Using the TSK165x Embedded Tools

GU0108 April 29, 2008

Table of Contents

Manual Purpose and Structure

Windows Users

The documentation explains and describes how to use the TASKING TSK165x toolset to program a TSK165x processor.

You can use the tools either with the graphical Altium Designer or from the command line in a command prompt window.

Structure

The toolset documentation consists of a user's manual (this manual), which includes a Getting Started section, and a separate reference manual (*TSK165x Embedded Tools Reference*).

Start by reading the *Getting Started* in Chapter 1.

The other chapters explain how to use the assembler, linker and the various utilities.

Once you are familiar with these tools, you can use the reference manual to lookup specific options and details to make full use of the TASKING toolset.

The reference manual describes the assembly language.

Short Table of Contents

Conventions Used in this Manual

Notation for syntax

The following notation is used to describe the syntax of command line input:

bold Type this part of the syntax literally.

italics Substitute the italic word by an instance. For example:

filename

Type the name of a file in place of the word *filename*.

{ } Encloses a list from which you must choose an item.

[ ] Encloses items that are optional. For example

as165x [**-?**]

Both **`as165x`** and **`as165x -?`** are valid commands.

| Separates items in a list. Read it as OR.

... You can repeat the preceding item zero or more times.

Example

`as165x` [*option*]... *filename*

You can read this line as follows: enter the command **`as165x`** with or without an option, follow this by zero or more options and specify a *filename*. The following input lines are all valid:

```
as165x test.asm
as165x -g test.asm
as165x -g -l test.asm
```

Not valid is:

```
as165x -g
```

According to the syntax description, you have to specify a filename.

Icons

The following illustrations are used in this manual:


Note: notes give you extra information.


Warning: read the information carefully. It prevents you from making serious mistakes or from loosing information.


This illustration indicates actions you can perform with the mouse. Such as Altium Designer menu entries and dialogs.


Command line: type your input on the command line.


Reference: follow this reference to find related topics.

Related Publications

C Standards

- ISO/IEC 9899:1999(E), Programming languages – C [ISO/IEC]
  More information on the standards can be found at `http://www.ansi.org`
- DSP-C, An Extension to ISO/IEC 9899:1999(E),
  Programming languages – C [TASKING, TK0071-14]

MISRA-C

- Guidelines for the Use of the C Language in Vehicle Based Software [MIRA limited, 1998]
  See also `http://www.misra.org.uk`
- MISRA-C:2004: Guidelines for the use of the C Language in critical systems [MIRA limited, 2004]
  See also `http://www.misra-c.com`

TASKING Tools

- TSK165x Embedded Tools Reference
  [Altium, TR0106]
- TSK165x RISC MCU Core Reference
  [Altium, CR0114]

1 Getting Started with Embedded Software

Summary

This tutorial shows how to create an embedded software project with Altium Designer.

1.1 Introduction

This tutorial presumes you are familiar with programming in C/assembly and have basic knowledge of embedded programming. It contains an overview of the TASKING tools available in Altium Designer. It describes how you can add, create and edit source files in an embedded project and how to build an embedded application. An embedded software project is normally used as a subproject for an FPGA project and once they are built, they are downloaded and executed inside an FPGA device.

The example used in this tutorial is a sample program in assembly. Other examples are supplied in the `\Examples\NanoBoard Common\Processor Examples` folder relative to the installation path.

1.2 Embedded Software Tools

With the TASKING embedded software tools in Altium Designer you can write, compile, assemble and link applications for several targets, such as the TSK51x/TSK52x, TSK80x, TSK165x, PowerPC, TSK3000, MicroBlaze, Nios II and ARM. Figure 1-1 shows all components of the TASKING toolset with their input and output files.

The assembler, linker and debugger are target dependent, whereas the librarian is target independent. The **bold** names in the figure are the executable names of the tools. Substitute ***target*** with one of the supported target names, for example, **as165x** is the TSK165x assembler.

