macro invocations with the expanded macro, replacing the formal parameters with the actual arguments used at invocation.

- The translator attempts to translate any macro that has the same name as a mnemonic instruction. Insure that macro names are different from mnemonic instructions.
11.2 Translator Development Flow

Figure 6–1 shows the translator’s role in the assembly language development process. The assembler accepts mnemonic or algebraic syntax.

Figure 11–1. Translator Development Flow
11.3 Invoking the Translator

To invoke the translator, enter:

```
mnem2alg [option] inputfile
```

`mnem2alg` is the command that invokes the translator. 
`option` specifies the translator mode (see Section 11.4, Translation Modes, on page 11-5). The options are:

- `-t` Literal mode, which is the default if no option is specified
- `-e` Expansion mode

`inputfile` names the assembly source file you want to translate. If you do not specify an extension, `asm` is assumed.
11.4 Translation Modes

The translator runs in one of the following modes:

<table>
<thead>
<tr>
<th>Mode</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Literal</td>
<td>Keeps the original mnemonic instruction, commented out, followed by the translated instruction</td>
</tr>
<tr>
<td>Expansion</td>
<td>Expands and preprocesses macro invocations and replaces substitution symbols</td>
</tr>
</tbody>
</table>

11.4.1 Literal Mode (–t Option)

When running in the default literal mode (–t option), the translator translates instructions without any preprocessing. The translator does not process macros, nor does it expand substitution symbols. When the translator does not recognize a macro invocation or instruction, it prints a message to standard output and does not translate the code. The translator creates a file with the same name as the assembler source file and an extension of cnv.

![Literal Mode Process](image)

**Command:** mnem2alg filename.asm

**Translation:** Translator

**Converted file:** filename.cnv

11.4.2 About Symbol Names in Literal Mode

In literal mode, the translator treats symbol names defined by .asg as labels and not as the value they represent. In the following example, the source code is translated as shown, with sym treated as a data memory address:

**Example 11–1. Treatment of Symbol Names in Literal Mode**

(a) Source code:

```
sym .asg *AR2
LD sym, B
```

(b) Converted code:

```
sym .asg *AR2
B = @sym
```
11.4.3 Expansion Mode (–e Option)

Expansion mode is invoked using the –e option. In expansion mode, the translator preprocesses macros and substitution symbols and then translates instructions. The translator invokes the assembler with a switch that preprocesses the input to expand macros and insert substitution symbols. The assembler creates a file with an exp extension. The exp file is passed back to the translator for processing. The translator creates a file with the same name as the assembler source file and an extension of cnv.

Since the translator invokes the assembler in expansion mode, you must include the assembler executable in your path. The assembler executable version must be 1.11 or above. If the assembler encounters errors during preprocessing, the translator aborts and no output is produced.

Figure 11–3. Expansion Mode Process

Command: menm2alg –e filename.asm

Assembly with switch: Assembler

Intermediate file: filename.exp

Translation: Translator

Converted file: filename.cnv

The following example demonstrates how expansion mode works. In the intermediate file, the macro invocation is commented out and the expanded macro is inserted in its place, with the actual arguments substituted in. Although the macro definition was not translated, the resulting cnv file can be assembled by the algebraic assembler to produce output. The assembler does not process macro definitions (for the same reasons the translator does not translate definitions). The exp intermediate file that the assembler produces is deleted after the translation is complete.
Translation Modes

Example 11-2. Expansion Mode

(a) Source code

```
file.asm
********************************
.asg *AR0,sym

mymac .macro parm1,parm2
LD parm1,parm2
ADD sym,5,parm2,B
.endm

mymac sym,A
********************************
```

(b) Intermediate code

```
file.exp – after preprocessing
before translation
********************************
.asg *AR0,sym

mymac .macro parm1,parm2
LD parm1,parm2
ADD sym,5,parm2,B
.endm

; mymac sym,A
LD *AR0,A
ADD *AR0,5,A,B
********************************
```

(c) Converted code

```
file.cnv – after translation
********************************
.asg *AR0, sym

mymac .macro parm1,parm2
LD parm1,parm2
ADD sym,5,parm2,B
.endm

; mymac sym,A
A = *AR0
B = A + *AR0 << 5
********************************
```
11.5 How the Translator Works With Macros

This section describes how the translator works with macros. The following subjects are discussed:

- Directives in macros
- Macro local variables
- Defining labels when invoking a macro

11.5.1 Directives in Macros

When macro invocations are expanded, directives in macro definitions are not copied to the intermediate file. Instead, the macro is inlined, and the code is no longer in a macro environment. The following source code preprocesses to the intermediate code as shown:

Example 11–3. Directives in Macros

(a) Source code

```
mymac .macro parm1
   .var temp
   .eval parm1, temp
   .word temp
 .endm
mymac 5
```

(b) Intermediate code

```
mymac .macro parm1
   .var temp
   .eval parm1, temp
   .word temp
 .endm

;   mymac 5
 .word 5
```
11.5.2 Macro Local Variables

When macro local variables are encountered, they are changed so that repeated calls to the macro do not generate identical labels. The following source code preprocesses to the intermediate code as shown:

Example 11–4. Macro Local Variables

(a) Source code

```
mymac .macro parm1
lab? .word parm1
.endm
mymac 4
mymac 40
mymac 400
```

(b) Intermediate code

```
mymac .macro parm1
lab? .word parm1
.endm

;   mymac 4
lab$1$ .word 4
;   mymac 40
lab$2$ .word 40
;   mymac 400
lab$3$ .word 400
```

The local label name is appended with $n$, where $n$ is the number of the macro invocation. Insure that there are no other labels that could be identical to a generated macro local label.
11.5.3 Defining Labels When Invoking A Macro

If there is a label associated with a macro invocation, that label is not used after expansion and translation. This is because the label is commented out with the macro invocation. The following source code preprocesses to the intermediate code as shown:

Figure 11–4. Defining Labels

(a) Source code:

```plaintext
mymac .macro
    .word F403
    .endm
LABEL mymac
```

(b) Intermediate code:

```plaintext
mymac .macro
    .word F403
    .endm
;LABEL    mymac
    .word F403
```

LABEL is not defined when the code is assembled. Insure that label definitions do not appear on the same line as the macro invocations. Rewrite the source code in the example above as follows:

Figure 11–5. Rewritten Source Code

```plaintext
mymac .macro
    .word F403
    .endm
LABEL
    mymac
```
Common Object File Format

The compiler, assembler, and linker create object files in common object file format (COFF). COFF is an implementation of an object file format of the same name that was developed by AT&T for use on UNIX-based systems. This format is used because it encourages modular programming and provides more powerful and flexible methods for managing code segments and target system memory.

Sections are a basic COFF concept. Chapter 2, Introduction to Common Object File Format, discusses COFF sections in detail. If you understand section operation, you will be able to use the assembly language tools more efficiently.

This appendix contains technical details about COFF object file structure. Much of this information pertains to the symbolic debugging information that is produced by the C/C++ compiler. The purpose of this appendix is to provide supplementary information about the internal format of COFF object files.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.1</td>
<td>COFF File Structure</td>
</tr>
<tr>
<td>A.2</td>
<td>File Header Structure</td>
</tr>
<tr>
<td>A.3</td>
<td>Optional File Header Format</td>
</tr>
<tr>
<td>A.4</td>
<td>Section Header Structure</td>
</tr>
<tr>
<td>A.5</td>
<td>Structuring Relocation Information</td>
</tr>
<tr>
<td>A.6</td>
<td>Line-Number Table Structure</td>
</tr>
<tr>
<td>A.7</td>
<td>Symbol Table Structure and Content</td>
</tr>
</tbody>
</table>
A.1 COFF File Structure

The elements of a COFF object file describe the file’s sections and symbolic debugging information. These elements are:

- A file header
- Optional header information
- A table of section headers
- Raw data for each initialized section
- Relocation information for each initialized section
- Line-number entries for each initialized section
- A symbol table
- A string table

The assembler and linker produce object files with the same COFF structure; however, a program that is linked for the final time does not usually contain relocation entries. Figure A–1 illustrates the overall object file structure.

Figure A–1. COFF File Structure
Figure A–2 shows a typical example of a COFF object file that contains the three default sections, .text, .data, and .bss, and a named section (referred to as <named>). By default, the tools place sections into the object file in the following order: .text, .data, initialized named sections, .bss, and uninitialized named sections. Although uninitialized sections have section headers, notice that they have no raw data, relocation information, or line-number entries. This is because the .bss and .usect directives simply reserve space for uninitialized data; uninitialized sections contain no actual code.

Figure A–2. COFF Object File
A.1.1 Impact of Switching Operating Systems

The C54x COFF files are recognized by all operating system versions of the development tools. When you switch from one operating system to another, only the file header information in the COFF files needs to be byte swapped. The raw data in the COFF files does not need any changes.

The C54x development tools can detect the difference in the file headers and automatically compensate for it. This is true if using only C54x development tools.

To tell the difference between COFF files, you can look at the magic number in the optional file header. Bytes 0 and 1 contain the magic number. For the SunOS™ or HP-UX™ operating systems, the magic number is 108h. For the DOS operating system, the magic number is 801h.
A.2 File Header Structure

The file header contains 22 bytes of information that describe the general format of an object file. Table A–1 shows the structure of the COFF file header.

Table A–1. File Header Contents

<table>
<thead>
<tr>
<th>Byte Number</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–1</td>
<td>Unsigned short integer</td>
<td>Version ID; indicates version of COFF file structure</td>
</tr>
<tr>
<td>2–3</td>
<td>Unsigned short integer</td>
<td>Number of section headers</td>
</tr>
<tr>
<td>4–7</td>
<td>Long integer</td>
<td>Time and date stamp; indicates when the file was created</td>
</tr>
<tr>
<td>8–11</td>
<td>Long integer</td>
<td>File pointer; contains the symbol table’s starting address</td>
</tr>
<tr>
<td>12–15</td>
<td>Long integer</td>
<td>Number of entries in the symbol table</td>
</tr>
<tr>
<td>16–17</td>
<td>Unsigned short integer</td>
<td>Number of bytes in the optional header. This field is either 0 or 28; if it is 0, then there is no optional file header</td>
</tr>
<tr>
<td>18–19</td>
<td>Unsigned short integer</td>
<td>Flags (see Table A–2)</td>
</tr>
<tr>
<td>20–21</td>
<td>Unsigned short integer</td>
<td>Target ID; magic number indicates the file can be executed in a TMS320C54x™ system</td>
</tr>
</tbody>
</table>

Table A–2 lists the flags that can appear in bytes 18 and 19 of the file header. Any number and combination of these flags can be set at the same time (for example, if bytes 18 and 19 are set to 0003h, F_RELFLG and F_EXEC are both set.)

Table A–2. File Header Flags (Bytes 18 and 19)

<table>
<thead>
<tr>
<th>Mnemonic</th>
<th>Flag</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>F_RELFLG</td>
<td>0001h</td>
<td>Relocation information was stripped from the file.</td>
</tr>
<tr>
<td>F_EXEC</td>
<td>0002h</td>
<td>The file is relocatable (it contains no unresolved external references).</td>
</tr>
<tr>
<td>F_LNNO</td>
<td>0004h</td>
<td>Line numbers were stripped from the file.</td>
</tr>
<tr>
<td>F_LSYMS</td>
<td>0008h</td>
<td>Local symbols were stripped from the file.</td>
</tr>
<tr>
<td>F_LITTLE</td>
<td>0100h</td>
<td>The file has the byte ordering used by C54x devices (16 bits per word, least significant byte first)</td>
</tr>
<tr>
<td>F_SYMMERGE</td>
<td>1000h</td>
<td>Duplicate symbols were removed.</td>
</tr>
</tbody>
</table>
A.3 Optional File Header Format

The linker creates the optional file header and uses it to perform relocation at download time. Partially linked files do not contain optional file headers. Table A–3 illustrates the optional file header format.

Table A–3. Optional File Header Contents

<table>
<thead>
<tr>
<th>Byte Number</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–1</td>
<td>Short integer</td>
<td>Magic number (for SunOS or HP-UX it is 108h; for DOS it is 801h)</td>
</tr>
<tr>
<td>2–3</td>
<td>Short integer</td>
<td>Version stamp</td>
</tr>
<tr>
<td>4–7</td>
<td>Long integer</td>
<td>Size (in words) of executable code</td>
</tr>
<tr>
<td>8–11</td>
<td>Long integer</td>
<td>Size (in words) of initialized .data sections</td>
</tr>
<tr>
<td>12–15</td>
<td>Long integer</td>
<td>Size (in words) of uninitialized .bss sections</td>
</tr>
<tr>
<td>16–19</td>
<td>Long integer</td>
<td>Entry point</td>
</tr>
<tr>
<td>20–23</td>
<td>Long integer</td>
<td>Beginning address of executable code</td>
</tr>
<tr>
<td>24–27</td>
<td>Long integer</td>
<td>Beginning address of initialized data</td>
</tr>
</tbody>
</table>
A.4 Section Header Structure

COFF object files contain a table of section headers that define where each section begins in the object file. Each section has its own section header. The COFF1 and COFF2 file types contain different section header information. Table A–4 shows the section header contents for COFF1 files. Table A–5 shows the section header contents for COFF2 files.

Table A–4. Section Header Contents for COFF1 Files

<table>
<thead>
<tr>
<th>Byte</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–7</td>
<td>Character</td>
<td>8-character section name, padded with nulls</td>
</tr>
<tr>
<td>8–11</td>
<td>Long integer</td>
<td>Section’s physical address</td>
</tr>
<tr>
<td>12–15</td>
<td>Long integer</td>
<td>Section’s virtual address</td>
</tr>
<tr>
<td>16–19</td>
<td>Long integer</td>
<td>Section size in words</td>
</tr>
<tr>
<td>20–23</td>
<td>Long integer</td>
<td>File pointer to raw data</td>
</tr>
<tr>
<td>24–27</td>
<td>Long integer</td>
<td>File pointer to relocation entries</td>
</tr>
<tr>
<td>28–31</td>
<td>Long integer</td>
<td>File pointer to line-number entries</td>
</tr>
<tr>
<td>32–33</td>
<td>Unsigned short integer</td>
<td>Number of relocation entries</td>
</tr>
<tr>
<td>34–35</td>
<td>Unsigned short integer</td>
<td>Number of line-number entries</td>
</tr>
<tr>
<td>36–37</td>
<td>Unsigned short integer</td>
<td>Flags (see Table A–6)</td>
</tr>
<tr>
<td>38</td>
<td>Character</td>
<td>Reserved</td>
</tr>
<tr>
<td>39</td>
<td>Character</td>
<td>Memory page number</td>
</tr>
</tbody>
</table>

Table A–5. Section Header Contents for COFF2 Files

<table>
<thead>
<tr>
<th>Byte</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–7</td>
<td>Character</td>
<td>8-character section name, padded with nulls</td>
</tr>
<tr>
<td>8–11</td>
<td>Long integer</td>
<td>Section’s physical address</td>
</tr>
<tr>
<td>12–15</td>
<td>Long integer</td>
<td>Section’s virtual address</td>
</tr>
<tr>
<td>16–19</td>
<td>Long integer</td>
<td>Section size in words</td>
</tr>
<tr>
<td>20–23</td>
<td>Long integer</td>
<td>File pointer to raw data</td>
</tr>
<tr>
<td>24–27</td>
<td>Long integer</td>
<td>File pointer to relocation entries</td>
</tr>
<tr>
<td>28–31</td>
<td>Long integer</td>
<td>File pointer to line-number entries</td>
</tr>
<tr>
<td>32–35</td>
<td>Unsigned long</td>
<td>Number of relocation entries</td>
</tr>
<tr>
<td>36–39</td>
<td>Unsigned long</td>
<td>Number of line-number entries</td>
</tr>
<tr>
<td>40–43</td>
<td>Unsigned long</td>
<td>Flags (see Table A–6)</td>
</tr>
<tr>
<td>44–45</td>
<td>Short</td>
<td>Reserved</td>
</tr>
<tr>
<td>46–47</td>
<td>Unsigned short</td>
<td>Memory page number</td>
</tr>
</tbody>
</table>
Table A–6 lists the flags that can appear in the section header. The flags can be combined. For example, if the flag’s word is set to 024h, both STYP_GROUP and STYP_TEXT are set.

Table A–6. Section Header Flags

<table>
<thead>
<tr>
<th>Mnemonic</th>
<th>Flag</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>STYP_REG</td>
<td>0000h</td>
<td>Regular section (allocated, relocated, loaded)</td>
</tr>
<tr>
<td>STYP_DSECT</td>
<td>0001h</td>
<td>Dummy section (relocated, not allocated, not loaded)</td>
</tr>
<tr>
<td>STYP_NOLOAD</td>
<td>0002h</td>
<td>Noload section (allocated, relocated, not loaded)</td>
</tr>
<tr>
<td>STYP_GROUP</td>
<td>0004h</td>
<td>Grouped section (formed from several input sections)</td>
</tr>
<tr>
<td>STYP_PAD</td>
<td>0008h</td>
<td>Padding section (loaded, not allocated, not relocated)</td>
</tr>
<tr>
<td>STYP_COPY</td>
<td>0010h</td>
<td>Copy section (relocated, loaded, but not allocated; relocation and line-number entries are processed normally)</td>
</tr>
<tr>
<td>STYP_TEXT</td>
<td>0020h</td>
<td>Section that contains executable code</td>
</tr>
<tr>
<td>STYP_DATA</td>
<td>0040h</td>
<td>Section that contains initialized data</td>
</tr>
<tr>
<td>STYP_BSS</td>
<td>0080h</td>
<td>Section that contains uninitialized data</td>
</tr>
<tr>
<td>STYP_CLINK</td>
<td>4000h</td>
<td>Section that is conditionally linked</td>
</tr>
</tbody>
</table>

Note: The term loaded means that the raw data for this section appears in the object file.

The flags are in:

<table>
<thead>
<tr>
<th>Bytes</th>
<th>For This COFF Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>36 and 37</td>
<td>COFF1</td>
</tr>
<tr>
<td>40 to 43</td>
<td>COFF2</td>
</tr>
</tbody>
</table>

Section Header Structure
Figure A–3 illustrates how the pointers in a section header would point to the elements in an object file that are associated with the .text section.

Figure A–3. Section Header Pointers for the .text Section

As Figure A–2 on page A-3 shows, uninitialized sections (created with the .bss and .usect directives) vary from this format. Although uninitialized sections have section headers, they have no raw data, relocation information, or line-number information. They occupy no actual space in the object file. Therefore, the number of relocation entries, the number of line-number entries, and the file pointers are 0 for an uninitialized section. The header of an uninitialized section simply tells the linker how much space for variables it should reserve in the memory map.
A.5 Structuring Relocation Information

A COFF object file has one relocation entry for each relocatable reference. The assembler automatically generates relocation entries. The linker reads the relocation entries as it reads each input section and performs relocation. The relocation entries determine how references within each input section are treated.

COFF file relocation information entries use the 12-byte format shown in Table A–7.

Table A–7. Relocation Entry Contents

<table>
<thead>
<tr>
<th>Byte Number</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–3</td>
<td>Long integer</td>
<td>Virtual address of the reference</td>
</tr>
<tr>
<td>4–7</td>
<td>Unsigned long integer</td>
<td>Symbol table index</td>
</tr>
<tr>
<td>8–9</td>
<td>Unsigned short integer</td>
<td>For COFF1 files: Reserved</td>
</tr>
<tr>
<td></td>
<td></td>
<td>For COFF2 files: Additional byte used for extended address calculations</td>
</tr>
<tr>
<td>10–11</td>
<td>Unsigned short integer</td>
<td>Relocation type (see Table A–8)</td>
</tr>
</tbody>
</table>

The virtual address is the symbol’s address in the current section before relocation; it specifies where a relocation must occur. (This is the address of the field in the object code that must be patched.)

Following is an example of code that generates a relocation entry:

```plaintext
2 .global X
3 0000 FF80 B X
0001 0000!
```

In this example, the virtual address of the relocatable field is 0001.

The symbol table index is the index of the referenced symbol. In the preceding example, this field would contain the index of X in the symbol table. The amount of the relocation is the difference between the symbol’s current address in the section and its assembly-time address. The relocatable field must be relocated by the same amount as the referenced symbol. In the example, X has a value of 0 before relocation. Suppose X is relocated to address 2000h. This is the relocation amount (2000h – 0 = 2000h), so the relocation field at address 1 is patched by adding 2000h to it.

You can determine a symbol’s relocated address if you know which section it is defined in. For example, if X is defined in .data and .data is relocated by 2000h, X is relocated by 2000h.
If the symbol table index in a relocation entry is –1 (0FFFFh), this is called an *internal relocation*. In this case, the relocation amount is simply the amount by which the current section is being relocated.