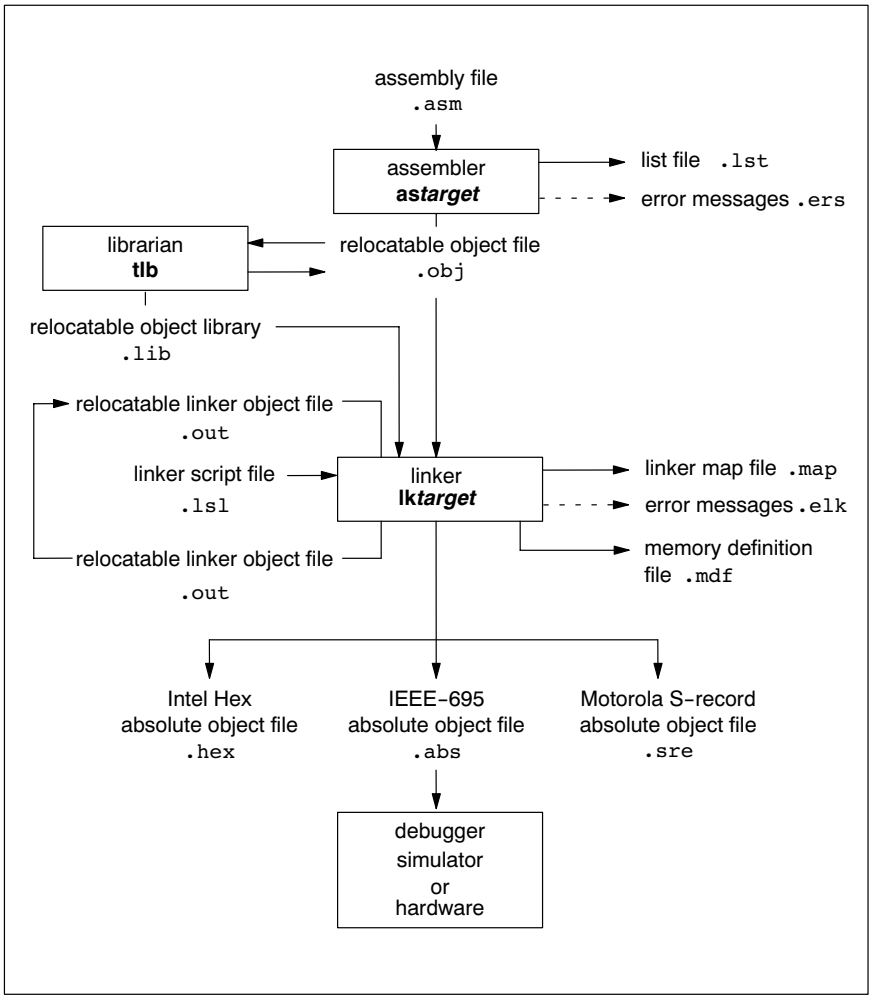


Figure 1-1: Toolset overview

The following table lists the file types used by the TASKING toolset.

Extension	Description
Source files	
.asm	Assembler source file, hand coded
.lsl	Linker script file
Object files	
.obj	IEEE-695 relocatable object file, generated by the assembler
.lib	Archive with IEEE-695 object files
.out	Relocatable linker output file
.abs	IEEE-695 absolute object file, generated by the locating part of the llinker
.hex	Absolute Intel Hex object file
.sre	Absolute Motorola S-record object file
List files	
.lst	Assembler list file
.map	Linker map file
Error list files	
.ers	Assembler error messages file
.elk	Linker error messages file

Table 1-1: File extensions

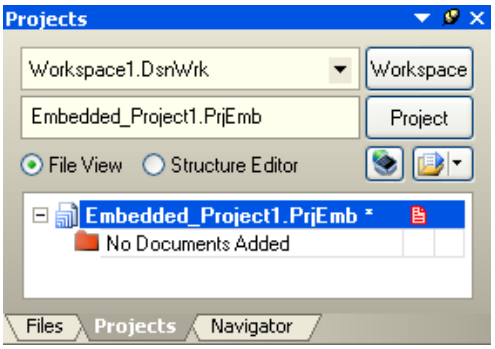
1.3 Creating an Embedded Project

To start working with Altium Designer, you first need a project. A project makes managing your source documents and any generated outputs much easier. For embedded software, you need to create an Embedded Software project.

To create a new Embedded Software project:

1. Select **File » New » Project » Embedded Project** form the menu, or click on **Blank Project (Embedded)** in the **New** section of the **Files** panel. If this panel is not displayed, click on the **Files** tab at the bottom of the Design Manager panel.

   *The **Projects** panel displays a new project file,* `Embedded_Project1.PrjEmb`.



2. Rename the new project file (with a `.PrjEmb` extension) by selecting **File » Save Project As**.

   Navigate to the location where you want to save your project, type the name `GettingStarted.PrjEmb` in the **File name** field and click on **Save**.

1.3.1 Adding a new source file to the project

If you want to add a new source file (assembly or text file) to your project, proceed as follows:

1. In the **Projects** panel, right-click on `GettingStarted.PrjEmb` and select **Add New to Project » Assembly File**.

   A new Assembly source file, `Source1.ASM`*, is added to the Embedded Software project under the folder named* `Source Documents` *in the **Projects** panel. The Text Editor opens ready for your input.*

   
   For a new text file select **Text Document** instead of **Assembly File**.

2. Enter the source code required. For this tutorial enter the following code:

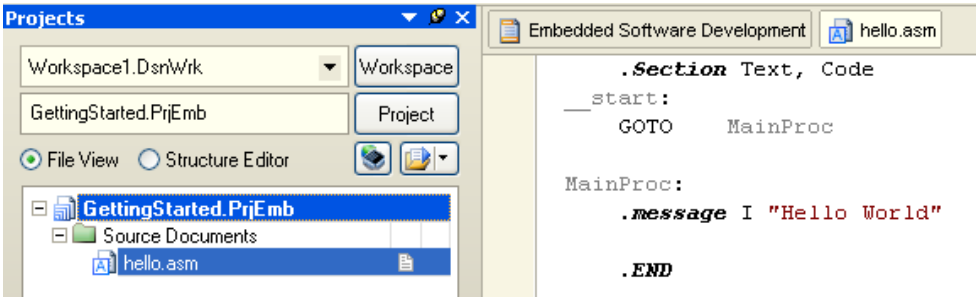
```
    .Section Text, Code
__start:
    GOTO MainProc

MainProc:
    .message I "Hello World"

    .END
```

3. Save the source file by selecting **File » Save As**.

   Navigate to the location where you want to store the source, type the name `hello.asm` in the **File name** field and click on **Save**.

4. Save your project by right-clicking on `GettingStarted.PrjEmb` in the **Projects** panel and select **Save Project**.

   Your project now looks like:



1.3.2 Adding an existing source file to the project

If you want to add an exisiting source file to your project, proceed as follows:

1. In the **Projects** panel, right-click on `GettingStarted.PrjEmb` and select **Add Existing to Project**.

   The Choose Documents to Add to Project dialog appears.