The *relocation type* specifies the size of the field to be patched and describes how to calculate the patched value. The type field depends on the addressing mode that was used to generate the relocatable reference. In the preceding example, the actual address of the referenced symbol (X) will be placed in a 16-bit field in the object code. This is a 16-bit direct relocation, so the relocation type is R_RELWORD. Table A–8 lists the relocation types.

**Table A–8. Relocation Types (Bytes 8 and 9)**

<table>
<thead>
<tr>
<th>Mnemonic</th>
<th>Flag</th>
<th>Relocation Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_ABS</td>
<td>0000h</td>
<td>No relocation</td>
</tr>
<tr>
<td>R_REL24</td>
<td>0005h</td>
<td>24-bit direct reference to symbol’s address</td>
</tr>
<tr>
<td>R_RELBYTE</td>
<td>0017h</td>
<td>8-bit direct reference to symbol’s address</td>
</tr>
<tr>
<td>R_REL13</td>
<td>002Ah</td>
<td>13-bit direct reference</td>
</tr>
<tr>
<td>R_RELWORD</td>
<td>0020h</td>
<td>16-bit direct reference to symbol’s address</td>
</tr>
<tr>
<td>R_RELLONG</td>
<td>0021h</td>
<td>32-bit direct reference to symbol’s address</td>
</tr>
<tr>
<td>R_PARTLS7</td>
<td>0028h</td>
<td>7 LSBs of an address</td>
</tr>
<tr>
<td>R_PARTMS9</td>
<td>0029h</td>
<td>9 MSBs of an address</td>
</tr>
</tbody>
</table>
A.6 Line-Number Table Structure

The object file contains a table of line-number entries that are useful for symbolic debugging. When the C/C++ compiler produces several lines of assembly language code, it creates a line-number entry that maps these lines back to the original line of C/C++ source code that generated them. Each single line-number entry contains 6 bytes of information. Table A–9 shows the format of a line-number entry.

Table A–9. Line-Number Entry Format

<table>
<thead>
<tr>
<th>Byte Number</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
</table>
| 0–3         | Long integer    | This entry may have one of two values:
|             |                 | 1) If it is the first entry in a block of line-number entries, it points to a symbol entry in the symbol table. |
|             |                 | 2) If it is not the first entry in a block, it is the physical address of the line indicated by bytes 4–5. |
| 4–5         | Unsigned short integer | This entry may have one of two values:
|             |                 | 1) If this field is 0, this is the first line of a function entry. |
|             |                 | 2) If this field is not 0, this is the line number of a line in C/C++ source code. |

Figure A–4 shows how line-number entries are grouped into blocks.

Figure A–4. Line-Number Blocks

As Figure A–4 shows, each entry is divided as follows:

- For the first line of a function, bytes 0–3 point to the name of a symbol or a function in the symbol table, and bytes 4–5 contain a 0, which indicates the beginning of a block.
For the remaining lines in a function, bytes 0–3 show the physical address (the number of words created by a line of C/C++ source) and bytes 4–5 show the address of the original C/C++ source, relative to its appearance in the C/C++ source program.

The line-number entry table can contain many of these blocks.

Figure A–5 illustrates line-number entries for a function named XYZ. As shown, the function name is entered as a symbol in the symbol table. The first portion on XYZ’s block of line-number entries points to the function name in the symbol table. Assume that the original function in the C/C++ source contained three lines of code. The first line of code produces 4 words of assembly language code, the second line produces 3 words, and the third line produces 10 words.

Figure A–5. Line-Number Entries

(Note that the symbol table entry for XYZ has a field that points back to the beginning of the line-number block.)

Because line numbers are not often needed, the linker provides an option (–s) that strips line-number information from the object file; this provides a more compact object module.)
A.7 Symbol Table Structure and Content

The order of symbols in the symbol table is very important; they appear in the sequence shown in Figure A–6.

Figure A–6. Symbol Table Contents

Static variables refer to symbols defined in C/C++ that have storage class static outside any function. If you have several modules that use symbols with the same name, making them static confines the scope of each symbol to the module that defines it (this eliminates multiple-definition conflicts).
The entry for each symbol in the symbol table contains the symbol’s:

- Name (or a pointer into the string table)
- Type
- Value
- Section it was defined in
- Storage class
- Basic type (integer, character, etc.)
- Derived type (array, structure, etc.)
- Dimensions
- Line number of the source code that defined the symbol

Section names are also defined in the symbol table.

All symbol entries, regardless of class and type, have the same format in the symbol table. Each symbol table entry contains the 18 bytes of information listed in Table A–10. Each symbol may also have an 18-byte auxiliary entry; the special symbols listed in Table A–11 on page A-16 always have an auxiliary entry. Some symbols may not have all the characteristics listed above; if a particular field is not set, it is set to null.

**Table A–10. Symbol Table Entry Contents**

<table>
<thead>
<tr>
<th>Byte Number</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
</table>
| 0–7         | Character | This field contains one of the following:  
1) An 8-character symbol name, padded with nulls  
2) A pointer into the string table if the symbol name is longer than 8 characters |
| 8–11        | Long integer | Symbol value; storage class dependent |
| 12–13       | Short integer | Section number of the symbol |
| 14–15       | Unsigned short integer | Basic and derived type specification |
| 16          | Character | Storage class of the symbol |
| 17          | Character | Number of auxiliary entries (always 0 or 1) |
A.7.1 Special Symbols

The symbol table contains some special symbols that are generated by the compiler, assembler, and linker. Each special symbol contains ordinary symbol table information as well as an auxiliary entry. Table A–11 lists these symbols.

Table A–11. Special Symbols in the Symbol Table

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>.file</td>
<td>File name</td>
</tr>
<tr>
<td>.text</td>
<td>Address of the .text section</td>
</tr>
<tr>
<td>.data</td>
<td>Address of the .data section</td>
</tr>
<tr>
<td>.bss</td>
<td>Address of the .bss section</td>
</tr>
<tr>
<td>.bb</td>
<td>Address of the beginning of a block</td>
</tr>
<tr>
<td>.eb</td>
<td>Address of the end of a block</td>
</tr>
<tr>
<td>.bf</td>
<td>Address of the beginning of a function</td>
</tr>
<tr>
<td>.ef</td>
<td>Address of the end of a function</td>
</tr>
<tr>
<td>.target</td>
<td>Pointer to a structure or union that is returned by a function</td>
</tr>
<tr>
<td>.nfake</td>
<td>Dummy tag name for a structure, union, or enumeration</td>
</tr>
<tr>
<td>.eos</td>
<td>End of a structure, union, or enumeration</td>
</tr>
<tr>
<td>etext</td>
<td>Next available address after the end of the .text output section</td>
</tr>
<tr>
<td>edata</td>
<td>Next available address after the end of the .data output section</td>
</tr>
<tr>
<td>end</td>
<td>Next available address after the end of the .bss output section</td>
</tr>
</tbody>
</table>

Several of these symbols appear in pairs:

- .bb/.eb indicate the beginning and end of a block.
- .bf/.ef indicate the beginning and end of a function.
- .nfake/.eos name and define the limits of structures, unions, and enumerations that were not named. The .eos symbol is also paired with named structures, unions, and enumerations.

When a structure, union, or enumeration has no tag name, the compiler assigns it a name so that it can be entered into the symbol table. These names are of the form nfake, where n is an integer. The compiler begins numbering these symbol names at 0.
A.7.1.1 Symbols and Blocks

In C, a block is a compound statement that begins and ends with braces. A block always contains symbols. The symbol definitions for any particular block are grouped together in the symbol table and are delineated by the .bb/.eb special symbols. Blocks can be nested in C, and their symbol table entries can be nested correspondingly. Figure A–7 shows how block symbols are grouped in the symbol table.

Figure A–7. Symbols for Blocks

![Diagram of symbol table showing block symbols grouped]

A.7.1.2 Symbols and Functions

The symbol definitions for a function appear in the symbol table as a group, delineated by .bf/.ef special symbols. The symbol table entry for the function name precedes the .bf special symbol. Figure A–8 shows the format of symbol table entries for a function.

Figure A–8. Symbols for Functions

![Diagram of symbol table showing function symbol]

If a function returns a structure or union, a symbol table entry for the special symbol .target will appear between the entries for the function name and the .bf special symbol.
A.7.2 Symbol Name Format

The first eight bytes of a symbol table entry (bytes 0–7) indicate a symbol’s name:

- If the symbol name is eight characters or less, this field has type character. The name is padded with nulls (if necessary) and stored in bytes 0–7.
- If the symbol name is greater than 8 characters, this field is treated as two long integers. The entire symbol name is stored in the string table. Bytes 0–3 contain 0, and bytes 4–7 are an offset into the string table.

A.7.3 String Table Structure

Symbol names that are longer than eight characters are stored in the string table. The field in the symbol table entry that would normally contain the symbol’s name contains, instead, a pointer to the symbol’s name in the string table. Names are stored contiguously in the string table, delimited by a null byte. The first four bytes of the string table contain the size of the string table in bytes; thus, offsets into the string table are greater than or equal to four.

Figure A–9 is a string table that contains two symbol names, Adaptive-Filter and Fourier-Transform. The index in the string table is 4 for Adaptive-Filter and 20 for Fourier-Transform.

Figure A–9. String Table
A.7.4 Storage Classes

Byte 16 of the symbol table entry indicates the storage class of the symbol. Storage classes refer to the method in which the C/C++ compiler accesses a symbol. Table A–12 lists valid storage classes.

**Table A–12. Symbol Storage Classes**

<table>
<thead>
<tr>
<th>Mnemonic</th>
<th>Value</th>
<th>Storage Class</th>
<th>Mnemonic</th>
<th>Value</th>
<th>Storage Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_NULL</td>
<td>0</td>
<td>No storage class</td>
<td>C_UNTAG</td>
<td>12</td>
<td>Union tag</td>
</tr>
<tr>
<td>C_AUTO</td>
<td>1</td>
<td>Automatic variable</td>
<td>C_TPDEF</td>
<td>13</td>
<td>Type definition</td>
</tr>
<tr>
<td>C_EXT</td>
<td>2</td>
<td>External symbol</td>
<td>C_USTATIC</td>
<td>14</td>
<td>Uninitialized static</td>
</tr>
<tr>
<td>C_STAT</td>
<td>3</td>
<td>Static</td>
<td>C_ENTAG</td>
<td>15</td>
<td>Enumeration tag</td>
</tr>
<tr>
<td>C_REG</td>
<td>4</td>
<td>Register variable</td>
<td>C_MOE</td>
<td>16</td>
<td>Member of an enumeration</td>
</tr>
<tr>
<td>C_EXTREF</td>
<td>5</td>
<td>External definition</td>
<td>C_REGPARM</td>
<td>17</td>
<td>Register parameter</td>
</tr>
<tr>
<td>C_LABEL</td>
<td>6</td>
<td>Label</td>
<td>C_FIELD</td>
<td>18</td>
<td>Bit field</td>
</tr>
<tr>
<td>C_ULABEL</td>
<td>7</td>
<td>Undefined label</td>
<td>C_BLOCK</td>
<td>100</td>
<td>Beginning or end of a block; used only for the .bb and .eb special symbols</td>
</tr>
<tr>
<td>C_MOS</td>
<td>8</td>
<td>Member of a structure</td>
<td>C_FCN</td>
<td>101</td>
<td>Beginning or end of a function; used only for the .bf and .ef special symbols</td>
</tr>
<tr>
<td>C_ARG</td>
<td>9</td>
<td>Function argument</td>
<td>C_EOS</td>
<td>102</td>
<td>End of structure; used only for the .eos special symbol</td>
</tr>
<tr>
<td>C_STRTAG</td>
<td>10</td>
<td>Structure tag</td>
<td>C_FILE</td>
<td>103</td>
<td>Filename; used only for the .file special symbol</td>
</tr>
<tr>
<td>C_MOU</td>
<td>11</td>
<td>Member of a union</td>
<td>C_LINE</td>
<td>104</td>
<td>Used only by utility programs</td>
</tr>
</tbody>
</table>

Some special symbols are restricted to certain storage classes. Table A–13 lists these symbols and their storage classes.
Table A–13. Special Symbols and Their Storage Classes

<table>
<thead>
<tr>
<th>Special Symbol</th>
<th>Restricted to This Storage Class</th>
<th>Special Symbol</th>
<th>Restricted to This Storage Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>.file</td>
<td>C_FILE</td>
<td>.eos</td>
<td>C_EOS</td>
</tr>
<tr>
<td>.bb</td>
<td>C_BLOCK</td>
<td>.text</td>
<td>C_STAT</td>
</tr>
<tr>
<td>.eb</td>
<td>C_BLOCK</td>
<td>.data</td>
<td>C_STAT</td>
</tr>
<tr>
<td>.bf</td>
<td>C_FCN</td>
<td>.bss</td>
<td>C_STAT</td>
</tr>
<tr>
<td>.ef</td>
<td>C_FCN</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A.7.5 Symbol Values

Bytes 8–11 of a symbol table entry indicate a symbol’s value. A symbol’s value depends on the symbol’s storage class; Table A–14 summarizes the storage classes and related values.

Table A–14. Symbol Values and Storage Classes

<table>
<thead>
<tr>
<th>Storage Class</th>
<th>Value Description</th>
<th>Storage Class</th>
<th>Value Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_AUTO</td>
<td>Stack offset in bits</td>
<td>C_UNTAG</td>
<td>0</td>
</tr>
<tr>
<td>C_EXT</td>
<td>Relocatable address</td>
<td>C_TPDEF</td>
<td>0</td>
</tr>
<tr>
<td>C_STAT</td>
<td>Relocatable address</td>
<td>C_ENTAG</td>
<td>0</td>
</tr>
<tr>
<td>C_REG</td>
<td>Register number</td>
<td>C_MOE</td>
<td>Enumeration value</td>
</tr>
<tr>
<td>C_LABEL</td>
<td>Relocatable address</td>
<td>C_REGPARM</td>
<td>Register number</td>
</tr>
<tr>
<td>C_MOS</td>
<td>Offset in bits</td>
<td>C_FIELD</td>
<td>Bit displacement</td>
</tr>
<tr>
<td>C_ARG</td>
<td>Stack offset in bits</td>
<td>C_BLOCK</td>
<td>Relocatable address</td>
</tr>
<tr>
<td>C_STRTAG</td>
<td>0</td>
<td>C_FCN</td>
<td>Relocatable address</td>
</tr>
<tr>
<td>C_MOU</td>
<td>Offset in bits</td>
<td>C_FILE</td>
<td>0</td>
</tr>
</tbody>
</table>

If a symbol’s storage class is C_FILE, the symbol’s value is a pointer to the next .file symbol. Thus, the .file symbols form a one-way linked list in the symbol table. When there are no more .file symbols, the final .file symbol points back to the first .file symbol in the symbol table.

The value of a relocatable symbol is its virtual address. When the linker relocates a section, the value of a relocatable symbol changes accordingly.
A.7.6 Section Number

Bytes 12–13 of a symbol table entry contain a number that indicates which section the symbol was defined in. Table A–15 lists these numbers and the sections they indicate.

Table A–15. Section Numbers

<table>
<thead>
<tr>
<th>Mnemonic</th>
<th>Section Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>N_DEBUG</td>
<td>–2</td>
<td>Special symbolic debugging symbol</td>
</tr>
<tr>
<td>N_ABS</td>
<td>–1</td>
<td>Absolute symbol</td>
</tr>
<tr>
<td>N_UNDEF</td>
<td>0</td>
<td>Undefined external symbol</td>
</tr>
<tr>
<td>N_SCNUM</td>
<td>1</td>
<td>.text section (typical)</td>
</tr>
<tr>
<td>N_SCNUM</td>
<td>2</td>
<td>.data section (typical)</td>
</tr>
<tr>
<td>N_SCNUM</td>
<td>3</td>
<td>.bss section (typical)</td>
</tr>
<tr>
<td>N_SCNUM</td>
<td>4–32,767</td>
<td>Section number of a named section, in the order in which the named sections are encountered</td>
</tr>
</tbody>
</table>

If there were no .text, .data, or .bss sections, the numbering of named sections would begin with 1.

If a symbol has a section number of 0, –1, or –2, it is not defined in a section. A section number of –2 indicates a symbolic debugging symbol, which includes structure, union, and enumeration tag names; type definitions; and the filename. A section number of –1 indicates that the symbol has a value but is not relocatable. A section number of 0 indicates a relocatable external symbol that is not defined in the current file.

A.7.7 Type Entry

Bytes 14–15 of the symbol table entry define the symbol’s type. Each symbol has one basic type and one to six derived types.

Following is the format for this 16-bit type entry:

<table>
<thead>
<tr>
<th>Derived Type 6</th>
<th>Derived Type 5</th>
<th>Derived Type 4</th>
<th>Derived Type 3</th>
<th>Derived Type 2</th>
<th>Derived Type 1</th>
<th>Basic Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

Size (in bits):

Bits 0–3 of the type field indicate the basic type. Table A–16 lists valid basic types.
### Table A–16. Basic Types

<table>
<thead>
<tr>
<th>Mnemonic</th>
<th>Value</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>T_NULL</td>
<td>0</td>
<td>Type not assigned</td>
</tr>
<tr>
<td>T_CHAR</td>
<td>2</td>
<td>Character</td>
</tr>
<tr>
<td>T_SHORT</td>
<td>3</td>
<td>Short integer</td>
</tr>
<tr>
<td>T_INT</td>
<td>4</td>
<td>Integer</td>
</tr>
<tr>
<td>T_LONG</td>
<td>5</td>
<td>Long integer</td>
</tr>
<tr>
<td>T_FLOAT</td>
<td>6</td>
<td>Floating point</td>
</tr>
<tr>
<td>T_DOUBLE</td>
<td>7</td>
<td>Double word</td>
</tr>
<tr>
<td>T_STRUCT</td>
<td>8</td>
<td>Structure</td>
</tr>
<tr>
<td>T_UNION</td>
<td>9</td>
<td>Union</td>
</tr>
<tr>
<td>T_ENUM</td>
<td>10</td>
<td>Enumeration</td>
</tr>
<tr>
<td>T_MOE</td>
<td>11</td>
<td>Member of an enumeration</td>
</tr>
<tr>
<td>T_UCHAR</td>
<td>12</td>
<td>Unsigned character</td>
</tr>
<tr>
<td>T_USHORT</td>
<td>13</td>
<td>Unsigned short integer</td>
</tr>
</tbody>
</table>

Bits 4–15 of the type field are arranged as six 2-bit fields that can indicate one to six derived types. Table A–17 lists the possible derived types.

### Table A–17. Derived Types

<table>
<thead>
<tr>
<th>Mnemonic</th>
<th>Value</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>DT_NON</td>
<td>0</td>
<td>No derived type</td>
</tr>
<tr>
<td>DT_PTR</td>
<td>1</td>
<td>Pointer</td>
</tr>
<tr>
<td>DT_FCN</td>
<td>2</td>
<td>Function</td>
</tr>
<tr>
<td>DT_ARY</td>
<td>3</td>
<td>Array</td>
</tr>
</tbody>
</table>

An example of a symbol with several derived types would be a symbol with a type entry of 0000000011010011₂. This entry indicates that the symbol is an array of pointers to short integers.
A.7.8 Auxiliary Entries

Each symbol table entry may have one or no auxiliary entry. An auxiliary symbol table entry contains the same number of bytes as a symbol table entry (18), but the format of an auxiliary entry depends on the symbol's type and storage class. Table A–18 summarizes these relationships.

Table A–18. Auxiliary Symbol Table Entries Format

<table>
<thead>
<tr>
<th>Name</th>
<th>Storage Class</th>
<th>Derived Type</th>
<th>Basic Type</th>
<th>Auxiliary Entry Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>.file</td>
<td>C_FILE</td>
<td>DT_NON</td>
<td>T_NULL</td>
<td>Filename (see Table A–19)</td>
</tr>
<tr>
<td>.text, .data, .bss</td>
<td>C_STAT</td>
<td>DT_NON</td>
<td>T_NULL</td>
<td>Section (see Table A–20)</td>
</tr>
<tr>
<td>tagname</td>
<td>C_STRTAG</td>
<td>DT_NON</td>
<td>T_NULL</td>
<td>Tag name (see Table A–21)</td>
</tr>
<tr>
<td></td>
<td>C_UNTAG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C_ENTAG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.eos</td>
<td>C_EOS</td>
<td>DT_NON</td>
<td>T_NULL</td>
<td>End of structure (see Table A–22)</td>
</tr>
<tr>
<td>fcname</td>
<td>C_EXT</td>
<td>DT_FCN</td>
<td>(See note 1)</td>
<td>Function (see Table A–23)</td>
</tr>
<tr>
<td></td>
<td>C_STAT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>arrname</td>
<td>(See note 2)</td>
<td>DT_ARY</td>
<td>(See note 1)</td>
<td>Array (see Table A–24)</td>
</tr>
<tr>
<td>.bb, .eb</td>
<td>C_BLOCK</td>
<td>DT_NON</td>
<td>T_VOID</td>
<td>Beginning and end of a block (see Table A–25 and Table A–26)</td>
</tr>
<tr>
<td>.bf, .ef</td>
<td>C_FCN</td>
<td>DT_NON</td>
<td>T_VOID</td>
<td>Beginning and end of a function (see Table A–25 and Table A–26)</td>
</tr>
<tr>
<td>Name related to a structure, union, or enumeration</td>
<td>(See note 2)</td>
<td>DT_PTR</td>
<td>T_STRUCT</td>
<td>Name related to a structure, union, or enumeration (see Table A–27)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DT_ARR</td>
<td>T_UNION</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>DT_NON</td>
<td>T_ENUM</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1) Any type except T_MOE
2) C_AUTO, C_STAT, C_MOS, C_MOU, C_TPDEF

In Table A–18, tagname refers to any symbol name (including the special symbol ntake). Fcname and arrname refer to any symbol name.

A symbol that satisfies more than one condition in Table A–18 should have a union format in its auxiliary entry. A symbol that satisfies none of these conditions should not have an auxiliary entry.
A.7.8.1 Filenames

Each of the auxiliary table entries for a filename contains a 14-character filename in bytes 0–13. Bytes 14–17 are unused.

Table A–19. Filename Format for Auxiliary Table Entries

<table>
<thead>
<tr>
<th>Byte Number</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–13</td>
<td>Character</td>
<td>File name</td>
</tr>
<tr>
<td>14–17</td>
<td>—</td>
<td>Unused</td>
</tr>
</tbody>
</table>

A.7.8.2 Sections

Table A–20 illustrates the format of auxiliary table entries.

Table A–20. Section Format for Auxiliary Table Entries

<table>
<thead>
<tr>
<th>Byte Number</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–3</td>
<td>Long integer</td>
<td>Section length</td>
</tr>
<tr>
<td>4–6</td>
<td>Unsigned short integer</td>
<td>Number of relocation entries</td>
</tr>
<tr>
<td>7–8</td>
<td>Unsigned short integer</td>
<td>Number of line-number entries</td>
</tr>
<tr>
<td>9–17</td>
<td>—</td>
<td>Not used (zero filled)</td>
</tr>
</tbody>
</table>

A.7.8.3 Tag Names

Table A–21 illustrates the format of auxiliary table entries for tag names.

Table A–21. Tag Name Format for Auxiliary Table Entries

<table>
<thead>
<tr>
<th>Byte Number</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–5</td>
<td>—</td>
<td>Unused (zero filled)</td>
</tr>
<tr>
<td>6–7</td>
<td>Unsigned short integer</td>
<td>Size of structure, union, or enumeration</td>
</tr>
<tr>
<td>8–11</td>
<td>—</td>
<td>Unused (zero filled)</td>
</tr>
<tr>
<td>12–15</td>
<td>Long integer</td>
<td>Index of next entry beyond this function</td>
</tr>
<tr>
<td>16–17</td>
<td>—</td>
<td>Unused (zero filled)</td>
</tr>
</tbody>
</table>
A.7.8.4 End of Structure

Table A–22 illustrates the format of auxiliary table entries for ends of structures.

Table A–22. End-of-Structure Format for Auxiliary Table Entries

<table>
<thead>
<tr>
<th>Byte Number</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–3</td>
<td>Long integer</td>
<td>Tag index</td>
</tr>
<tr>
<td>4–5</td>
<td>—</td>
<td>Unused (zero filled)</td>
</tr>
<tr>
<td>6–7</td>
<td>Unsigned short integer</td>
<td>Size of structure, union, or enumeration</td>
</tr>
<tr>
<td>8–17</td>
<td>—</td>
<td>Unused (zero filled)</td>
</tr>
</tbody>
</table>

A.7.8.5 Functions

Table A–23 illustrates the format of auxiliary table entries for functions.

Table A–23. Function Format for Auxiliary Table Entries

<table>
<thead>
<tr>
<th>Byte Number</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–3</td>
<td>Long integer</td>
<td>Tag index</td>
</tr>
<tr>
<td>4–7</td>
<td>Long integer</td>
<td>Size of function (in bits)</td>
</tr>
<tr>
<td>8–11</td>
<td>Long integer</td>
<td>File pointer to line number</td>
</tr>
<tr>
<td>12–15</td>
<td>Long integer</td>
<td>Index of next entry beyond this function</td>
</tr>
<tr>
<td>16–17</td>
<td>—</td>
<td>Unused (zero filled)</td>
</tr>
</tbody>
</table>
A.7.8.6 Arrays

Table A–24 illustrates the format of auxiliary table entries for arrays. Note that multi-dimensional arrays are limited to 4 dimensions. This limitation can be avoided by using DWARF format (compile with the –gw shell option).

Table A–24. Array Format for Auxiliary Table Entries

<table>
<thead>
<tr>
<th>Byte Number</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–3</td>
<td>Long integer</td>
<td>Tag index</td>
</tr>
<tr>
<td>4–5</td>
<td>Unsigned short integer</td>
<td>line-number declaration</td>
</tr>
<tr>
<td>6–7</td>
<td>Unsigned short integer</td>
<td>Size of array</td>
</tr>
<tr>
<td>8–9</td>
<td>Unsigned short integer</td>
<td>First dimension</td>
</tr>
<tr>
<td>10–11</td>
<td>Unsigned short integer</td>
<td>Second dimension</td>
</tr>
<tr>
<td>12–13</td>
<td>Unsigned short integer</td>
<td>Third dimension</td>
</tr>
<tr>
<td>14–15</td>
<td>Unsigned short integer</td>
<td>Fourth dimension</td>
</tr>
<tr>
<td>16–17</td>
<td>—</td>
<td>Unused (zero filled)</td>
</tr>
</tbody>
</table>

A.7.8.7 End of Blocks and Functions

Table A–25 illustrates the format of auxiliary table entries for the ends of blocks and functions.

Table A–25. End-of-Blocks/Functions Format for Auxiliary Table Entries

<table>
<thead>
<tr>
<th>Byte Number</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–3</td>
<td>—</td>
<td>Unused (zero filled)</td>
</tr>
<tr>
<td>4–5</td>
<td>Unsigned short integer</td>
<td>C source line number</td>
</tr>
<tr>
<td>6–17</td>
<td>—</td>
<td>Unused (zero filled)</td>
</tr>
</tbody>
</table>
A.7.8.8 Beginning of Blocks and Functions

Table A–26 illustrates the format of auxiliary table entries for the beginnings of blocks and functions.

Table A–26. Beginning-of-Blocks/Functions Format for Auxiliary Table Entries

<table>
<thead>
<tr>
<th>Byte Number</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–3</td>
<td>—</td>
<td>Unused (zero filled)</td>
</tr>
<tr>
<td>4–5</td>
<td>Unsigned short integer</td>
<td>C source line number</td>
</tr>
<tr>
<td>6–11</td>
<td>—</td>
<td>Unused (zero filled)</td>
</tr>
<tr>
<td>12–15</td>
<td>Long integer</td>
<td>Index of next entry past this block</td>
</tr>
<tr>
<td>16–17</td>
<td>—</td>
<td>Unused (zero filled)</td>
</tr>
</tbody>
</table>

A.7.8.9 Names Related to Structures, Unions, and Enumerations

Table A–27 illustrates the format of auxiliary table entries for the names of structures, unions, and enumerations.

Table A–27. Structure, Union, and Enumeration Names Format for Auxiliary Table Entries

<table>
<thead>
<tr>
<th>Byte Number</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–3</td>
<td>Long integer</td>
<td>Tag index</td>
</tr>
<tr>
<td>4–5</td>
<td>—</td>
<td>Unused (zero filled)</td>
</tr>
<tr>
<td>6–7</td>
<td>Unsigned short integer</td>
<td>Size of the structure, union, or enumeration</td>
</tr>
<tr>
<td>8–17</td>
<td>—</td>
<td>Unused (zero filled)</td>
</tr>
<tr>
<td>16–17</td>
<td>—</td>
<td>Unused (zero filled)</td>
</tr>
</tbody>
</table>
The TMS320C54x™ assembler supports several directives that the TMS320C54x C/C++ compiler uses for symbolic debugging:

- The `sym` directive defines a global variable, a local variable, or a function. Several parameters allow you to associate various debugging information with the symbol or function.

- The `stag`, `etag`, and `utag` directives define structures, enumerations, and unions, respectively. The `member` directive specifies a member of a structure, enumeration, or union. The `eos` directive ends a structure, enumeration, or union definition.

- The `func` and `endfunc` directives specify the beginning and ending lines of a C/C++ function.

- The `block` and `endblock` directives specify the bounds of C/C++ blocks.

- The `file` directive defines a symbol in the symbol table that identifies the current source file name.

- The `line` directive identifies the line number of a C/C++ source statement.

These symbolic debugging directives are not usually listed in the assembly language file that the compiler creates. If you want them to be listed, invoke the compiler shell with the –g option, as shown below:

```
c1500 -g input file
```

This appendix contains an alphabetical directory of the symbolic debugging directives. With the exception of the `file` directive, each directive contains an example of C/C++ source and the resulting assembly language code.
.block/.endblock  Define a Block

Syntax

- .block beginning line number
- .endblock ending line number

Description

The .block and .endblock directives specify the beginning and end of a C/C++ block. The line numbers are optional; they specify the location in the source file where the block is defined.

Block definitions can be nested. The assembler will detect improper block nesting.

Example

Following is an example of C source that defines a block, and the resulting assembly language code.

C source:

```c
{ /* Beginning of a block */
  int a,b;
  a = b;  /* End of a block */
}
```

Resulting assembly language code:

```assembly
.block 8
.sym _a,2,4,1,16
.sym _b,3,4,1,16
.line 9
LD        *SP(3),A               ; cycle 3
STL       A,*SP(2)               ; cycle 4
.endblock 10
```
Supply a File Identifier  .file

Syntax

\texttt{.file "filename"}

Description

The \texttt{.file} directive allows a debugger to map locations in memory back to lines in a C/C++ source file. The \textit{filename} is the name of the file that contains the original C/C++ source program. The first 14 characters of the filename are significant.

You can also use the \texttt{.file} directive in assembly code to provide a name in the file and improve program readability.

Example

In the following example, the filename \texttt{text.c} contained the C source that produced this directive.

\texttt{.file "text.c"}
**.func/.endfunc  Define a Function**

**Syntax**

```
.func beginning line number
.endfunc ending line number
```

**Description**
The `.func` and `.endfunc` directives specify the beginning and end of a C/C++ function. The line numbers are optional; they specify the location in the source file where the function is defined. Function definitions cannot be nested.

**Example**
Following is an example of C source that defines a function, and the resulting assembly language code:

```
C source:

power(x, n) /* Beginning of a function */
int x,n;
{
    int i, p;
    p = 1;
    for (i = 1; i <= n; ++i)
        p = p * x;
    return p; /* End of function */
}
```
Define a Function .func/.endfunc

Resulting assembly language code:

```assembly
.global _power
.sym   _power,_power,36,2,0
.func   3

;***************************************************************
;* FUNCTION DEF: _power                                    *
;***************************************************************
000000 _power:
000000 eefd FRAME #–3
000001 f495 nop

;* A assigned to _x
.sym    _x,0,4,17,16
.sym    _n,4,4,9,16
.sym    _x,0,4,1,16
.sym    _i,1,4,1,16
.sym    _p,2,4,1,16
.line   3
000002 8000 STL   A,*SP(0)
.line   5
000003 7602 ST   #1,*SP(2)
000004 0001
000005 7601 ST #1,*SP(1)
000006 0001
000007 f7b8 SSBX SXM
000008 f495 nop
000009 1004 LD *SP(4),A
00000a 0801 SUB *SP(1),A
00000b f843 BC L3,ALT
00000c 0018' branch occurs
00000d 1002 LD *SP(2),A
00000e 3102 MPYA *SP(2)
00000f 8102 STL B,*SP(2)
.line   6
000010 6b01 ADDM #1,*SP(1)
000011 0001
000012 f7b8 SSBX SXM
000013 f495 nop
000014 1004 LD *SP(4),A
000015 0801 SUB *SP(1),A
000016 f842 BC L2,AGEQ
000017 000d' branch occurs
000018 L3:
.line   8
000019 1002 LD *SP(2),A
.line   9
00001a ee03 FRAME #3
00001b fc00 RET

; return occurs
.endfunc  9,000000000h, 3
```

Symbolic Debugging Directives B-5
.line  
Create a Line Number Entry

Syntax

.line line number [, address]

Description

The .line directive creates a line number entry in the object file. Line number entries are used in symbolic debugging to associate addresses in the object code with the lines in the source code that generated them.

The .line directive has two operands:

- The line number indicates the line of the C/C++ source that generated a portion of code. Line numbers are relative to the beginning of the current function. This is a required parameter.

- The address is an expression that is the address associated with the line number. This is an optional parameter; if you don’t specify an address, the assembler will use the current SPC value.

Example

The .line directive is followed by the assembly language source statements that are generated by the indicated line of C source. For example, assume that the lines of C source below are line 4 and 5 in the original C source; line 5 produces the assembly language source statements that are shown below.

C source:

```
for (i = 1; i <= n; ++i)
    p = p * x;
```

Resulting assembly language code:

```
31 .line 7
32 00000d 4400 LD *SP(0),16,A ; cycle 1
33 00000e 3102 MPYA *SP(2) ; cycle 2
34 00000f 8102 STL B,*SP(2) ; cycle 3
35 .line 6
36 000010 6b01 ADDM #1,*SP(1) ; cycle 4
000011 0001
37 000012 f7b8 SSBX SXM ; cycle 6
38 000013 f495 nop
39 000014 1004 LD *SP(4),A ; cycle 8
40 000015 0801 SUB *SP(1),A ; cycle 9
41 000016 f842 BC L2,AGEQ ; cycle 10
000017 000d'
42 ; branch occurs ; cycle 15
43 000018 L3:
44 .line 8
45 000018 1002 LD *SP(2),A
46 .line 9
47 000019 ee03 FRAME #3 ; cycle 1
48 00001a fc00 RET ; cycle 2
49 ; branch occurs ; cycle 7
50 .endfunc 9,000000000h,3
```
Define a Member

Syntax

```
.member name, value [, type, storage class, size, tag, dims]
```

Description

The `.member` directive defines a member of a structure, union, or enumeration. It is valid only when it appears in a structure, union, or enumeration definition.

- **Name** is the name of the member that is put in the symbol table. The first 32 characters of the name are significant.
- **Value** is the value associated with the member. Any legal expression (absolute or relocatable) is acceptable.
- **Type** is the C/C++ type of the member. Appendix A, *Common Object File Format*, contains more information about C/C++ types.
- **Storage class** is the C/C++ storage class of the member. Appendix A, *Common Object File Format*, contains more information about C/C++ storage classes.
- **Size** is the number of bits of memory required to contain this member.
- **Tag** is the name of the type (if any) or structure of which this member is a type. This name must have been previously declared by a `.stag`, `.etag`, or `.utag` directive.
- **Dims** may be one to four expressions separated by commas. This allows up to four dimensions to be specified for the member.

The order of parameters is significant. The name and value are required parameters. All other parameters may be omitted or empty. (Adjacent commas indicate an empty entry.) This allows you to skip a parameter and specify a parameter that occurs later in the list. Operands that are omitted or empty assume a null value.

Example

Following is an example of a C structure definition and the corresponding assembly language statements:

**C source:**

```c
struct doc {
    char title;
    char group;
    int job_number;
} doc_info;
```

**Resulting assembly language code:**

```assembly
.stag _doc,48
.member _title,0,2,8,16
.member _group,16,2,8,16
.member _job_number,32,4,8,16
.eos
```
.stag/.etag/.utag/.eos  Define a Structure

Syntax

```
stag name [, size]
member definitions
eos
etag name [, size]
member definitions
eos
utag name [, size]
member definitions
eos
```

Description

The .stag directive begins a structure definition. The .etag directive begins an enumeration definition. The .utag directive begins a union definition. The .eos directive ends a structure, enumeration, or union definition.

- **Name** is the name of the structure, enumeration, or union. The first 32 characters of the name are significant. This is a required parameter.

- **Size** is the number of bits the structure, enumeration, or union occupies in memory. This is an optional parameter; if omitted, the size is unspecified.

The .stag, .etag, or .utag directive should be followed by a number of .member directives, which define members in the structure. The .member directive is the only directive that can appear inside a structure, enumeration, or union definition.

The assembler does not allow nested structures, enumerations, or unions. The C/C++ compiler unwinds nested structures by defining them separately and then referencing them from the structure they are referenced in.

Example 1

Following is an example of a structure definition.

**C source:**

```c
struct doc
{
    char title;
    char group;
    int job_number;
} doc_info;
```

**Resulting assembly language code:**

```
stag   _doc, 48
member _title, 0, 2, 8, 16
member _group, 16, 2, 8, 16
member _job_number, 32, 4, 8, 16
eos
```
Example 2

Following is an example of a union definition.

**C source:**

```c
union u_tag {
    int    val1;
    float  val2;
    char   valc;
} valu;
```

**Resulting assembly language code:**

```assembly
.utag     _u_tag,32
.member   _val1,0,4,11,16
.member   _val2,0,6,11,32
.member   _valc,0,2,11,16
.eos
```

Example 3

Following is an example of an enumeration definition.

**C Source:**

```c
{    enum o_ty { reg_1, reg_2, result } otypes;
}
```

**Resulting assembly language code:**

```assembly
.etag     _o_ty,16
.member   _reg_1,0,4,16,16
.member   _reg_2,1,4,16,16
.member   _result,2,4,16,16
.eos
```
Define a Symbol

Syntax

\texttt{.sym \textit{name}, \textit{value} [\textit{, type, storage class, size, tag, dims}]}

Description

The .sym directive specifies symbolic debug information about a global variable, local variable, or a function.

- \textit{Name} is the name of the variable that is put in the object symbol table. The first 32 characters of the name are significant.

- \textit{Value} is the value associated with the variable. Any legal expression (absolute or relocatable) is acceptable.

- \textit{Type} is the C/C++ type of the variable. Appendix A, Common Object File Format, contains more information about C/C++ types.

- \textit{Storage class} is the C/C++ storage class of the variable. Appendix A, Common Object File Format, contains more information about C/C++ storage classes.

- \textit{Size} is the number of bits of memory required to contain this variable.

- \textit{Tag} is the name of the type (if any) or structure of which this variable is a type. This name must have been previously declared by a .stag, .etag, or .utag directive.

- \textit{Dims} may be up to four expressions separated by commas. This allows up to four dimensions to be specified for the variable.

The order of parameters is significant. The \textit{name} and \textit{value} are required parameters. All other parameters may be omitted or empty (adjacent commas indicate an empty entry). This allows you to skip a parameter and specify a parameter that occurs later in the list. Operands that are omitted or empty assume a null value.

Example

These lines of C source produce the .sym directives shown below:

\begin{verbatim}
C source:
struct s { int member1, member2; } str;
int ext;
int array[5][10];
long *ptr;
int strcmp();
main(arg1,arg2)
   int arg1;
   char *arg2;
   { register r1;
   }
\end{verbatim}
Define a Symbol .sym

Resulting assembly language code:

```
.global _array
.bss _array,50,0,0
.sym _array,_array,244,2,800,,5,10
.global _ptr
.bss _ptr,1,0,0
.sym _ptr,_ptr,21,2,16
.global _str
.bss _str,2,0,0
.sym _str,_str,8,2,32,_s
.global _ext
.bss _ext,1,0,0
.sym _ext,_ext,4,2,16
```
The flexible hex conversion utility offers many options and capabilities. Once you understand the proper ways to configure the EPROM system and the requirements of the EPROM programmer, you will find that converting a file for a specific application is easy.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.1 Base Code for the Examples</td>
<td>C-2</td>
</tr>
<tr>
<td>C.2 Example 1: Building a Hex Command File for Two 8-Bit EPROMs</td>
<td>C-3</td>
</tr>
<tr>
<td>C.3 Example 2: Avoiding Holes With Multiple Sections</td>
<td>C-8</td>
</tr>
<tr>
<td>C.4 Example 3: Generating a Boot Table</td>
<td>C-10</td>
</tr>
<tr>
<td>C.5 Example 4: Generating a Boot Table for LP Core Devices</td>
<td>C-17</td>
</tr>
</tbody>
</table>
C.1 Base Code for the Examples

The three major examples in this appendix show how to develop a hex command file for multiple EPROM memory systems, avoid holes, and generate a boot table. The first two examples use the assembly code shown in Example C–1.