2. Navigate to the file you want to add to your project and click **Open**.

   *The source file is added to the project and listed in the **Projects** panel.*

To edit or view the recently added file in the Text Editor:

3. Double-click on the filename.

Save your project:

4. In the **Projects** panel, right-click on `GettingStarted.PrjEmb` and select **Save Project**.

1.4 Setting the Embedded Project Options

An embedded project in Altium Designer has a set of embedded options associated with it. After you have added files to your project, and have written your application (`hello.asm` in our example), the next steps in the process of building your embedded application are:

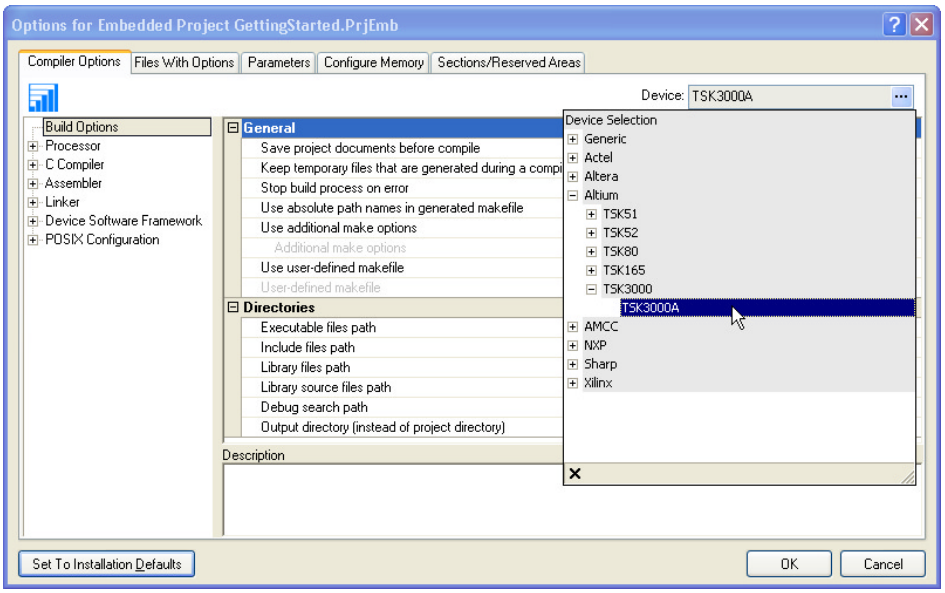
- selecting a device (resulting in an associated toolset)
- specifying the options of the tools in the toolset, such as the assembler and linker options. (Different toolset configurations may have different sets of options.)

1.4.1 Selecting a device

For an embedded project, you must specify the device for which you want to build your embedded project first:

1. In the **Projects** panel, right-click on `GettingStarted.PrjEmb` and select **Project Options**.
   Alternatively: select **Project** » **Project Options**.

   The Options for Embedded Project dialog appears.



2. In the **Compiler Options** tab, select the **Device**. You can make a selection based on manufacturer, or you can select a generic device. If you select a device from a manufacturer, the correct processor type is selected automatically. If you select a generic device, you have to specify the target processor type manually.

To specify the target processor type manually (only for a Generic device):

3. In the left pane, expand the **Processor** entry and select **Processor Definition**.
4. In the right pane, expand the **General** entry and set **Select processor** to the correct target processor.
5. Click **OK** to accept the new device.

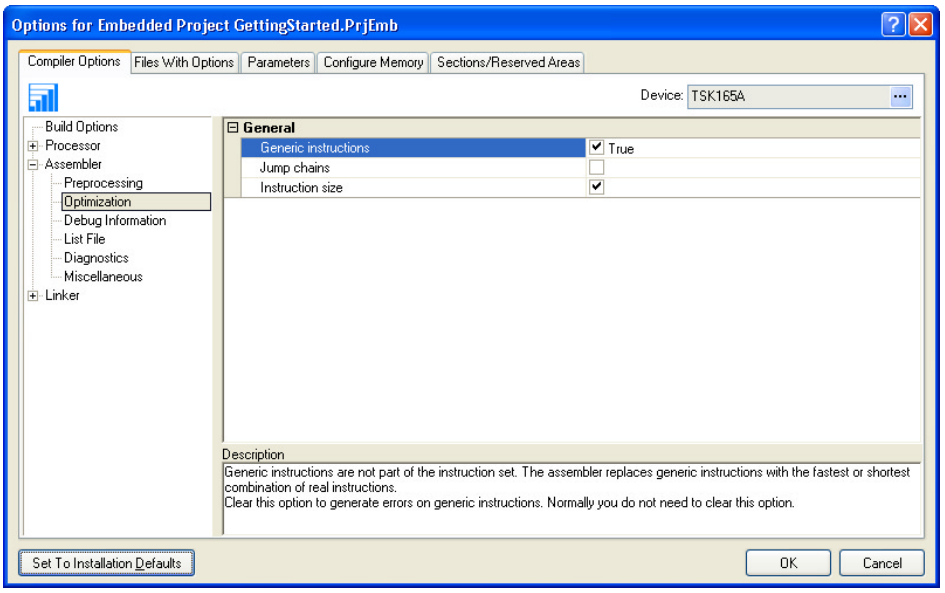
1.4.2 Setting the tool options

You can set embedded options commonly for all files in the project and you can set file specific options.

Setting project wide options

1. In the **Projects** panel, right-click on `GettingStarted.PrjEmb` and select **Project Options**.
   Alternatively: select **Project » Project Options**.

   The Options for Embedded Project dialog appears.



2. In the left pane, expand the **Assembler** entry.
   This entry contains several pages where you can specify assembler settings.
3. In the right pane, set the options to the values you want. Do this for all pages.
4. Repeat steps 2 and 3 for the other tools like the linker.
5. Click **OK** to confirm the new settings.

Based on the embedded project options, Altium Designer creates a so-called *makefile* which it uses to build your embedded application.

On the **Miscellaneous** page of each tool entry, the **Command line options** field shows how your settings are translated to command line options.

Setting options for an individual document

1. In the **Projects** panel, right-click on `hello.asm` and select **Document Options**.
   Alternatively: select **Project » Document Options**.

   The Options for Document dialog appears.

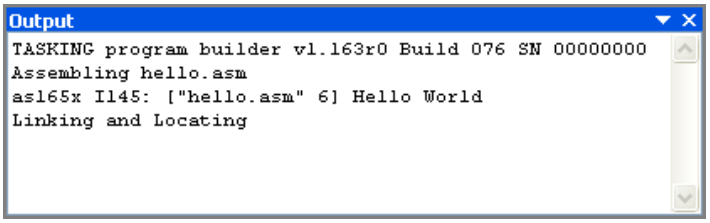
Steps 2 to 5 are the same as the steps for setting project wide options. The **Files With Options** tab in the *Options for Embedded Project* dialog shows which files have deviating settings. If you right-click on a file in this tab, a menu provides you with functions to copy options quickly from and to other individual files.

1.5 Building your Embedded Application

You are now ready to build your embedded application.

1. Select **Project » Compile Embedded Project GettingStarted.PrjEmb** or click on the  button.

   The TASKING program builder compiles, assembles, links and locates the files in the embedded project that are out-of-date or that have been changed during a previous build. The resulting file is the absolute object file `GettingStarted.abs` in the IEEE-695 format.
2. You can view the results of the build in the Output panel (**View » Workspace Panels » System » Output**).



1.5.1 Compiling a single source file

If you want to compile a single source file:

1. Right-click on the file (`hello.asm`) you want to compile and select **Compile Document hello.asm**. Alternatively, you can open a file in the Text Editor and select **Project » Compile Document hello.asm**.
2. Open the Messages panel to view any errors that may have occurred during compilation by selecting **View » Workspace Panels » System » Messages**, or selecting **System » Messages** from the **Panels** tab.
3. Correct any errors in your source files. Save your project files.

1.5.2 Rebuiling your entire application

If you want to build your embedded application from scratch, regardless of their date/time stamp, you can perform a recompile:

1. Select **Project » Recompile Embedded Project GettingStarted.PrjEmb**.
2. The TASKING program builder compiles, assembles, links and locates all files in the embedded project unconditionally.