Example C–1. Assembly Code for Hex Conversion Utility Examples

```
* Assemble two words into section, "sec1"    *
* ********************************************
.sect "sec1"
.word 1234h
.word 5678h

* Assemble two words into section, "sec2"    *
* ********************************************
.sect "sec2"
.word 0aabdh
.word 0ccddh
.end
```
C.2 Example 1: Building A Hex Command File for Two 8-Bit EPROMs

Example 1 shows how to build the hex command file you need for converting a COFF object file for the memory system shown in Figure C–1. In this system, there are two external 64K × 8-bit EPROMs interfacing with a C54x target processor. Each of the EPROMs contributes 8 bits of a 16-bit word for the target processor.

Figure C–1. A Two 8-Bit EPROM System

By default, the hex conversion utility uses the linker load address as the base for generating addresses in the converted output file. However, for this application, the code will reside at physical EPROM address 0x0010, rather than the address specified by the linker (0x1400). The circuitry of the target board handles the translation of this address space. The paddr parameter allocates a section and burns the code at EPROM address 0x0010.

The paddr parameter is specified within the SECTIONS directive (see Section 10.6, The SECTIONS Directive, on page 10-22 for details). If you use the paddr parameter to specify a load address for one section included in the conversion, then you must specify a paddr for each section included in the conversion. When setting the paddr parameter, you must ensure that the specified addresses do not overlap the linker-assigned load addresses of sections that follow.

In Example 1, two sections are defined: sec1 and sec2. You can easily add a paddr parameter for each of these sections from within the SECTIONS directive. However, the task may become unmanageable for large applications with many sections, or in cases where section sizes may change often during code development.
To work around this problem, you can combine the sections at link stage, creating a single section for conversion. To do this, use the linker command shown in Example C–2.

Example C–2. A Linker Command File for Two 8-Bit EPROMs

```
  test.obj
  -o test.out
  -m test.map

  MEMORY
  {
    PAGE 0 : EXT_PRG : org = 0x1400 , len = 0xEB80
  }

  SECTIONS
  {
    outsec: { *(sec1)
             *(sec2) } > EXT_PRG PAGE 0
  }
```

The EPROM programmer in this example has the following system requirements:

- EPROM system memory width must be 16 bits.
- ROM1 contains the upper 8 bits of a word.
- ROM0 contains the lower 8 bits of a word.
- The hex conversion utility must locate code starting at EPROM address 0x0010.
- Intel format must be used.
- Byte increment must be selected for addresses in the hex conversion utility output file (memory width is the default).

Use the following options to set up the requirements of the system:

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>–i</td>
<td>Create Intel format</td>
</tr>
<tr>
<td>–byte</td>
<td>Select byte increment for addresses in converted output file</td>
</tr>
<tr>
<td>–memwidth 16</td>
<td>Set EPROM system memory width to 16</td>
</tr>
<tr>
<td>–romwidth 8</td>
<td>Set physical ROM width to 8</td>
</tr>
</tbody>
</table>
Example 1: Building a Command File for Two 8-Bit EPROMS

With the memory width and ROM width values above, the utility will automatically generate two output files. The ratio of memory width to ROM width determines the number of output files. The ROM0 file contains the lower 8 of the 16 bits of raw data, and the ROM1 file contains the upper 8 bits of the corresponding data.

Example C–3 shows the hex command file with all of the selected options.

Example C–3. A Hex Command File for Two 8-Bit EPROMs

```
test.out        /* COFF object input file               */
-map example1.mxp
/*-----------------------------------------------*/
/* Set parameters for EPROM programmer            */
/*-----------------------------------------------*/
-i              /* Select Intel format                  */
-byte           /* Select byte increment for addresses   */
/*-----------------------------------------------*/
/* Set options required to describe EPROM memory system */
/*-----------------------------------------------*/
-memwidth 16    /* Set EPROM system memory width        */
-romwidth  8    /* Set physical width of ROM device      */
ROMS
{ PAGE 0 : EPROM : origin = 0x00, length = 0x10000, 
  files = {low8.bit, upp8.bit} 
}
SECTIONS 
{ outsec: paddr = 0x10 }
```

Figure C–2 (a) shows the contents of the converted file for ROM0 (low8.bit) containing the lower 8 bits. Figure C–2 (b) shows the contents of the converted file for ROM1 (upp8.bit) containing the upper 8 bits of data.
Example 1: Building a Command File for Two 8-Bit EPROMS

Figure C–2. Data From Output File

(a) low8.bit (Lower Bits)

Data from converted output file
:040010003478BBDDA8
:00000001FF

Corresponding map in EPROM — ROM0 (See Example C–1 on page C-2)

(b) upp8.bit (Upper Bits)

Data from converted output file
:040010001256AACC0E
:00000001FF

Corresponding map in EPROM — ROM1 (See Example C–1 on page C-2)
To illustrate precisely how the utility performs the conversion, specify the –map option. Although not required, the –map option generates useful information about the output. The resulting map is shown in Example C–4.


```
******************************************************
TMS320C54x COFF/Hex Converter                      Version x.xx
******************************************************
Fri Oct 11 15:10:53 2001

INPUT FILE NAME: <test.out>
OUTPUT FORMAT:   Intel

PHYSICAL MEMORY PARAMETERS
    Default data width:    16
    Default memory width: 16
    Default output width:  8

OUTPUT TRANSLATION MAP
----------------------------------------
00000000..0000ffff  Page=0 Memory Width=16 ROM Width=8 "EPROM"

----------------------------------------
OUTPUT FILES: low8.bit [b0..b7]
              upp8.bit [b8..b15]

CONTENTS: 00000010..00000017  outsec Data Width=2
```
C.3 Example 2: Avoiding Holes With Multiple Sections

When the memory width is less than the data width, holes may appear at the beginning of a section or between sections. This is due to multiplication of the load address by a correction factor. See Section 10.10, *Controlling the ROM Device Address*, on page 10-35 for more information.

You must eliminate the holes between converted sections. The sections can be made contiguous in one of two ways:

- Specify a paddr value for each section listed in a SECTIONS directive. This forces the hex conversion utility to use that specific address for the output file address field. You must ensure that the section addresses do not overlap. Example C–5 (a) shows a linker command file for this method. The linker should be executed with this command file; then, the hex conversion utility should be executed with the set of commands shown in Example C–5 (b).

- Link the sections together into one output section for conversion. Example C–6 (a) shows a linker command file for this method. The linker should be executed with this command file; then, the hex conversion utility should be executed with the set of commands shown in Example C–6 (b).

Example C–5. Method One for Avoiding Holes

(a) Linker command file

```plaintext
/* SPECIFY THE SYSTEM MEMORY MAP */

MEMORY
{
    PAGE 0: DARAM: org = 0x0080 , length = 0x1370
            EXT: org = 0x1400 , length = 0xEB80
}

/* SPECIFY THE SECTIONS ALLOCATION INTO MEMORY */

SECTIONS
{
    sec1 : load = EXT PAGE 0
    sec2 : load = EXT PAGE 0
}
```
Example 2: Avoiding Holes With Multiple Sections

(b) Hex command file

```
-i test.out
-map example.mxp
ROMS
{ PAGE 0: ROM: org = 0x0000, length = 0x800, romwidth = 8, memwidth = 8 }
SECTIONS
{ sec1: paddr = 0x0000
  sec2: paddr = 0x0004
}
```

Example C–6. Method Two for Avoiding Holes

(a) Linker command file

```
/* SPECIFY THE SYSTEM MEMORY MAP */
MEMORY
{ PAGE 0: DARAM: org = 0x0080 , length = 0x1370
  EXT: org = 0x1400 , length = 0xEB80 }
SECTIONS
{ outsec: { *(sec1)
  *(sec2) } > EXT PAGE 0 }
```

(b) Hex command file

```
-i test.out
-map example.mxp
ROMS
{ PAGE 0: ROM : org = 0x0100, length = 0x0800, romwidth = 8, memwidth = 8,
  files = {examp2_2.hex}
}
SECTIONS
{ outsec: paddr = 0x100
}
```
C.4 Example 3: Generating a Boot Table

Example 3 shows how to use the linker and the hex conversion utility to build a boot load table for the C54x devices. The code used in this section is shown in Example C–7.

Note:
This example is for non-LP ‘C54x devices only.
For ‘C54xLP devices, see Section C.5, Example 4: Generating a Boot Table for LP Core Devices, on page C-17.

Example C–7. C Code for Example 3

```c
int array[]={1,2,3,4};
main()
{
    array[0] = 5;
}
```

Figure C–3 shows the EPROM memory system for which the output file will be generated. In this application, the single C54x device is booted from a 128K × 8-bit EPROM. The requirement of the system is that the boot table must reside at EPROM memory address 0.

Figure C–3. EPROM System for a C54x
The on-chip boot loader loads only a single block. This may present a problem when you are loading C code compiled with the TMS320C54x C compiler. The TMS320C54x C compiler creates several sections or blocks when it compiles C source code. Some applications may require that all sections associated with the program be included in the boot to have a complete executable program. In this case, the individual sections must be combined into a single section for boot.

The hex conversion utility does not combine individual sections; therefore, you must use the linker to group those sections.

The sections that the compiler creates are divided into two categories: initialized sections (sections that contain data or code) and uninitialized sections (sections that reserve space but contain no actual data). Initialized sections created by the TMS320C54x C compiler include .text, .cinit, .const, and .data. Uninitialized sections are ignored by the hex conversion utility and are not converted.

Most applications require that .text and .cinit sections are included in the boot. This allows code and information for the C boot routine (c_int00 defined in boot.asm) to load and run, initializing the C environment and branching to the main function in the applications code.

The .text and .cinit sections must be linked together as a single section in the linker command file. The .cinit section contains the initialization data and tables for all global or static C symbols that were declared with an initial value (i.e. int x = 5; ). Note that the linker handles the .cinit section differently than the other sections.

When the linker encounters a .cinit section specified as an output section in the link, it automatically:

- Sets the symbol cinit to point to the start of the included .cinit section
- Appends a single word to the end of the section

This last word contains a zero that is used to mark the end of the initialization table. However, if .cinit is included as an input section only, the linker sets cinit to −1, indicating that no initialization tables were loaded. Therefore, the C boot routine, c_int00, does not attempt to initialize any of the global or static C symbols.

When linking the .cinit section into an output section other than .cinit, the linker does not perform the automatic functions listed above. Therefore, these functions must be implemented explicitly within the linker command file. The following example shows a linker command file that places .text and .cinit into a single output section named boot_sec.
Example C–8. Linker Command File to Form a Single Boot Section

```
-c
-1 rts.lib
-m boot1.map
-o boot.out

MEMORY
{
    PAGE 0 : PROG     : origin = 001400h, length = 01000h
    PAGE 1 : DATA     : origin = 0080h,   length = 01000h
}

SECTIONS
{
    boot_sec: { *(.text)
        /*–––––––––––––––––––––––––––––––––––––*/
        /* Set start address for C init table */
        /*–––––––––––––––––––––––––––––––––––––*/
        cinit = .;
        /*–––––––––––––––––––––––––––––––––––––*/
        /* Include all cinit sections */
        /*–––––––––––––––––––––––––––––––––––––*/
        *(.cinit)
        /*–––––––––––––––––––––––––––––––––––––*/
        /* Reserve a single space for the zero */
        /* word to mark end of C init */
        /*–––––––––––––––––––––––––––––––––––––*/
        .+=1;
    }

    fill = 0x0000, /* Make sure fill value is 0 */
    load = PROG PAGE 0

    .data   : {} > DATA PAGE 1
    .bss    : {} > DATA PAGE 1
    .const   : {} > DATA PAGE 1
    .sysmem : {} > DATA PAGE 1
    .stack  : {} > DATA PAGE 1
}
```

Example C–9 shows a portion of the map file generated when the linker is executed with this command file.
### Example C–9. Section Allocation Portion of Map File Resulting From the Command File

**SECTION ALLOCATION MAP**

<table>
<thead>
<tr>
<th>section</th>
<th>page</th>
<th>origin</th>
<th>length</th>
<th>attributes/ input sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>boot_sec 0</td>
<td>00001400</td>
<td>00000006e</td>
<td></td>
<td>boot.obj (.text)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>00001404</td>
<td>0000002b</td>
<td>rts.lib : boot.obj (.text)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0000142f</td>
<td>00000035</td>
<td>: exit.obj (.text)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>00001464</td>
<td>00000006</td>
<td>boot.obj (.cinit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0000146a</td>
<td>00000003</td>
<td>rts.lib : exit.obj (.cinit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0000146d</td>
<td>00000001</td>
<td>--HOLE-- [fill = 0000]</td>
</tr>
<tr>
<td>.data 1</td>
<td>00000080</td>
<td>00000000</td>
<td>UNINITIALIZED</td>
<td>boot.obj (.data)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>00000080</td>
<td>00000000</td>
<td>rts.lib : exit.obj (.data)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>00000080</td>
<td>00000000</td>
<td>: boot.obj (.data)</td>
</tr>
<tr>
<td>.bss 1</td>
<td>00000080</td>
<td>00000025</td>
<td>UNINITIALIZED</td>
<td>boot.obj (.bss)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>00000080</td>
<td>00000004</td>
<td>rts.lib : boot.obj (.bss)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>00000084</td>
<td>00000001</td>
<td>: exit.obj (.bss)</td>
</tr>
<tr>
<td>.const 1</td>
<td>00000080</td>
<td>00000000</td>
<td>UNINITIALIZED</td>
<td>boot.obj (.const)</td>
</tr>
<tr>
<td>.sysmem 1</td>
<td>00000080</td>
<td>00000000</td>
<td>UNINITIALIZED</td>
<td>boot.obj (.sysmem)</td>
</tr>
<tr>
<td>.stack 1</td>
<td>0000000a5</td>
<td>00000040</td>
<td>UNINITIALIZED</td>
<td>rts.lib : boot.obj (.stack)</td>
</tr>
</tbody>
</table>

**GLOBAL SYMBOLS**

<table>
<thead>
<tr>
<th>address</th>
<th>name</th>
<th>address</th>
<th>name</th>
</tr>
</thead>
<tbody>
<tr>
<td>00000080</td>
<td>.bss</td>
<td>00000080</td>
<td>edata</td>
</tr>
<tr>
<td>00000080</td>
<td>.data</td>
<td>00000080</td>
<td>.data</td>
</tr>
<tr>
<td>00000400</td>
<td>__STACK_SIZE</td>
<td>00000080</td>
<td>__array</td>
</tr>
<tr>
<td>0000145e</td>
<td>__abort</td>
<td>00000080</td>
<td>.bss</td>
</tr>
<tr>
<td>00000080</td>
<td>__array</td>
<td>000000a5</td>
<td>end</td>
</tr>
<tr>
<td>00001448</td>
<td>__atexit</td>
<td>00000040</td>
<td>__STACK_SIZE</td>
</tr>
<tr>
<td>00001404</td>
<td>__c_int00</td>
<td>00001400</td>
<td>_main</td>
</tr>
<tr>
<td>0000142f</td>
<td>_exit</td>
<td>00001404</td>
<td>__c_int00</td>
</tr>
<tr>
<td>00001400</td>
<td>_main</td>
<td>0000142f</td>
<td>_exit</td>
</tr>
<tr>
<td>00001464</td>
<td>cinit</td>
<td>00001448</td>
<td>__atexit</td>
</tr>
<tr>
<td>00000080</td>
<td>edata</td>
<td>0000145e</td>
<td>__abort</td>
</tr>
<tr>
<td>000000a5</td>
<td>end</td>
<td>00001464</td>
<td>cinit</td>
</tr>
</tbody>
</table>

[12 symbols]
Notice that the linker placed a hole at the end of the section boot_sec with a fill value of 0, as specified in the command file. Also, the global symbol cinit coincides with the start of the first .cinit section included in the link. When the linker is executed with the command file in Example C–8 on page C-12, the linker issues warnings that the output file contains no .text section and that the global symbol cinit is being redefined. These warnings may be ignored in this instance.

Executing the linker with the command file in Example C–8 on page C-12 yields a COFF file that can be used as input to the hex conversion utility to build the desired boot table.

The hex conversion utility has options that describe the requirements for the EPROM programmer and options that describe the EPROM memory system. For Example 3, assume that the EPROM programmer has only one requirement: that the hex file be in Intel format.

In the EPROM memory system illustrated in Figure C–3 on page C-10, the EPROM system memory width is 8 bits, and the physical ROM width is 8 bits. You must set the following options in the hex command file to reflect the requirements of the system:

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>–i</td>
<td>Create Intel format.</td>
</tr>
<tr>
<td>–memwidth 8</td>
<td>Set EPROM system memory width to 8.</td>
</tr>
<tr>
<td>–romwidth 8</td>
<td>Set physical ROM width to 8.</td>
</tr>
</tbody>
</table>

Because the application requires the building of a boot table for parallel boot mode, you must set the following options in the hex command file to reflect the requirements of the system:

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>–boot</td>
<td>Create a boot load table.</td>
</tr>
<tr>
<td>–bootorg 0x0000</td>
<td>Place boot table at address 0x0000.</td>
</tr>
</tbody>
</table>
Example C–10. Hex Command File for Converting a COFF File

```plaintext
boot.out /* Input COFF file */
-i /* Select Intel format */
-map boot2.map
-o boot.hex /* Name the hex output file */
-memwidth 8 /* Set EPROM system memory width */
-romwidth 8 /* Set physical ROM width */
-boot /* Make all sections bootable */
-bootorg 0x0000 /* Place boot table in EPROM */
/* starting at address 0x0000 */

ROMS
{
  PAGE 0 : ROM : origin = 0x0000, length = 0x20000
}
```

In Example 3, memory width and ROM width are the same; therefore, the hex conversion utility creates a single output file. The number of output files is determined by the ratio of memwidth to romwidth.

Example C–11 shows the map file boot2.map, resulting from executing the command file in Example C–10, which includes the –map option.
Example C–11. Map File Resulting From the Command File in Example C–10

```
**************************************************
TMS320C54x COFF/Hex Converter           Version x.xx
**************************************************
Fri Oct 11 15:27:46 2001
INPUT FILE NAME: <boot.out>
OUTPUT FORMAT: Intel
PHYSICAL MEMORY PARAMETERS
  Default data width: 16
  Default memory width: 8 (MS-->LS)
  Default output width: 8
BOOT LOADER PARAMETERS
OUTPUT TRANSLATION MAP

00000000..0001ffff  Page=0  Memory Width=8  ROM Width=8  "ROM"

OUTPUT FILES: boot.hex [b0..b7]
 CONTENTS: 00000000..00000138  BOOT TABLE
     boot_sec : dest=00001400  size=00000139 width=00000002
```

The hex conversion utility output file boot.hex, resulting from the command file in Example C–10, is shown in Example C–12.

Example C–12. Hex Conversion Utility Output File Resulting From the Command File in Example C–10

```
:20000001400007976F800800005FC00771800A66BF8001803FF68F80018FFFEF7B8F7BED9
:20002000F4AFB76B5FB6F0F0146DF100001F84D142BF07314257EF80012F00000010C
:200400047F80117E9200F8011F00000017EF80011F00000016C89141AF074140F74CF
:200600014674A117211008410F80011FA451444A16E8F4811F00000868816F495F4927
:200800010EEFFFF4E36C4F0F143E10F80085F845144B10F80085F4E3F495F073144COF
:200A0000F7B811F80084F3100020FA4B145BF495411F273145F495E801721108491198
:200C0008E10086F300001E8081F000848A11FC00EEFEE801F074142FE01FC0000045D
:180E000080090200030004000100840000001008500000073
:0000001FF
```
C.5 Example 4: Generating a Boot Table for LP Core Devices

Example 4 shows how to use the linker and the hex conversion utility to build a boot load table for the 'C54xLP devices. For the 'C54xLP devices, you can specify multiple sections. It is not necessary, therefore, to group sections at link time as with the non-LP devices.

Note:
This example is for 'C54xLP devices only.
For non-LP 'C54x devices, see Section C.4, Example 3: Generating a Boot Table, on page C-10.

Example C–13. C Code for a 'C54xLP

```c
int array[]={1,2,3,4};
main()
{
    array[0] = 5;
}
```

Note that this example is compiled with the –v548 shell option.

Figure C–4 shows the EPROM memory system for which the output file will be generated. In this application, the single 'C54xLP device is booted from a 128K × 8-bit EPROM. The requirements of the system are that the boot table must reside at EPROM memory address 0.

Figure C–4. EPROM System for a 'C54xLP
Example 4: Generating a Boot Table for LP Core Devices

The sections that the compiler creates are divided into two categories: initialized sections (sections that contain data or code) and uninitialized sections (sections that reserve space but contain no actual data). Initialized sections created by the TMS320C54x C compiler include .text, .cinit, .const, and .data. Uninitialized sections are ignored by the hex conversion utility and are not converted.

Most applications require that .text and .cinit sections are included in the boot. This allows code and information for the C boot routine (c_int00 defined in boot.asm) to load and run, initializing the C environment and branching to the main function in the applications code.

The .cinit section contains the initialization data and tables for all global or static C symbols that were declared with an initial value (i.e. int x = 5; ). Note that the linker handles the .cinit section differently than the other sections.

When the linker encounters a .cinit section specified as an output section in the link, it automatically:

- Sets the symbol cinit to point to the start of the included .cinit section
- Appends a single word to the end of the section

This last word contains a zero that is used to mark the end of the initialization table. However, if .cinit is included as an input section only, the linker sets cinit to –1, indicating that no initialization tables were loaded. Therefore, the C boot routine, c_int00, does not attempt to initialize any of the global or static C symbols.

When linking the .cinit section into an output section other than .cinit, the linker does not perform the automatic functions listed above. Therefore, these functions must be implemented explicitly within the linker command file. Example C–14 shows a linker command file for a C54xLP device.
Example 4: Generating a Boot Table for LP Core Devices

Example C–14. Linker Command File for a 'C54xLP

```
-c
c54xlp.obj
-l rts.lib
-m c54xlp.map
-o c54xlp.out
MEMORY
{
   PAGE 0 : PROG     : origin = 001400h, length = 01000h
   PAGE 1 : DATA     : origin = 0080h,   length = 01000h
}
SECTIONS
{
   .text : {} > PROG   PAGE 0
   .cinit : {} > PROG   PAGE 0
   .data : {} > DATA   PAGE 1
   .bss : {} > DATA   PAGE 1
   .const : {} > DATA   PAGE 1
   .sysmem : {} > DATA   PAGE 1
   .stack : {} > DATA   PAGE 1
}
```

Example C–15 shows the map file generated when the linker is executed with the command file in Example C–14. Linking with this command file creates a COFF file you use as input to the hex conversion utility to build the desired boot table.

Example C–15. Section Allocation Portion of Map File Resulting From the Command File in Example C–14

```
OUTPUT FILE NAME:   <c54xlp.out>
ENTRY POINT SYMBOL: ”_c_int00”  address: 00001404

MEMORY CONFIGURATION

<table>
<thead>
<tr>
<th>name</th>
<th>origin</th>
<th>length</th>
<th>used</th>
<th>attributes</th>
<th>fill</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAGE 0: PROG</td>
<td>00001400</td>
<td>000001000</td>
<td>0000007a</td>
<td>RWIX</td>
<td></td>
</tr>
<tr>
<td>PAGE 1: DATA</td>
<td>00000080</td>
<td>000001000</td>
<td>00000426</td>
<td>RWIX</td>
<td></td>
</tr>
</tbody>
</table>
```
Example 4: Generating a Boot Table for LP Core Devices

Example C–15. Section Allocation Portion of Map File Resulting From the Command File in Example C–14 (Continued)

<table>
<thead>
<tr>
<th>SECTION ALLOCATION MAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>output</td>
</tr>
<tr>
<td>section</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>.text</td>
</tr>
<tr>
<td>.cinit</td>
</tr>
<tr>
<td>.data</td>
</tr>
<tr>
<td>.bss</td>
</tr>
<tr>
<td>.const</td>
</tr>
<tr>
<td>.sysmem</td>
</tr>
<tr>
<td>.stack</td>
</tr>
</tbody>
</table>

GLOBAL SYMBOLS

<table>
<thead>
<tr>
<th>address</th>
<th>name</th>
<th>address</th>
<th>name</th>
</tr>
</thead>
<tbody>
<tr>
<td>00000080</td>
<td>.bss</td>
<td>00000001</td>
<td>__lflags</td>
</tr>
<tr>
<td>00000080</td>
<td>.data</td>
<td>00000080</td>
<td>__array</td>
</tr>
<tr>
<td>00001400</td>
<td>.text</td>
<td>00000080</td>
<td>.data</td>
</tr>
<tr>
<td>0000144b</td>
<td>C$$EXIT</td>
<td>00000080</td>
<td>.bss</td>
</tr>
<tr>
<td>00000400</td>
<td>__STACK_SIZE</td>
<td>00000080</td>
<td>edata</td>
</tr>
<tr>
<td>00000085</td>
<td>__cleanup_ptr</td>
<td>00000085</td>
<td>__cleanup_ptr</td>
</tr>
<tr>
<td>00000001</td>
<td>__flags</td>
<td>000000a6</td>
<td>end</td>
</tr>
<tr>
<td>00001467</td>
<td>_abort</td>
<td>00000400</td>
<td>__STACK_SIZE</td>
</tr>
<tr>
<td>00000080</td>
<td>__array</td>
<td>00001400</td>
<td>.text</td>
</tr>
<tr>
<td>0000144e</td>
<td>_atexit</td>
<td>00001400</td>
<td>__main</td>
</tr>
<tr>
<td>00001404</td>
<td>_c_int00</td>
<td>00001404</td>
<td>_c_int00</td>
</tr>
<tr>
<td>0000142f</td>
<td>_exit</td>
<td>0000142f</td>
<td>_exit</td>
</tr>
<tr>
<td>00001400</td>
<td>__main</td>
<td>0000144b</td>
<td>C$$EXIT</td>
</tr>
<tr>
<td>0000146d</td>
<td>cinit</td>
<td>0000144e</td>
<td>_atexit</td>
</tr>
<tr>
<td>00000080</td>
<td>edata</td>
<td>00001467</td>
<td>_abort</td>
</tr>
<tr>
<td>000000a6</td>
<td>end</td>
<td>0000146d</td>
<td>etext</td>
</tr>
<tr>
<td>0000146d</td>
<td>etext</td>
<td>0000146d</td>
<td>cinit</td>
</tr>
<tr>
<td>ffffffff</td>
<td>pinit</td>
<td>ffffffff</td>
<td>pinit</td>
</tr>
</tbody>
</table>

[18 symbols]
The hex conversion utility has options that describe the requirements for the EPROM programmer and options that describe the EPROM memory system. For Example 4, assume that the EPROM programmer has only one requirement: that the hex file be in Intel format.

In the EPROM memory system illustrated in Figure C–4 on page C-17, the EPROM system memory width is 8 bits and the physical ROM width is 8 bits. The following options are selected to reflect the requirements of the system:

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>–i</td>
<td>Create Intel format.</td>
</tr>
<tr>
<td>–memwidth 8</td>
<td>Set EPROM system memory width to 8.</td>
</tr>
<tr>
<td>–romwidth 8</td>
<td>Set physical ROM width to 8.</td>
</tr>
</tbody>
</table>

Because the application requires the building of a boot table for parallel boot mode, the following options must be selected as well:

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>–boot</td>
<td>Create a boot load table.</td>
</tr>
<tr>
<td>–bootorg 0x0000</td>
<td>Place boot table at address 0x0000.</td>
</tr>
</tbody>
</table>

---

*Example 4: Generating a Boot Table for LP Core Devices*
Example 4: Generating a Boot Table for LP Core Devices

Example C–16. Hex Command File for Converting a COFF File

c54xlp.out /* Input COFF file */
-i /* Select Intel format */
-map c54xlp.mxp /* Name hex utility map file */
-o c54xlp.hex /* Name the hex output file */
-memwidth 8 /* Set EPROM system memory width */
-romwidth 8 /* Set physical ROM width */
-boot /* Make all sections bootable */
-bootorg 0x0000 /* Place boot table in EPROM */
/* starting at address 0x0000 */

ROMS
{
  PAGE 0 : ROM : origin = 0x0000, length = 0x20000
}

In Example 4, memory width and ROM width are the same; therefore, the hex conversion utility creates a single output file. The number of output files is determined by the ratio of memwidth to romwidth.

Example C–17 shows the map file c54xlp.mxp, resulting from executing the command file in Example C–16, which includes the –map option.
Example 4: Generating a Boot Table for LP Core Devices

Example C–17. Map File Resulting From the Command File in Example C–16

```
SAT SEP 21 17:01:13 2001

INPUT FILE NAME: <c54xlp.out>
OUTPUT FORMAT:   Intel

PHYSICAL MEMORY PARAMETERS
  Default data width:    16
  Default memory width:  8 (MS-->LS)
  Default output width:  8

BOOT LOADER PARAMETERS
  Table Address: 0000, PAGE 0

OUTPUT TRANSLATION MAP

<table>
<thead>
<tr>
<th>Address Range</th>
<th>Page</th>
<th>Memory Width</th>
<th>ROM Width</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>00000000..0001ffff</td>
<td>0</td>
<td>8</td>
<td>8</td>
<td>ROM</td>
</tr>
</tbody>
</table>

OUTPUT FILES: c54xlp.hex [b0..b7]
- .text : dest=00001400 size=0000006d
  width=00000002
- .cinit : dest=0000146d size=0000000d
  width=00000002
```

The hex conversion utility output file c54xlp.hex, resulting from the command file in Example C–16, is shown in Example C–18.

Example C–18. Hex Conversion Utility Output File Resulting From the Command File in Example C–16

```
:2000000008AA7FF8F007FF008700014007680080005FE00E00F495771800A68A:
:2002006BF8001803FF68F80018FFFEF78F7BF8F6B9F4A0F6B7F6B5F6B6F0201487F10087:
:2004000001F84D1430F273142AF6B8F4957EF80012F000000147F800117E9200F800115A:
:2006000F00000017EFG80011F00000016C89141FF7B8ECEF020F8001000001F84D144B9:
:2008000F273143E4E202F495F5E35027E001100FA4C143C6B030001F6B8EE04F071400F4:
:200A000F07144A4A14A16721100A410F80011FA45146F0495EEFF4811F0000088816F:
:200C000F495F49510EFFFFF4E36CE9FFFFF145A10F800A5F845146710F800A5F4E3F0742D:
:200E000184EE018A168A11FC00F7B8E9204A1109F800A4F84E147F82731482F495E8014B:
:1E010007211100A49118E1008F3000001E80081F800A48A11FC00F495F07148566:
:20011F000000D0001487000400080001000200030004000100A40000000100A5000000040:
:02013E0000000BF:
:00000001FF
```
Appendix D

Assembler Error Messages

When the assembler completes its second pass, it reports any errors that it encountered during the assembly. It also prints these errors in the listing file (if one is created). An error is printed following the source line that incurred it. You should attempt to correct the first error that occurs in your code first. A single error condition can cause a cascade of spurious errors.

If you have received an assembler error message, use this appendix to find possible solutions to the problem you encountered. First, locate the error message class number. Then, locate the error message that you encountered within that class. Each class number has an alphabetical list of error messages that are associated with it. Each class has a Description of the problem and an Action that suggests possible remedies.
Assembler Error Messages

E0000

Attempt to nest repeat block
Comma required to separate arguments
Comma required to separate parameters
Commas must separate directive elements
Illegal combination of shift operands
Illegal identifier after keyword unsigned
Illegal instruction
Illegal keyword
Illegal repeat block open – check delay slot
Illegal repeat block open – missing 'repeat'
Illegal shift for parallel operation
Left parenthesis expected
Left parenthesis is missing
Matching right parenthesis is missing
Missing comma
Missing left parenthesis
Missing opening brace
Missing right parenthesis
Missing right parenthesis for value specification
Missing right quote of string constant
No matching right parenthesis
Open repeat block at EOF
Right parenthesis expected
Syntax Error
Syntax requires parentheses
Unrecognized character type

Description These are errors about general syntax. The required syntax is not present.

Action Correct the source per the error message text.
E0002

Invalid mnemonic specification
Description This error relates to invalid mnemonics. The instruction, macro, or directive specified was not recognized.
Action Check the directive or instruction used.

Invalid instruction for specified processor version
Description The indicated instruction is not allowed for the processor version specified with the .version directive.
Action Check the instruction and .version directive.

E0003

Cluttered character operand encountered
Cluttered identifier operand encountered
Cluttered register operand encountered
Cluttered string constant operand encountered
Conditionals cannot begin in the first column
Condition must be EQ, LT, GT, or NEQ
Condition must be srcEQ, NEQ, LT, LEQ, GT, or GEQ
Expecting ARn for src,dst
Expecting shift or accumulator
Illegal auxiliary register specified
Illegal condition operand
Illegal condition operand or combination
Illegal indirect memaddr specification
Illegal operand
Illegal smem operand
Immediate value out of range
Invalid binary constant specified
Invalid constant specification
Invalid decimal constant specified
Invalid float constant specified
Invalid hex constant specified
Assembler Error Messages

Invalid immediate or shift value
Invalid octal constant specified
Invalid Operand 2
Invalid operand x
Invalid shift value
Must add AR0 to destination
Must subtract AR0 from destination
Only labels and comments may begin in first column
Operand must be the A accumulator
Operand must be the B accumulator
Section is not defined
Shift value must be 16
Syntax error – Operand nnn
The accumulator arguments must be the same
The accumulator arguments must not be the same
The dst accumulator arguments must be the same
The dst,src1 arguments must be the same
The smem operands must be the same
Unexpected parallel instruction delimiters

Description These are errors about invalid operands. The instruction, parameter, or other operand specified was not recognized.

Action Correct the source per the error message text.
E0004

Absolute, well-defined integer value expected
Expecting accumulator A or B
Expecting ASM or shift value
Expecting dual memory addressing
Identifier expected
Identifier operand expected
Illegal character argument specified
Illegal combination of Smem operands
Illegal floating-point expression
Illegal operand
Illegal shift operation
Illegal structure reference
Incorrect bit symbol for specified status register
Invalid data size for relocation
Invalid float constant specified
Invalid identifier, sym, specified
Invalid macro parameter specified
Invalid operand, "char"
Must add to the destination operand
No parameters available for macro arguments
Not expecting direct operand op
Not expecting immediate value operand op
Not expecting indirect operand op
Offset Addressing modes not legal for MMR addressing
Operand must be auxiliary register or SP
Operand must be auxiliary register
Operand must be T
Register must be ARn or SP
Single character operand expected
String constant or substitution symbol expected
String operand expected
Structure/Union tag symbol expected
Substitution symbol operand expected
The accumulator operands must be different
The operands must be SP

Description These errors are about illegal operands. The instruction, parameter or other operand specified was not legal for this syntax.

Action Correct the source per the error message text.
E0005

**Missing field value operand**

**Missing operand(s)**

**Operand missing**

**Tag identification operand required**

**Tag symbol identifier required**

*Description* These are errors about missing operands; a required operand is not supplied.

*Action* Correct the source so that all required operands are declared.

E0006

**.break must occur within a loop**

**Conditional assembly mismatch**

**Matching .endloop missing**

**No matching .if specified**

**No matching .endif specified**

**No matching .endloop specified**

**No matching .if specified**

**No matching .loop specified**

**Open block(s) inside macro**

**Unmatched .endloop directive**

**Unmatched .if directive**

*Description* These are errors about unmatched conditional assembly directives. A directive was encountered that requires a matching directive but the assembler could not find the matching directive.

*Action* Correct the source per the error message text.

E0007

**Conditional nesting is too deep**

**Loop count out of range**

*Description* These are errors about conditional assembly loops. Conditional block nesting cannot exceed 32 levels.

E0008

Bad use of .access directive
Matching .struct directive is not present
Matching .union directive is not present

*Description* These are errors about unmatched structure definition directives. In a .struct/.endstruct sequence, a directive was encountered that requires a matching directive but the assembler could not find the matching directive.

*Action* Check the source for mismatched structure definition directives and correct.

E0009

Cannot apply bitwise NOT to floats
Illegal struct/union reference dot operator
Missing structure/union member or tag
Section "name" is not an initialized section
Structure or union tag symbol expected
Structure or union tag symbol not found

*Description* These are errors about an illegally used operator. The operator specified was not legal for the given operands.

*Action* Correct the source per the error message text so that all required operands are declared.

E0100

Label missing
Label required
.setsym requires a label

*Description* These are errors about required labels. The given directive requires a label, but none is specified.

*Action* Correct the source by specifying the required label.
E0101

Labels are not allowed with this directive
Standalone labels not permitted in structure/union defs

*Description*  These are errors about invalid labels. The given directive does not permit a label, but one is specified.

*Description*  Remove the invalid label.
E0102

Local label *number* defined differently in each pass
Local label *number* is multiply defined
Local label *number* is not defined in this section
Local labels can’t be used with directives

*Description*  These are errors about the illegal use of local labels.

*Action*  Correct the source per the error message text. Use .newblock to reuse local labels.

E0200

Bad term in expression
Binary operator can’t be applied
Cannot resolve symbol in expression
Difference between segment symbols not permitted
Expression evaluation failed
Illegal divide by zero
Illegal remainder by zero
Integer divide by zero
Integer remainder by zero
Offset expression must be integer value
Operation cannot be performed on given operands
Unable to compose expression
Unary operator can’t be applied
Value of expression has changed due to jump expansion
Well-defined expression required

*Description*  These are errors about general expressions. An illegal operation combination was used, or an arithmetic type is required but not present.

*Action*  Correct the source per the error message text.
### E0201

**Absolute operands required for FP operations!**
- Floating–point divide by zero
- Floating–point overflow
- Floating–point underflow
- Floating–point expression required
- Illegal floating–point expression
- Invalid floating–point operation

**Description**
These are errors about floating-point expressions. A floating-point expression was used where an integer expression is required, an integer expression was used where a floating-point expression is required, or a floating-point value is invalid.

**Action**
Correct the source per the error message text.

### E0300

**Cannot equate an external symbol to an external**
- Cannot redefine this section name
- Cannot tag an undefined symbol
- Empty structure or union definition
- Illegal structure or union tag
- Missing closing ‘}’ for repeat block
- Redefinition of “sym” attempted
- Structure tag can’t be global
- Symbol can’t be defined in terms of itself
- Symbol expected
- Symbol expected in label field
- Symbol, sym, has already been defined
- Symbol, sym, is not defined in this source file
- Symbol, sym, is operand to both .ref and .def
- Structure/union member, sym, not found
- The following symbols are undefined:
- Union member previously defined
- Union tag can’t be global

**Description**
These are errors about general symbols. An attempt was made to redefine a symbol or to define a symbol illegally.

**Action**
Correct the source per the error message text.
E0301

Cannot redefine local substitution symbol
Substitution stack overflow
Substitution symbol not found

Description These are errors about general substitution symbols. An attempt was made to redefine a symbol or to define a symbol illegally.

Action Correct the source per the error message text. Make sure that the operand of a substitution symbol is defined either as a macro parameter or with a .asg or .eval directive.

E0400

Symbol table entry is not balanced

Description A symbolic debugging directive does not have a complementing directive (i.e., a .block without an .endblock).

Action Check the source for mismatched conditional assembly directives.

E0500

Macro argument string is too long
Missing macro name
Too many variables declared in macro

Description These are errors about general macros. A macro definition was probably corrupted.

Action Correct the source per the error message text.

E0501

Macro definition not terminated with .endm
Matching .endm missing
Matching .macro missing .mexit directive outside macro definition
No active macro definition

Description These are errors about macro definition directives. A macro directive does not have a complementing directive (that is, a .macro without a .endm).

Action Correct the source per the error message text.

E0600

Bad archive entry for macro name
Bad archive name
Can’t read a line from archive entry
library name macro library not found
library name is not in archive format

Description These are errors about macro library accessing. A problem was encountered reading from or writing to a macro library archive file. It is likely that the creation of the archive file was not done properly.

Action Make sure that the macro libraries are unassembled assembler source files. Also make sure that the macro name and member name are the same, and the extension of the file is .asm.

E0700

Can’t use –g on assembly code with .line directives
Illegal structure/union member
No structure/union currently open
.sym not allowed inside structure/union

Description These are errors about the illegal use of symbolic debugging directives; a symbolic debugging directive is not used in an appropriate place.

Action Correct the source per the error message text.
### E0800

Control flow change in delayed branch slot  
Instructions not permitted in structure/union definitions  
Parallel operator without instruction  
Too many words in delayed branch slot

**Description**  
These are errors about parallel or branch instructions. These errors are normally target-specific.

**Action**  
Correct the source per the error message text.

### E0801

Too many parallel instructions

**Description**  
This error is caused by having too many instructions in parallel.

**Action**  
Check the source for parallel instruction problems and correct per the error message text.

### E0900

Cannot change version after 1st instruction  
Cannot change parsing mode after 1st instruction  
Can’t include a file inside a loop or macro  
Illegal structure member  
Illegal structure definition contents  
Illegal union member  
Illegal union definition contents  
Invalid load-time label  
Invalid structure/union contents  
.setsect only valid if absolute listing produced (use –a option)
Assembler Error Messages

.setsym only valid if absolute listing produced (use –a option)
.var allowed only within macro definitions

Description These are errors about illegally used directives. Specific directives were encountered where they are not permitted because they will cause a corruption of the object file. Many directives are not permitted inside of structure or union definitions.

Action Correct the source per the error message text.

E1000

Include/Copy file not found or opened

Description The specified filename cannot be found.

Action Check spelling, pathname, environment variables, etc.
E1300

Copy limit has been reached
Exceeded limit for macro arguments
Macro nesting limit exceeded

Description These errors are about general assembler limits that have been exceeded. The nesting of .copy/.include files in limited to 10 levels. Macro arguments are limited to 32 parameter. Macro nesting is limited to 32 levels.

Action Check the source to determine how limits have been exceeded.

E9999

Pass conflict

Description This is an internal assembler error. If it occurs repeatedly, the assembler may be corrupt or confused.

Action Assemble a smaller file. If a smaller file does not assemble, reinstall the assembler.

Pipeline conflict detected

Description This error reports a pipeline conflict.

Action Check the source to determine what caused the problem and correct the source.

Illegal use of *(EXPR) notation
Illegal use of *SP notation

Description This error reports a notation problem.

Action Check the source to determine what caused the problem and correct the source.
Assembler Error Messages

**W0000**

Ambiguous assignment
Invalid page number specified – ignored
Macro parameter conflict
No operands expected. Operands ignored
Specified alignment is outside accessible memory – ignored
Trailing operand does not exist
Trailing operands ignored
Unrecognized operand, ignored
*+ARn addressing is for write-only

**Description**
These are warnings about operands. The assembler encountered operands that it did not expect.

**Action**
Check the source to determine what caused the problem and whether you need to correct the source.
W0001

Field value truncated to *value*
Field width truncated to *size in bits*
Immediate value out of range
Legal shift values are ...
Minimum alignment is to 32K boundary – alignment ignored
Offset expression – value out of range
Power of 2 required, *next larger power of 2* assumed
Section Name is limited to 8 characters
Section name, *name*, truncated to 8 chars
Set value must be 0 or 1
Shift value out of range
Status bit value out of range
Status register must be 0 or 1
String is too long – will be truncated
Valid values are 1 and 2
Value values to *xxx* are *nnn*
Value truncated
Value truncated to *x*-bit width
Value truncated to byte size
Value out of range

*Description* These are warnings about truncated values. The expression given was too large to fit within the instruction opcode or the required number of bits.

*Action* Check the source to make sure the result will be acceptable, or change the source if an error has occurred.

W0002

Address expression will wrap-around
Expression will overflow, value truncated

*Description* These are warnings about arithmetic expressions. The assembler has done a calculation that will produce the indicated result, which may or may not be acceptable.

*Action* Verify the result will be acceptable, or change the source if an error has occurred.
**W0003**

**Incorrect size for the type**

* .sym for *function name* required before .func

**Description**
This is a warning about problems with symbolic debugging directives. A .sym directive defining the function does not appear before the .func directive.

**Action**
Correct the source.

---

**W0004**

* .access only allowed in top-most structure definition

* Access point has already been defined

* Open block(s) at EOF

**Description**
These are warnings about problems with structure definitions.

**Action**
Correct the source per the error message text.

---

**W9999**

* A branch to an empty label just inside the loop-closing brace is a branch out of the loop

* Far mode valid only for C548

* First instruction following XC must be a 1-word instruction

* Open branch delay slot at end of section

* Power of 2 required, *next larger power of 2* assumed

* Second instruction following XC must be a 1-word instruction

* Section *name* absolute address set to 0

* Section *name* is larger than 64K

* Value truncated to byte size

**Description**
These are general warnings.

**Action**
Correct the source per the warning message text.
Appendix A

This appendix lists the linker error messages in alphabetical order according to the error message. In these listings, the symbol (...) represents the name of an object that the linker is attempting to interact with when an error occurs.

**absolute symbol (...) being redefined**

*Description* An absolute symbol cannot be redefined.

*Action* Check the syntax of all expressions, and check the input directives for accuracy.

**adding name (...) to multiple output sections**

*Description* The input section is mentioned twice in the SECTIONS directive.

**ALIGN illegal in this context**

*Description* Alignment of a symbol is performed outside of a SECTIONS directive.

**alignment for (...) must be a power of 2**

*Description* Section alignment was not a power of 2.

*Action* Make sure that in hexadecimal, all powers of 2 consist of the integers 1, 2, 4, or 8 followed by a series of zero or more 0s.
alignment for (...) redefined
Description More than one alignment is supplied for a section.

attempt to decrement DOT
Description A statement such as \texttt{-= value} is supplied; this is illegal. Assignments to \texttt{dot} can be used only to create holes.

bad fill value
Description The fill value must be a 16-bit constant.

binding address (...) for section (...) is outside all memory on page (...) Description Not every section falls within memory configured with the MEMORY directive.
Action If you are using a linker command file, check that MEMORY and SECTIONS directives allow enough room to ensure that no sections are being placed in unconfigured memory.

binding address (...) for section (...) overlays (...) at (...) Description Two sections overlap and cannot be allocated.
Action If you are using a linker command file, check that MEMORY and SECTIONS directives allow enough room to ensure that no sections are being placed in unconfigured memory.

binding address for (...) redefined Description More than one binding value is supplied for a section.

binding address (...) incompatible with alignment for section (...) Description The section has an alignment requirement from an \texttt{.align} directive or previous link. The binding address violates this requirement.

blocking for (...) must be a power of 2
Description Section blocking is not a power of 2
Action Make sure that in hexadecimal, all powers of 2 consist of the integers 1, 2, 4, or 8 followed by a series of zero or more 0s.
blocking for (...) redefined
Description More than one blocking value is supplied for a section.

-c requires fill value of 0 in .cinit (... overridden)
Description The .cinit tables must be terminated with 0, therefore, the fill value of the .cinit section must be 0.

cannot complete output file (...), write error
Description This usually means that the file system is out of space.

cannot create output file (...)
Description This usually indicates an illegal filename.
Action Check spelling, pathname, environment variables, etc. The filename must conform to operating system conventions.

cannot resize (...), section has initialized definition in (...)
Description An initialized input section named .stack or .heap exists, preventing the linker from resizing the section.

cannot specify a page for a section within a GROUP
Description A section was specified to a specific page within a group. The entire group is treated as one unit, so the group may be specified to a page of memory, but the sections making up the group cannot be handled individually.

cannot specify both binding and memory area for (...)
Description Both binding and memory were specified. The two are mutually exclusive.
Action If you wish the code to be placed at a specific address, use binding only.
can’t align a section within GROUP – (...) not aligned

Description  A section in a group was specified for individual alignment. The entire group is treated as one unit, so the group may be aligned or bound to an address, but the sections making up the group cannot be handled individually.

can’t align within UNION – section (...) not aligned

Description  A section in a union was specified for individual alignment. The entire union is treated as one unit, so the union may be aligned or bound to an address, but the sections making up the union cannot be handled individually.

can’t allocate (...), size ... (page ...)

Description  A section can’t be allocated, because no existing configured memory area is large enough to hold it.

Action  If you are using a linker command file, check that the MEMORY and SECTIONS directives allow enough room to ensure that no sections are being placed in unconfigured memory.

can’t create map file (...)

Description  Usually indicates an illegal filename.

Action  Check spelling, pathname, environment variables, etc. The filename must conform to operating system conventions.

can’t find input file filename

Description  The file, filename, is not in your PATH, is misspelled, etc.

Action  Check spelling, pathname, environment variables, etc. The filename must conform to operating system conventions.

can’t open (...)

Description  The specified file does not exist.

Action  Check spelling, pathname, environment variables, etc. The filename must conform to operating system conventions.
can’t open filename
Description The specified file does not exist.
Action Check spelling, pathname, environment variables, etc. The filename must conform to operating system conventions.

can’t read (...) 
Description The file may be corrupt.
Action If the input file is corrupt, try reassembling it.

can’t seek (...) 
Description The file may be corrupt.
Action If the input file is corrupt, try reassembling it.

can’t write (...) 
Description Disk may be full or protected.
Action Check disk volume and protection.

command file nesting exceeded with file (...) 
Description Command file nesting is allowed up to 16 levels.
Linker Error Messages

**E**

-e flag does not specify a legal symbol name (...)
*Description* The -e option is not supplied with a valid symbol name as an operand.

entry point other than _c_int00 specified
*Description* For -c or -cr option only. A program entry point other than the value of _c_int00 was supplied. The runtime conventions of the compiler assume that _c_int00 is the one and only entry point.

entry point symbol (...) undefined
*Description* The symbol used with the -e option is not defined.

errors in input – (...) not built
*Description* Previous errors prevent the creation of an output file.

**F**

fail to copy (...)
*Description* The file may be corrupt.
*Action* If the input file is corrupt, try reassembling it.

fail to read (...)
*Description* The file may be corrupt.
*Action* If the input file is corrupt, try reassembling it.

fail to seek (...)
*Description* The file may be corrupt.
*Action* If the input file is corrupt, try reassembling it.
fail to skip (...)
Description The file may be corrupt.
Action If the input file is corrupt, try reassembling it.

fail to write (...)
Description The disk may be full or protected.
Action Check disk volume and protection.

file (...) has no relocation information
Description You have attempted to relink a file that was not linked with −r.

file (...) is of unknown type, magic number = (...)
Description The binary input file is not a COFF file.

fill value for (...) redefined
Description More than one fill value is supplied for an output section. Individual holes can be filled with different values with the section definition.

–i path too long (...)
Description The maximum number of characters in an –i path is 256.

illegal input character
Description There is a control character or other unrecognized character in the command file.

illegal memory attributes for (...)
Description The attributes are not some combination of R, W, I, and X.
illegal operator in expression
Description Review legal expression operators.

illegal option within SECTIONS
Description The –l (lowercase L) option is the only option allowed within a SECTIONS directive.

illegal relocation type (...) found in section(s) of file (...)
Description The binary file is corrupt.

internal error (...)
Description This linker has an internal error.

invalid archive size for file (...)
Description The archive file is corrupt.

invalid path specified with –i flag
Description The operand of the –i option (flag) is not a valid file or path-name.

invalid value for –f flag
Description The value for –f option (flag) is not a 2-byte constant.

invalid value for –heap flag
Description The value for –heap option (flag) is not a 2-byte constant.

invalid value for –stack flag
Description The value for –stack option (flag) is not a 2-byte constant.

invalid value for –v flag
Description The value for –v option (flag) is not a constant.

I/O error on output file (...)
Description The disk may be full or protected.
Action Check disk volume and protection.
length redefined for memory area (...)
Description A memory area in a MEMORY directive has more than one
length.

library (...) member (...) has no relocation information
Description The library member has no relocation information. It is
possible for a library member to not have relocation information; this means that it cannot satisfy unresolved references in
other files when linking.

line number entry found for absolute symbol
Description The input file may be corrupt.
Action If the input file is corrupt, try reassembling it.

load address for uninitialized section (...) ignored
Description A load address is supplied for an uninitialized section. Unini-
tialized sections have no load addresses—only run address-
es.

load address for UNION ignored
Description UNION refers only to the section’s run address.

load allocation required for initialized UNION member (...)
Description A load address is supplied for an initialized section in a union.
UNIONS refer to runtime allocation only. You must specify the
load address for all sections within a union separately.

–m flag does not specify a valid filename
Description You did not specify a valid filename for the file you are writing
the output map file to.

making aux entry filename for symbol n out of sequence
Description The input file may be corrupt.
Action If the input file is corrupt, try reassembling it.
memory area for (...) redefined
Description More than one named memory allocation is supplied for an output section.

memory page for (...) redefined
Description More than one page allocation is supplied for a section.

memory attributes redefined for (...
Description More than one set of memory attributes is supplied for an output section.

memory types (...) and (...) on page (...) overlap
Description Memory ranges on the same page overlap.
Action If you are using a linker command file, check that MEMORY and SECTIONS directives allow enough room to ensure that no sections are being placed in unconfigured memory.

missing filename on –l; use –l <filename>
Description No filename operand is supplied for the –l (lowercase L) option.

misuse of DOT symbol in assignment instruction
Description The "." symbol is used in an assignment statement that is outside the SECTIONS directive.

no allocation allowed for uninitialized UNION member
Description A load address was supplied for an uninitialized section in a union. An uninitialized section in a union gets its run address from the UNION statement and has no load address, so no load allocation is valid for the member.
no allocation allowed with a GROUP–allocation for section (...) ignored
Description A section in a group was specified for individual allocation. The entire group is treated as one unit, so the group may be aligned or bound to an address, but the sections making up the group cannot be handled individually.

no input files
Description No COFF files were supplied. The linker cannot operate without at least one input COFF file.

no load address specified for (...); using run address
Description No load address is supplied for an initialized section. If an initialized section has a run address only, the section is allocated to run and load at the same address.

no run allocation allowed for union member (...)   
Description A UNION defines the run address for all of its members; therefore, individual run allocations are illegal.

no string table in file filename
Description The input file may be corrupt.
Action If the input file is corrupt, try reassembling it.

no symbol map produced – not enough memory
Description Available memory is insufficient to produce the symbol list. This is a nonfatal condition that prevents the generation of the symbol list in the map file.
–o flag does not specify a valid file name: string
Description: The filename must follow the operating system file naming conventions.

origin missing for memory area (...)
Description: An origin is not specified with the MEMORY directive. An origin specifies the starting address of a memory range.

out of memory, aborting
Description: Your system does not have enough memory to perform all required tasks.
Action: Try breaking the assembly language files into multiple smaller files and do partial linking. See Section 7.16, Partial (Incremental) Linking, on page 7-70.

output file has no .bss section
Description: This is a warning. The .bss section is usually present in a COFF file. There is no requirement for it to be present.

output file has no .data section
Description: This is a warning. The .data section is usually present in a COFF file. There is no requirement for it to be present.

output file has no .text section
Description: This is a warning. The .text section is usually present in a COFF file. There is no requirement for it to be present.

output file (...) not executable
Description: The output file created may have unresolved symbols or other problems stemming from other errors. This condition is not fatal.

overwriting aux entry filename of symbol n
Description: The input file may be corrupt.
Action: If the input file is corrupt, try reassembling it.
**PC-relative displacement overflow at address (...) in file (...)**

*Description*  The relocation of a PC-relative jump resulted in a jump displacement too large to encode in the instruction.

**–r incompatible with –s (–s ignored)**

*Description*  Both the –r option and the –s option were used. Since the –s option strips the relocation information and –r requests a relocatable object file, these options are in conflict with each other.

**relocation entries out of order in section (...) of file (...)**

*Description*  The input file may be corrupt.

*Action*  If the input file is corrupt, try reassembling it.

**relocation symbol not found: index (...), section (...), file (...)**

*Description*  The input file may be corrupt.

*Action*  If the input file is corrupt, try reassembling it.

**section (...) at (...) overlays at address (...)**

*Description*  Two sections overlap and cannot be allocated.

*Action*  If you are using a linker command file, check that MEMORY and SECTIONS directives allow enough room to ensure that no sections overlap.

**section (...) enters unconfigured memory at address (...)**

*Description*  A section can’t be allocated because no existing configured memory area is large enough to hold it.

*Action*  If you are using a linker command file, check that MEMORY and SECTIONS directives allow enough room to ensure that no sections are being placed in unconfigured memory.
section (...) not built
Description    Most likely there is a syntax error in the SECTIONS directive.

section (...) not found
Description    An input section specified in a SECTIONS directive was not found in the input file.

section (...) won’t fit into configured memory
Description    A section can’t be allocated, because no configured memory area exists that is large enough to hold it.
Action         If you are using a linker command file, check that the MEMORY and SECTIONS directives allow enough room to ensure that no sections are being placed in unconfigured memory.

seek to (...) failed
Description    The input file may be corrupt.
Action         If the input file is corrupt, try reassembling it.

semicolon required after assignment
Description    There is a syntax error in the command file.

statement ignored
Description    There is a syntax error in an expression.

symbol referencing errors — (...) not built
Description    Symbol references could not be resolved. Therefore, an object module could not be built.

symbol (...) from file (...) being redefined
Description    A defined symbol is redefined in an assignment statement.

too few symbol names in string table for archive n
Description    The archive file may be corrupt.
Action         If the input file is corrupt, try recreating the archive.
too many arguments – use a command file
Description: You used more than ten arguments on a command line or in response to prompts.

too many –i options, 7 allowed
Action: More than seven –i options were used. Additional search directories can be specified with a C_DIR or A_DIR environment variable.

type flags for (...) redefined
Description: More than one section type is supplied for a section. Note that type COPY has all of the attributes of type DSECT, so DSECT need not be specified separately.

type flags not allowed for GROUP or UNION
Description: A type is specified for a section in a group or union. Special section types apply to individual sections only.

–u does not specify a legal symbol name
Description: The –u option did not specify a legal symbol name that exists in one of the files that you are linking.

unexpected EOF(end of file)
Description: There is a syntax error in the linker command file.

undefined symbol (...) first referenced in file (...)
Description: Either a referenced symbol is not defined, or the –r option was not used. Unless the –r option is used, the linker requires that all referenced symbols be defined. This condition prevents the creation of an executable output file.
Action: Link using the –r option or define the symbol.
undefined symbol in expression
Description An assignment statement contains an undefined symbol.

unrecognized option (...)
Action Check the list of valid options.

zero or missing length for memory area (...)
Description A memory range defined with the MEMORY directive did not have a nonzero length.
absolute address: An address that is permanently assigned to a TMS320C54x™ memory location.

absolute lister: A debugging tool that accepts linked files as input and creates .abs files as output. These .abs files can be assembled to produce a listing that shows the absolute addresses of object code. Without the tool, an absolute listing can be prepared with the use of many manual operations.

algebraic: An instruction that the assembler translates into machine code.

alignment: A process in which the linker places an output section at an address that falls on an n-bit boundary, where n is a power of 2. You can specify alignment with the SECTIONS linker directive.

allocation: A process in which the linker calculates the final memory addresses of output sections.

archive library: A collection of individual files that have been grouped into a single file.

archiver: A software program that allows you to collect several individual files into a single file called an archive library. The archiver also allows you to delete, extract, or replace members of the archive library, as well as to add new members.


assembler: A software program that creates a machine-language program from a source file that contains assembly language instructions, directives, and macro directives. The assembler substitutes absolute operation codes for symbolic operation codes, and absolute or relocatable addresses for symbolic addresses.

assembly-time constant: A symbol that is assigned a constant value with the .set directive.
**assignment statement:**  A statement that assigns a value to a variable.

**autointialization:**  The process of initializing global C variables (contained in the .cinit section) before beginning program execution.

**auxiliary entry:**  The extra entry that a symbol may have in the symbol table and that contains additional information about the symbol (whether it is a filename, a section name, a function name, etc.).

**binding:**  A process in which you specify a distinct address for an output section or a symbol.

**block:**  A set of declarations and statements that are grouped together with braces.

**.bss:**  One of the default COFF sections. You can use the .bss directive to reserve a specified amount of space in the memory map that can later be used for storing data. The .bss section is uninitialized.

**C compiler:**  A program that translates C source statements into assembly language source statements.

**COFF:**  Common object file format. A binary object file format that promotes modular programming by supporting the concept of sections.

**command file:**  A file that contains options, filenames, directives, or comments for the linker or hex conversion utility.

**comment:**  A source statement (or portion of a source statement) that is used to document or improve readability of a source file. Comments are not compiled, assembled, or linked; they have no effect on the object file.

**common object file format:**  See COFF.

**conditional processing:**  A method of processing one block of source code or an alternate block of source code, according to the evaluation of a specified expression.

**configured memory:**  Memory that the linker has specified for allocation.

**constant:**  A numeric value that can be used as an operand.

**cross-reference listing:**  An output file created by the assembler that lists the symbols that were defined, what line they were defined on, which lines referenced them, and their final values.
.data: One of the default COFF sections. The .data section is an initialized section that contains initialized data. You can use the .data directive to assemble code into the .data section.

directives: Special-purpose commands that control the actions and functions of a software tool (as opposed to assembly language instructions, which control the actions of a device).

emulator: A hardware development system that emulates TMS320C54x operation.

entry point: The starting execution point in target memory.

executable module: An object file that has been linked and can be executed in a TMS320C54x system.

expression: A constant, a symbol, or a series of constants and symbols separated by arithmetic operators.

external symbol: A symbol that is used in the current program module but is defined in a different program module.

field: For the TMS320C54x, a software-configurable data type whose length can be programmed to be any value in the range of 1–16 bits.

file header: A portion of a COFF object file that contains general information about the object file (such as the number of section headers, the type of system the object file can be downloaded to, the number of symbols in the symbol table, and the symbol table's starting address).

global: A kind of symbol that is either 1) defined in the current module and accessed in another, or 2) accessed in the current module but defined in another.

GROUP: An option of the SECTIONS directive that forces specified output sections to be allocated contiguously (as a group).
**Glossary**

**H**

**hex conversion utility:** A program that accepts COFF files and converts them into one of several standard ASCII hexadecimal formats suitable for loading into an EPROM programmer.

**high-level language debugging:** The ability of a compiler to retain symbolic and high-level language information (such as type and function definitions) so that a debugging tool can use this information.

**hole:** An area between the input sections that compose an output section that contains no actual code or data.

**I**

**incremental linking:** Linking files that will be linked in several passes. Often this means a very large file that will have sections linked and then will have the sections linked together.

**initialized section:** A COFF section that contains executable code or initialized data. An initialized section can be built up with the `.data`, `.text`, or `.sect` directive.

**input section:** A section from an object file that will be linked into an executable module.

**L**

**label:** A symbol that begins in column 1 of a source statement and corresponds to the address of that statement.

**line-number entry:** An entry in a COFF output module that maps lines of assembly code back to the original C source file that created them.

**linker:** A software tool that combines object files to form an object module that can be allocated into TMS320C54x system memory and executed by the device.

**listing file:** An output file, created by the assembler, that lists source statements, their line numbers, and their effects on the SPC.

**loader:** A device that loads an executable module into TMS320C54x system memory.
**Macro:** A user-defined routine that can be used as an instruction.

**Macro Call:** The process of invoking a macro.

**Macro Definition:** A block of source statements that define the name and the code that make up a macro.

**Macro Expansion:** The source statements that are substituted for the macro call and are subsequently assembled.

**Macro Library:** An archive library composed of macros. Each file in the library must contain one macro; its name must be the same as the macro name it defines, and it must have an extension of .asm.

**Magic Number:** A COFF file header entry that identifies an object file as a module that can be executed by the TMS320C54x.

**Map File:** An output file, created by the linker, that shows the memory configuration, section composition, and section allocation, as well as symbols and the addresses at which they were defined.

**Member:** The elements or variables of a structure, union, archive, or enumeration.

**Memory Map:** A map of target system memory space, which is partitioned into functional blocks.

**Mnemonic:** An instruction name that the assembler translates into machine code.

**Model Statement:** Instructions or assembler directives in a macro definition that are assembled each time a macro is invoked.

**Named Section:** An initialized section that is defined with a .sect directive.

**Object File:** A file that has been assembled or linked and contains machine-language object code.

**Object Format Converter:** A program that converts COFF object files into Intel format or Tektronix format object files.
**object library:** An archive library made up of individual object files.

**operands:** The arguments, or parameters, of an assembly language instruction, assembler directive, or macro directive.

**optional header:** A portion of a COFF object file that the linker uses to perform relocation at download time.

**options:** Command parameters that allow you to request additional or specific functions when you invoke a software tool.

**output module:** A linked, executable object file that can be downloaded and executed on a target system.

**output section:** A final, allocated section in a linked, executable module.

**overlay page:** A section of physical memory that is mapped into the same address range as another section of memory. A hardware switch determines which range is active.

**partial linking:** The linking of a file that will be linked again.

**quiet run:** Suppresses the normal banner and the progress information.

**RAM model:** An autoinitialization model used by the linker when linking C code. The linker uses this model when you invoke the linker with the –cr option. The RAM model allows variables to be initialized at load time instead of runtime.

**raw data:** Executable code or initialized data in an output section.

**relocation:** A process in which the linker adjusts all the references to a symbol when the symbol’s address changes.

**ROM model:** An autoinitialization model used by the linker when linking C code. The linker uses this model when you invoke the linker with the –c option. In the ROM model, the linker loads the .cinit section of data tables into memory, and variables are initialized at runtime.
ROM width: The width (in bits) of each output file, or, more specifically, the width of a single data value in the file. The ROM width determines how the utility partitions the data into output files. After the target words are mapped to memory words, the memory words are broken into one or more output files. The number of output files is determined by the ROM width.

run address: The address where a section runs.

section: A relocatable block of code or data that will ultimately occupy contiguous space in the TMS320C54x memory map.

section header: A portion of a COFF object file that contains information about a section in the file. Each section has its own header; the header points to the section’s starting address, contains the section’s size, etc.

section program counter: See SPC.

sign extend: To fill the unused MSBs of a value with the value’s sign bit.

simulator: A software development system that simulates TMS320C54x operation.

source file: A file that contains C code or assembly language code that will be compiled or assembled to form an object file.

SPC (Section Program counter): An element of the assembler that keeps track of the current location within a section; each section has its own SPC.

static: A kind of variable whose scope is confined to a function or a program. The values of static variables are not discarded when the function or program is exited; their previous value is resumed when the function or program is re-entered.

storage class: Any entry in the symbol table that indicates how to access a symbol.

string table: A table that stores symbol names that are longer than 8 characters (symbol names of 8 characters or longer cannot be stored in the symbol table; instead, they are stored in the string table). The name portion of the symbol’s entry points to the location of the string in the string table.

structure: A collection of one or more variables grouped together under a single name.
subsection: A smaller section within a section offering tighter control of the memory map. See also section.

symbol: A string of alphanumeric characters that represents an address or a value.

symbolic debugging: The ability of a software tool to retain symbolic information so that it can be used by a debugging tool such as a simulator or an emulator.

symbol table: A portion of a COFF object file that contains information about the symbols that are defined and used by the file.

tag: An optional type name that can be assigned to a structure, union, or enumeration.

target memory: Physical memory in a TMS320C54x system into which executable object code is loaded.

.text: One of the default COFF sections. The .text section is an initialized section that contains executable code. You can use the .text directive to assemble code into the .text section.

unconfigured memory: Memory that is not defined as part of the memory map and cannot be loaded with code or data.

uninitialized section: A COFF section that reserves space in the memory map but that has no actual contents. These sections are built up with the .bss and .usect directives.

UNION: An option of the SECTIONS directive that causes the linker to allocate the same address to multiple sections.

union: A variable that may hold objects of different types and sizes.

unsigned: A kind of value that is treated as a positive number, regardless of its actual sign.

well-defined expression: An expression that contains only symbols or assembly-time constants that have been defined before they appear in the expression.

word: A 16-bit addressable location in target memory.
–?
  assembler option 3-5
  linker option 7-6

; in assembly language source 3-14
# operand prefix 3-13
$ symbol for SPC 3-20
–@ assembler option 3-4
* in assembly language source 3-14
* operand prefix 3-13

A
–a
  archiver command 6-4
  assembler option 3-5
  hex conversion utility option 10-40
  linker option 7-8
A_DIR environment variable 3-9, 7-13, 7-16
abs500 command. See absolute lister, invoking
absolute address, defined F-1
absolute lister
  creating the absolute listing file 3-4 8-2
  defined F-1
described 1-4
development flow 8-2
example 8-5 to 8-10
invoking 8-3
options 8-3
absolute listing
  –a assembler option 3-5
  producing 8-2
absolute output module
  producing 7-8
  relocatable 7-8

algebraic
  defined F-1
  source file 3-6
translation from mnemonic 11-1 to 11-10
.algebraic directive 4-23 4-26
.align directive 4-15 4-27
  compatibility with C1x/C2x/C2xx/C5x 4-8
alignment
  defined F-1
  linker 7-38
allocation
  alignment 4-27 7-38
  binding 7-36 to 7-78
  blocking 7-38
default algorithm 7-58 to 7-60
defined F-1
described 2-3
GROUP 7-50
memory default 2-14 7-37
sections 7-35 to 7-43
UNION 7-48
alternate directories
  linker 7-14
  naming with –i option 3-8
  naming with A_DIR 3-9
  naming with directives 3-8 to 3-10
–ar linker option 7-9
ar500 command 6-4
archive library
  allocating individual members 7-43
  alternate directory 7-13
  back referencing 7-20
defined F-1
exhaustively reading macros 4-68
object 7-25 to 7-26
types of files 8-2
archiver 1-3
commands 6-4
defined 6-1
examples 6-3
in the development flow 6-3
invoking 6-4
options 6-5
overview 6-2
arithmetic operators 3-26
–arr hex conversion utility option 10-29
array definitions A-26
COFF limitation A-26
ASCII-Hex object format 10-40
.asg directive 4-21 4-28
listing control 4-17 4-41
use in macros 5-7
asm500 command 3-4
assembler
built-in functions 3-30 5-8
character strings 3-18
constants 3-15 to 3-17
cross-reference listings 3-7 3-37
defined F-1
described 1-3
error messages D-1 to D-18
expressions 3-25 3-26 3-27
extended addressing support 3-32
handling COFF sections 2-5 to 2-12
handling pipeline conflicts 2-6
in the development flow 3-3
invoking 3-4
LDX pseudo-op 3-32
macros 5-1 to 5-26
options 3-4

assembler directives 4-1 to 4-25
absolute lister
.setsect 8-8
.setsym 8-8
aligning the section program counter (SPC) 4-15 to 4-16
.align 4-15 4-27
.even 4-15 4-27
compatibility with C1x/C2x/C2xx/C5x 4-8
default directive 2-5
defining assembly-time symbols 4-21 to 4-22
.abs 4-21 4-28
.endstruct 4-21 4-86
.endunion 4-22 4-92
.equ 4-21 4-81
.eval 4-21 4-28
.label 4-21 4-60
.set 4-21 4-81
.struct 4-21 4-86
.tag 4-21 4-22 4-86 4-92
.union 4-22 4-92
defining sections 4-9 to 4-10
.bss 2-5 4-9 4-30
.clink 4-9 4-34
.data 2-5 4-9 4-39
.sect 2-5 4-9 4-80
.text 2-5 4-9 4-90
.usect 2-5 4-9 4-95

enabling conditional assembly 4-20
.break 4-20 4-66
.else 4-20 4-56
.elseif 4-20 4-56
.endif 4-20 4-56
.endloop 4-20 4-66
.if 4-20 4-56
.loop 4-20 4-66
.example 2-10 to 2-12
formatting the output listing 4-17 to 4-18
directive listing 4-17 to 4-18 4-41 to 4-100
definitions listings 3-7 3-37
example 3-33
overview 3-2
relocation
at runtime 2-19
described 2-16 to 2-18
during linking 7-8
remarks, suppressing 4-75
sections directives 2-5 to 2-12
source listings 3-33 to 3-36
suppressing remarks 3-6 4-75
symbols 3-19 3-21
.output listing
directive listing 4-17 to 4-18 4-41 to 4-100
example 3-33
overview 3-2
relocation
at runtime 2-19
described 2-16 to 2-18
during linking 7-8
remarks, suppressing 4-75
sections directives 2-5 to 2-12
source listings 3-33 to 3-36
suppressing remarks 3-6 4-75
symbols 3-19 3-21
assembler directives, formatting the output listing (continued)

- .ssnolist 4-12 4-83
- .tab 4-18 4-89
- .title 4-18 4-91
- .width 4-18 4-81

initializing constants 4-11 to 4-14

- .bes 4-11 4-82
- .byte 4-12 4-33
- .char 4-12 4-33
- .double 4-13 4-40
- .field 4-12 4-47
- .float 4-12 4-50
- .half 4-13 4-54
- .int 4-13 4-58
- .ldouble 4-13 4-44
- .long 4-13 4-64
- .pstring 4-13 4-85
- .short 4-13 4-54
- .space 4-11 4-82
- .string 4-13 4-85
- .ubyte 4-12 4-33
- .uchar 4-12 4-33
- .uhalf 4-13 4-54
- .uint 4-13 4-58
- .ulong 4-13 4-64
- .ushort 4-13 4-54
- .uword 4-13 4-58
- .xfloat 4-12 4-50
- .xlong 4-13 4-64

miscellaneous 4-23 to 4-24

- .algebraic 4-23 4-26
- .c_mode 4-23 4-26
- .emsg 4-24 4-43
- .end 4-23 4-44
- .far_mode 4-23 4-44
- .mmregs 4-23 4-71
- .msg 4-24 4-43
- .newblock 4-23 4-74
- .noremark 4-23 4-75
- .remark 4-23 4-75
- .sblock 4-23 4-75
- .version 4-23
- .wmsg 4-24 4-42

assembler directives (continued)

referencing other files 4-19

- .copy 4-19 4-38
- .def 4-19 4-51
- .global 4-19 4-51
- .include 4-19 4-36
- .ref 4-19 4-51

summary table 4-2 to 4-7

assembly-time constants defined F-1

assignment statement defined F-2

expressions 7-63 to 7-64

attr MEMORY specification 7-29

attributes 3-38 7-29

autostarting defined F-2

described 7-73 to 7-74

specifying type 7-10

auxiliary entry defined F-2

described A-23 to A-28

B

–b linker option 7-10

.bes directive 4-11 4-82

big-endian ordering 10-14

binary integer constants 3-15

binding defined F-2

named memory 7-36

sections 7-36

–bkr hex conversion utility option 10-29

block auxiliary table entry A-26 A-27

defined F-2

described A-17

reference B-3

.block symbolic debugging directive B-3

blocking 4-30 7-38

–boot hex conversion utility option 10-29

boot loader. See on-chip boot loader, boot table. See on-chip boot loader, boot table boot.obj 7-72 7-75

–bootorg hex conversion utility option 10-29

–bootpage hex conversion utility option 10-29
Index

..break directive 4-20, 4-66
   listing control 4-17, 4-41
   use in macros 4-15
~bscr hex conversion utility option 10-29
..bss directive 4-9, 4-30
   compatibility with C1x/C2x/C2xx/C5x 4-8
   in sections 2-5
   linker definition 7-65
..bss section 4-9, 4-30, A-3
   defined 7-2
   holes 7-68
   initializing 7-68
built-in functions 3-30, 5-8
~byte hex conversion utility option 10-37
..byte directive 4-12, 4-33
   limiting listing with .option directive 4-17, 4-76
..cinit
   section 7-73 to 7-74
   tables 7-73
   cinit symbol 7-73 to 7-74
..clink directive 4-3, 4-34

COFF
   array limitation A-26
   auxiliary entries A-23 to A-28
   conversion to hexadecimal format 10-1 to 10-46
   See also hex conversion utility
default allocation 7-58
   file structure A-2 to A-4
   file types 2-2
   headers
      file A-3
      optional section A-7 to A-9
   in the development flow 7-3, 10-2
   initialized sections 2-7
   line number entries B-7
   linker 7-1
   loading a program 2-20
   object file example A-3
   relocation 2-16 to 2-18, A-10 to A-11
   runtime relocation 2-19
   sections
      allocation 2-3
      assembler 2-5 to 2-12
      described 2-3 to 2-4
      linker 2-13 to 2-15
      named 2-8 to 2-9
      special types 7-61
      uninitialized 2-5 to 2-6
   storage classes
      string table A-18
   symbol table
      structure and content A-14 to A-28
      symbol values 4-20
   symbolic debugging A-12 to A-13
   symbols 2-21 to 2-22, A-16 to A-17
   technical details A-1 to A-28
   type entry A-21
   uninitialized sections 2-5 to 2-6

C
memory pool 7-12, 7-73
system stack 7-18, 7-73
~c
   assembler option 3-5
   linker option 7-10, 7-65
C code, linking 7-72 to 7-75
C compiler
   block definitions B-3
   COFF technical details A-1
   defined F-2
   enumeration definitions B-4
   file identification B-7
   function definitions B-5
   line-number entries B-7
   line-number information A-12 to A-13
   linking 7-10, 7-72 to 7-75
   member definitions B-8
   special symbols A-16 to A-17
   storage classes A-19
   structure definitions B-9
   symbol table entries B-11
   union definitions B-9
C_DIR environment variable 7-13 to 7-16
_c_int00 7-11, 7-75
_c_mode directive 4-23, 4-35
C54X_A_DIR environment variable 3-9, 7-13
C54X_C_DIR environment variable 7-13 to 7-16
..char directive 4-12, 4-33
   character constant 3-16
   string 3-18
..cinit
   section 7-73 to 7-74
   tables 7-73
   cinit symbol 7-73 to 7-74
..clink directive 4-3, 4-34

Index-4
command file
  defined F-2
  hex conversion utility 10-7 to 10-8
  linker
    constants in 7-24
described 7-21 to 7-24
  examples 7-76 to 7-78
  invoking 7-4
  reserved words 7-24

comments
  defined F-2
  extending past page width 4-61
  field 3-14
  in a linker command file 7-22
  in assembly language source code 3-14
  in macros 5-19
common object file format. See COFF
conditional blocks 5-15
  assembly directives 4-20
  listing of false conditional blocks 4-46
conditional processing
  assembly directives
    in macros 5-15 to 5-16
    maximum nesting levels 5-15
defined F-2
  expressions 3-27
configured memory
  defined F-2
described 7-59
.const 7-34
constant
  assembly-time 4-81
  binary integers 3-15
  character 3-16
  decimal integers 3-16
defined F-2
described 3-15
  floating-point 4-50
  hexadecimal integers 3-16
  in command files 7-24
  octal integers 3-15
  symbolic 3-19 3-20
data memory
  defined .const 7-34
described 7-59
.data directive 4-9 4-39
data section
  defined 7-65
  symbols
.def directive 4-19 4-51
default
  allocation 7-58
  fill value for holes 7-11
  memory allocation 2-14
  MEMORY configuration 7-58
  MEMORY model 7-27
  section. See COFF, sections
  SECTIONS configuration 7-32 7-58
development
  flow 1-2 6-3 7-3
tools 1-2
directives
  See also assembler directives
  defined F-3
  linker
    MEMORY 2-13 7-27 to 7-31
    SECTIONS 2-13 7-32 to 7-43
    symbolic debugging B-3 to B-13
directory search algorithm
  assembler 3-8
  linker 7-13
double directive 4-13 4-40
cross-reference lister
  creating the cross-reference listing 9-2
default example 9-4
  in the development flow 9-2
  invoking 9-3
  options 9-3
  symbol attributes 9-6
cross-reference listing
  assembler option 3-7
defined F-2
described 3-37
  producing with the .option directive 4-18 4-76
  producing with cross-reference lister 9-1 to 9-6

D
  archiver command 6-4
directives
  .data directive 4-9 4-39
directories
  assembler option 3-7
  .data directive 4-9 4-39
  .data section 2-5 4-9 4-39 A-3
defined 7-65
decimal integer constants 3-16
default
  allocation 7-58
  fill value for holes 7-11
  memory allocation 2-14
  MEMORY configuration 7-58
  MEMORY model 7-27
  section. See COFF, sections
  SECTIONS configuration 7-32 7-58
development
  flow 1-2 6-3 7-3
tools 1-2
directives
  See also assembler directives
  defined F-3
  linker
    MEMORY 2-13 7-27 to 7-31
    SECTIONS 2-13 7-32 to 7-43
    symbolic debugging B-3 to B-13
directory search algorithm
  assembler 3-8
  linker 7-13
double directive 4-13 4-40

Index-5
Index

.drlist directive 4-17, 4-41
use in macros 5-21
.drlist directive 4-17, 4-41
same effect with .option directive 4-17
use in macros 5-21
DSECT section 7-61
dummy section 7-61

DSECT section 7-61
dummy section 7-61

.error messages
displayed by assembler  D-1 to D-18
displayed by linker  E-1 to E-16
 generating 4-24, 4-42
hex conversion utility 10-45
producing in macros 5-19
.etag symbolic debugging directive  B-9
.etext linker symbol 7-65
.eval directive 4-21, 4-28
listing control 4-17, 4-41
use in macros 5-8
evaluation of expressions 3-25
even directive 4-15, 4-27
executable module, defined  F-3
executable output 7-8, 7-9
expression
absolute and relocatable 3-28
arithmetic operators in conditional 3-27
conditional operators in defined  F-3
described 3-25
illegal 3-28
line 7-63 to 7-64
overflow 3-26
precedence of operators 3-25
relocatable symbols in 3-28
underflow 3-26
well-defined 3-27
extended addressing, loading values into 3-32
external symbols 2-21
defined  F-3
relocatable 3-28

F

-f linker option 7-11
.far_mode directive 4-23, 4-45
.fcist directive 4-17, 4-46
listing control 4-17, 4-41
use in macros 5-21
.fcnolist directive 4-17, 4-46
listing control 4-17, 4-41
use in macros 5-21
field, defined  F-3
.field directive 4-12, 4-47
compatibility with C1x/C2x/C2xx/C5x 4-8

Index-6
file
  copy 3-5
  identification B-4
  include 3-5
file header
  defined F-3
  structure A-5
/file symbolic debugging directive B-4
filenames
  as character strings 3-18
  copy/include files 3-8
  extensions, changing defaults 8-3
  list file 3-4
  macros, in macro libraries 5-14
  object code 3-4
files ROMS specification 10-18
fill
  MEMORY specification 7-30
  ROMS specification 10-17
  value
    default 7-11
    explicit initialization 7-69
    setting 7-11
  –fill hex conversion utility option 10-27
fill value. See hole
.float directive 4-12, 4-50
  compatibility with C1x/C2x/C2xx/C5x 4-8
floating-point constants 4-50
.func symbolic debugging directive B-5
function definitions A-17, A-26, A-27, B-5
functions, built-in 3-30, 5-9

G
–g
  assembler option 3-5
  linker option 7-12
.global
  defined F-3
  symbols 7-12
.global directive 4-19, 4-51
  identifying external symbols 2-21
GROUP
  defined F-3
  linker directive 7-50

H
–h
  assembler option 3-5
  linker option 7-12
.half directive 4-13, 4-54
  limiting listing with .option directive 4-17
–hc assembler option 3-5
–heap linker option
  .sysmem section described 7-12
  –heap asm option 3-5
  linker option 7-6
hex conversion utility
  command file 10-7 to 10-8
  controlling ROM device address 10-35 to 10-38
  data width defined 1-3
  described 10-2
  error messages 10-45
  examples
    avoiding holes with multiple sections C-8 to C-9
    building a hex command file for two 8-bit EPROMS C-3 to C-7
    generating a boot table C-10 to C-16, C-17 to C-24
  image mode 10-26 to 10-27
  invoking 10-3 to 10-6
  memory width 10-10 to 10-11
  object formats 10-39 to 10-44
  on-chip boot loader 10-28 to 10-34
  options 10-4
  ordering memory words 10-14 to 10-15
  output filenames 10-24
  ROM width 10-11 to 10-13
  ROMS directive 10-16 to 10-21
  SECTIONS directive 10-22 to 10-23
  target width 10-10
hex500 command 10-3
hexadecimal integer constants 3-16
–hi assembler option 3-5
high-level language debugging, defined F-4
Index

hole
creating 7-66 to 7-68
default fill value 7-11
defined F-4
fill value, linker SECTIONS directive 7-33
filling 7-68 to 7-69
in output sections 7-66 to 7-69
in uninitialized sections 7-69

I

–i
assembler option 3-6, 3-8
hex conversion utility option 10-41
linker option 7-14
I MEMORY attribute 7-29
.if directive 4-20, 4-56
use in macros 5-15
–image hex conversion utility option 10-26
.include directive 3-8, 4-19, 4-36
include files 3-5, 3-8, 4-36
incremental linking
defined F-4
described 7-70 to 7-71
initialized section
defined F-4
described 7-66
initialized sections 2-7
data 2-7, 4-39
.sect 2-7, 4-90
.text 2-7, 4-90
sect 4-80
input
linker 7-3, 7-25 to 7-26
definition 7-4
described 7-38 to 7-40
.int directive 4-13, 4-58
Intel object format 10-41

J

–j linker option 7-16

K

–k linker option 7-16

keywords
allocation parameters 7-35
load 2-19, 7-35, 7-44
run 2-19, 7-35, 7-44 to 7-46

L

–l
assembler option 3-6, 3-8
hex conversion utility option 10-41
linker option 7-13
label
case sensitivity 3-5
cross-reference list 3-37
defined F-4
field 3-12
in assembly language source 3-12
local 3-22, 4-74
symbol used as 3-19
syntax 3-12
using with .byte directive 4-33
.label directive 4-21, 4-60
.idouble directive 4-13, 4-40
LDX pseudo-op 3-32
length
MEMORY specification 7-30
ROMS specification 10-17
.length directive 4-17
.listing control 4-17
library search algorithm 7-13
library-build utility, described 1-3
.line symbolic debugging directive 8-7
line-number, table structure A-12 to A-13
line-number entry
defined F-4
described 7-4
operator 7-40
allocation to multiple memory ranges 7-40
archive members, allocating 7-43
assigning symbols 7-62
assignment expressions 7-62 to 7-64
automatic splitting of output sections 7-41
>> operator 7-41
C code 7-10, 7-72 to 7-75
.COFF 7-1
command files 7-4, 7-21 to 7-24, 7-76
configured memory
defined F-4
Index

linker (continued)
described 1-3
error messages E-1 to E-16
examples 7-76 to 7-78
GROUP statement 7-48, 7-50
handling COFF sections
in the development flow 7-3
input 7-3, 7-21 to 7-24
invoking 7-4 to 7-5
keywords 7-24, 7-44 to 7-46, 7-56
loading a program 2-20
MEMORY directive 2-13, 7-27 to 7-31
object libraries 7-25 to 7-26
operators 7-64
options
  described 7-8 to 7-20
  summary table 7-6 to 7-7
output 7-3, 7-17, 7-76
overlay pages 7-53
overview 7-2
partial linking 7-70 to 7-71
section runtime address 7-44
sections
  in memory map 2-15
  special 7-61
SECTIONS directive 2-13, 7-32 to 7-43
symbols 2-21 to 2-22, 7-62, 7-65
unconfigured memory 7-61
UNION statement 7-48 to 7-50
.list directive 4-17, 4-62
  same effect with .option directive 4-18
lister
  absolute 8-1 to 8-10
  cross-reference 9-1 to 9-6
listing
  cross-reference listing 4-18, 4-76
  enabling 4-62
  file 4-17 to 4-18, 4-41
  creating with the –l option defined
  format 3-33 to 3-36
  list options 4-76
  macro listing 4-68, 4-70
  page eject 4-78
  page length 4-61
  page width 4-61
  substitution symbols 4-83
  suppressing 4-62
  tab size 4-89
little-endian ordering 10-14
lnk500 command 7-4
load address of a section
described 7-44
  referring to with a label 7-45 to 7-47
load linker keyword 2-19, 7-44 to 7-46
loader, defined F-4
loading a program 2-20
local labels 3-22
logical operators 3-26
.long directive 4-13, 4-64
  compatibility with C1x/C2x/C2xx/C5x 4-8
  limiting listing with .option directive 4-17, 4-76
.loop directive 4-20, 4-66
  use in macros 5-15

M

–m linker option 7-16
–m1 hex conversion utility option 10-42
–m2 hex conversion utility option 10-42
–m3 hex conversion utility option macro
  comments conditional assembly defined 5-15 to 5-16
to 5-16
  defining 5-3
directives summary 5-25
disabling macro expansion listing
  formatting the output listing 4-21
  labels 5-17 to 5-18
  libraries 6-14, 6-2
.mlib assembler directive 3-8
.mlist assembler directive 4-70
nested 5-22 to 5-24
parameters 5-6 to 5-13
producing messages 5-19
recursive 5-22 to 5-24
substitution symbols 5-6 to 5-13
using a macro 5-2
macro call, defined F-5
macro definition, defined F-5
macro directive
  summary table 5-25
macro expansion, defined F-5
macro library, defined F-5
magic number, defined F-5
Index

_main 7-11
malloc() 7-12 7-73
map file
creating 7-16
defined 7-78
example
math functions 3-30
member, defined 7-8
_member symbolic debugging directive 3-8
memory
allocation
default 2-14
described 7-58 to 7-60
map
defined 7-8
described 2-14
model 7-27
named 7-37
pool, C language 7-12, 7-73
unconfigured 7-28
widths
described 10-14 to 10-15
ordering memory words 10-14 to 10-15
ROM width 10-11 to 10-13 10-17
target width 10-10
word ordering 10-14 to 10-15
MEMORY linker directive
default model 7-27, 7-58
described 2-13, 7-27 to 7-31
overlay pages 7-53 to 7-57
PAGE option 7-27 to 7-29, 7-60
syntax 7-27 to 7-31
memory ranges
allocation to multiple 7-40
defined 7-27
MEMORY directive 7-29
messages
assembler 0-1 to D-18
linker 5-1 to E-16
.mexit directive 5-3
-mf assembler option 3-6
-mg assembler option 3-6
.mlbin directive 4-68 5-14
use in macros 3-8
.mlit directive 4-17 4-70
listing control 4-17 4-41
use in macros 5-21
.mmreg directive 4-23 4-71
.mmsg directive 4-24 4-42 5-19
listing control 4-17 4-41
.mnem2alg command
mnemonic
defined 7-5
field 3-12
translation to algebraic 11-1 to 11-10
mnemonic-to-algebraic translator utility. See translator
.mnolist directive
listing control 4-17 4-70
use in macros 4-17 4-41
model statement, defined 7-5
Motorola-S object format 10-42

N
name MEMORY specification 7-29
named sections 2-8 A-3
COFF format 2-8 4-60
.sect directive 2-8 4-80
.usect directive 2-8 4-95
nested macros 5-22
.newblock directive 4-23 4-74
.no_remark directive 4-23
.nolist directive 4-17 4-62
same effect with .option directive 4-17
NOLOAD section 7-61
.noremark directive 4-75

O
–o linker option 7-17
object
code source listing 3-34
forms
address bits 10-33
ASCII-Hex 10-40
Intel 10-41
Motorola-S 10-42
output width 10-33
Tektronix 10-44
TI-Tagged 10-43
library
altering search algorithm 7-13
defined 7-6
described 7-25 to 7-26
on-chip boot loader

boot table 10-28 to 10-34
booting from device peripheral 10-34
booting from EPROM 10-34
booting from the parallel port 10-34
booting from the serial port 10-33
controlling ROM device address 10-36 to 10-38
description 10-28, 10-33 to 10-35
options
    –e 10-32
    summary 10-29
setting the entry point 10-32
using the boot loader 10-33 to 10-35

operands
defined 3-13
field 3-13
immediate addressing 3-13
label 3-19
local label 3-22
prefixes 3-13
source statement format 3-13
operator precedence order 3-26

.options directive 4-17, 4-76

optional header
defined 3-4
format 3-6

options
absolute lister 3-3
archiver 3-5
assembler 3-4
cross-reference lister 9-3
defined 3-6
hex conversion utility 10-4 to 10-6
linker 7-6 to 7-20
translator 11-4
–order hex conversion utility option 10-15
ordering memory words 10-14 to 10-15

origin
MEMORY specification 7-29
ROMS specification 10-17
output
executable 7-8 to 7-9
hex conversion utility 10-24
linker 7-3, 7-17, 7-76
module
defined 7-17
name 7-17
section
allocation 7-35 to 7-43
defined 7-6
displaying a message 7-73
rules 7-53
output listing 4-17 to 4-18
output sections, splitting 3-26
overflow in an expression 7-41
overlay page
defined 7-6
described 7-53 to 7-57
using the SECTIONS directive 7-55 to 7-56
overlaying sections 7-48 to 7-50

P

paddr SECTIONS specification 10-23
page
eject 4-78
length 4-81
title 4-91
width 4-91
.page directive 4-18, 4-78
PAGEl option MEMORY directive 7-27 to 7-29
PAGE ROMS specification 10-16
pages
overlay 7-53 to 7-57
PAGE syntax 7-56 to 7-58
parentheses in expressions 3-25
partial linking
defined 7-6
described 7-70 to 7-71
path. See alternate directories; environment variables
pipeline conflicts 3-6
precedence groups 3-25
predefined names, –d assembler option 3-5
prefixes for operands 3-13
program counters. See SPC
program memory 7-27

Index
Index

.pstring directive 4-13 4-85
–pw assembler option 3-6

Q

–q
absolute lister option 8-3
archiver option 6-5
assembler option 3-6
cross-reference lister option 9-3
quiet run defined F-6
linker 7-17

R

–r
archiver command 6-4
assembler option 3-6, 4-75
linker option 7-9, 7-70 to 7-71
R MEMORY attribute 7-29
RAM model
autoinitilization defined F-6
raw data, defined F-6
recursive macros 3-22
.ref directive 4-19 4-51
identifying external symbols 2-21
register symbols 3-20
relational operators 3-27
relocatable
output module symbols 3-28
relocation
at runtime defined F-6
sections 2-16 to 2-18
structuring information A-10 to A-11
.remark directive 4-23 4-75
remarks, suppressing 4-75
reserved words, linker 7-24
resetting local labels 4-74

ROM
device address 10-35 to 10-38
model
autoinitilization defined F-6
width defined F-7
described 10-11 to 10-13
romname ROMS specification 10-16
ROMS hex conversion utility directive 10-16 to 10-21
romwidth ROMS specification 10-17
rts.lib 7-72 7-75
run address defined F-7
of a section 7-44 to 7-46
run linker keyword 2-19 7-44 to 7-46
runtime initialization and support

S

–s
archiver option 6-5
assembler option 3-6
linker option 7-17, 7-70 to 7-71
.sbblock directive 4-23 4-79
.sect directive 2-5 4-9 4-80
.sect section 4-9 4-80
section header defined F-7
described A-7 to A-9
section number A-21
section program counter
See also SPC defined F-7
SECTIONS
hex conversion utility directive 10-22 to 10-23
linker directive
alignment 7-38
allocation 7-35 to 7-43
allocation using multiple memory ranges 7-44
binding 7-36
blocking 7-36
default allocation 7-58 to 7-64
default model 7-24
described 2-12 7-12 to 7-43
fill value 7-33

Index-12
SECTIONS, linker directive (continued)

GROUP 7-50

input sections 7-33 to 7-40
.label directive 7-45 to 7-47
load allocation 7-33
memory 7-37 to 7-38
overlay pages 7-53 to 7-57
reserved words 7-24
run allocation 7-33
section specifications 7-33
section type 7-33
specifying 2-19, 7-44 to 7-47
splitting of output sections 7-32
syntax 7-33
uninitialized sections 7-45
UNION 7-48 to 7-52
use with MEMORY directive 7-27

sections
allocation 7-58 to 7-60
COFF 2-3 to 2-4
creating your own defined F-7
in the linker SECTIONS directive 7-33
initialized 2-7
named 2-3, 2-8
overlaying with UNION directive 7-48 to 7-50
relocation 2-16 to 2-19
special types 7-61
specifications 7-33
specifying a runtime address 7-44 to 7-47
specifying linker input sections 7-38 to 7-40
uninitialized 2-3 to 2-6
initializing 7-69
specifying a run address 7-43

.set directive 4-21, 4-81
.setsect directive 8-8
.setsym directive 8-8
.short directive 4-13, 4-54
sign extend, defined F-7
simulator, defined F-7
.sname SECTIONS specification 10-23

source statement
field 3-34
format 3-12 to 3-14
number in source listing 3-33
.syntax 3-11
.space directive 4-11, 4-82

SPC
aligning
by creating a hole 7-66 to 7-68

to word boundaries 4-15 to 4-16, 4-27

assembler symbol 3-12
assembler’s effect on 2-10 to 2-12
assigning a label to 2-9
defined F-7
described 2-9
linker symbol 7-63, 7-66
maximum number of predefined symbol for value
associated with labels 3-12
shown in source listings 3-33

–spc hex conversion utility option 10-29
–spce hex conversion utility option 10-29

special section types 7-61
special symbols A-16 to A-17

.sslist directive 4-18, 4-83
listing control 4-17, 4-41
use in macros 5-21

.ssnullist directive 4-18, 4-83
listing control 4-17, 4-41
use in macros 5-21

.stack 7-18, 7-73

–stack linker option 7-18, 7-73

__STACK_SIZE 7-18, 7-65

.stag, symbolic debugging directive B-9

static
defined F-7
symbols 7-12
variables A-14

storage class
defined F-7
described A-19

.string directive 4-13, 4-85
compatibility with C1x/C2x/C2xx/C5x 4-8
limiting listing with .option directive 4-18, 4-76

string functions 5-9
Index

string table
  defined F-7
  described A-18
stripping
  line number entries 7-17
  symbolic information 7-17
.pretty directive 4-21 4-86
structure
  .tag 4-21 4-86
  defined F-7
  definitions A-25 B-9
subsections
  defined F-8
  initialized 2-7
  overview 2-9
  uninitialized 2-6
substitution symbols
  arithmetic operations on 4-21 5-8
  as local variables in macros 5-13
  assigning character strings to built-in functions 3-21 4-21
  described 3-21
  directives that define 5-7 to 5-8
  expansion listing 4-18 4-83
  forcing substitution in macros 5-11
  maximum number per macro 5-6 to 5-13
  passing commas and semicolons 5-6
  recursive substitution 5-10
  subscripted substitution 5-12 to 5-13
  .var macro directive 5-13
suppressing assembler remarks 4-75
–swswr hex conversion utility option 10-29
.sym symbolic debugging directive B-11
symbol
  defined F-8
  definitions A-17
  names A-18
symbol table
  creating entries 2-22
  defined F-8
  described 2-22
  entry from .sym directive 5-11
  index A-10
  placing unresolved symbols in special symbols used in stripping entries 7-17
  structure and content 7-17
  values A-14 to A-28
symbolic constants 3-20
symbolic debugging
  –b linker option 7-10
  disable merge for linker
  enumeration definitions 7-10
  file identification B-4
  function definitions B-5
  line number entries B-7
  member definitions B-8
  producing error messages in macros 5-19
  –s assembler option 3-6
  stripping symbolic information 7-17
  structure definitions 3-38
  symbols B-11
  table structure and content A-14 to A-28
  union definitions B-9
symbols
  assembler-defined 3-5
  assigning values to
    at link time 4-21 4-22 4-81 4-86 4-92
  attributes 3-38
  case 3-5
  character strings 3-18
  cross-reference lister 9-6
  cross-reference listing 3-37
  defined
    by the assembler 2-21 to 2-22
    by the linker 7-65
    only for C support 7-65
  described 2-21 to 2-22 3-19
  external 2-21 4-51
  global 7-12
  number of statements that reference predefined
    $ symbol 3-20
    memory-mapped registers 3-20
  relocatable symbols in expressions
  reserved words 7-24
  setting to a constant value 3-18
  statement number that defines substitution 3-37
  unresolved 7-18
  used as labels 3-19
  value assigned 3-37
syntax
  assignment statements 7-62
  .source statement 3-11
  _SYSMEM_SIZE 7-12
  system stack 7-18 7-73
Index

T

–t
archiver command 6-4
hex conversion utility option 10-43
tag, defined F-8
tag directive 4-18, 4-89
target memory, defined F-8
target width 10-10
–tcsr hex conversion utility option 10-29
Tektronix object format 10-44
text directive 2-5, 4-9
linker definition 7-65
text section 4-9, 4-90, A-3
defined F-8
TI-Tagged object format 10-43
title directive 4-18, 4-91
translator
described 11-2
development flow 11-3
input files 11-2
invoking 11-4
limitations 11-2
modes 11-5 to 11-7
options 11-4
output files 11-2
–trta hex conversion utility option 10-29
type entry A-21

U

–u
assembler option 3-6
linker option 7-18
.ubyte directive 4-12, 4-33
.uchar directive 4-12, 4-33
.uhalf directive 4-13, 4-54
.uint directive 4-13, 4-58
 ulong directive 4-13, 4-64
unconfigured memory
defined F-8
described 7-28
DSECT type 7-61
underflow in an expression 3-26
uninitialized sections 2-5 to 2-6
.bss 2-6 4-30
.usect 2-6
defined F-8
described 7-66
initialization of 7-69
specifying a run address 7-45
.usect 4-95
UNION
defined F-8
linker directive 7-48 to 7-52
union
.tag 4-22, 4-92
defined F-8
symbolic debugging directives B-9
.union directive 4-22, 4-92
unsigned, defined F-8
.usect directive 2-5, 4-9, 4-95
compatibility with C1x/C2x/C2xx/C5x 4-8
.usect section 4-9
.ushort directive 4-13, 4-54
.utag symbolic debugging directive B-9
.uword directive 4-13, 4-58

V

–v
archiver option 6-5
assembler option 3-7
linker option 7-19
.var directive 4-98, 5-13
listing control 4-17, 4-41
variables, local, substitution symbols used as 5-13
.vectors 7-34
.version directive 4-23, 4-98

W

–w linker option 7-19
W MEMORY attribute 7-29
well-defined expression
defined F-8
described 3-27
.width directive 4-18, 4-61
listing control 4-17
widths. See memory widths
.wmsg directive 4-24, 4-42, 5-19
listing control 4-17, 4-41

Index-15
### Index

- **word, defined** [F-8](#)
- **word alignment** [4-27](#)
- **.word directive** [4-13](#)
  - limiting listing with .option directive [4-18](#) [4-76](#)
- **-x**
  - archiver command [6-4](#)
  - assembler option [3-7](#) [3-37](#)
  - hex conversion utility option [10-44](#)
  - linker option [7-20](#)
- **X MEMORY attribute** [7-29](#)
- **.xfloat directive** [4-12](#) [4-50](#)
- **.xlong directive** [4-13](#) [4-64](#)
- **xref500 command** [9-3](#)