You can now debug the resulting absolute object file `GettingStarted.abs`.

1.6 Debugging your Embedded Application

When you have built your embedded application, you can start debugging the resulted absolute object file with the simulator.

To start debugging, you have to execute one or more source lines:

- Select one of the source level or instruction level step options (**Debug » Step Into**, **Step Over**) to step through your source or select **Debug » Run** to run the simulation.

  A blue line indicates the current execution position.

To view more information about items such as registers, locals, memory or breakpoints, open the various workspace panels:

- Select **View » Workspace Panels » Embedded » (***a_panel***)**.

To end a debug session:

- Select **Debug » Stop Debugging**.

1.6.1 Setting breakpoints

You can set breakpoints when the embedded source file is opened. Small blue points indicate where you can set breakpoints:

- Click on the left margin next to the source line to toggle a breakpoint on and off.

  A red crossed circle and red line mark the breakpoint.

To change the breakpoint's properties:

- To change the breakpoint, right-click on the breakpoint and select **Breakpoint Properties...**

To disable or enable a breakpoint:

- Right-click on the breakpoint and select **Disable Breakpoint** (or **Enable Breakpoint** when it was disabled)

  A disabled breakpoint is marked with green color.

The breakpoint panel gives an overview of all (disabled) breakpoint and their properties:

- Select **View » Workspace Panels » Embedded » Breakpoints**.

1.6.2 Evaluating and watching expressions

While debugging, you can examine the value of expressions in the **Evaluate** panel.

1. Open the **Evaluate** panel by selecting **View » Workspace Panels » Embedded » Evaluate**.
2. In the edit field enter the expression you want to evaluate and click **Evaluate**.

   *The expression and its value appear below in the **Evaluate** panel. Click on the **Evaluate** button every time the variable in the code is modified.*

To watch an expression continuously, you can set a *watch*:

3. Select **Add Watch**

   *The new expression and its value appear in the **Watches** panel. The values in the **Watches** panel are updated continuously when the code is executing.*

   Alternatively: Select **Debug » Add Watch**; enter an expression and click **OK**.

The way an expression is evaluated, depends strongly on the amount of debug information in the object file. Also the optimization level influences the ease of debugging.

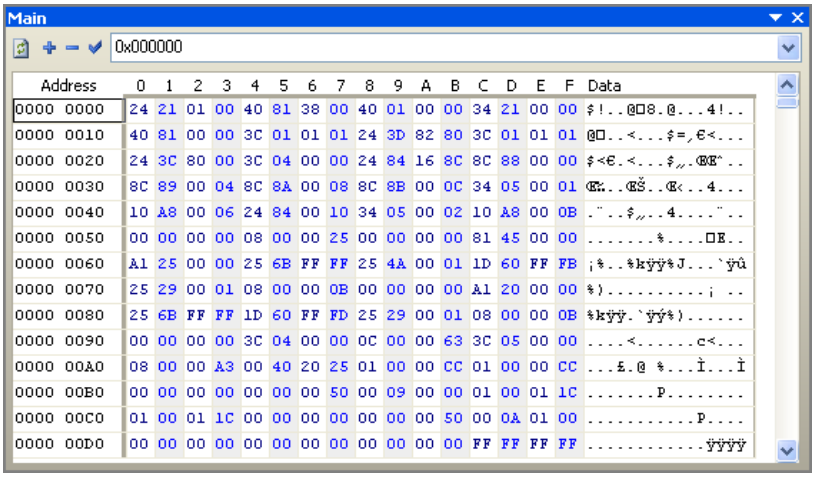
1.6.3 Viewing memory

It is possible to view the contents of the memory. You can open several memory windows. Remember, you must be in debugging mode. The type of memory windows you can open, depends on the selected target processor.

To open for example the Main memory window:

1. Select **View » Workspace Panels » Embedded » Main**.

   The Main memory window opens showing the contents of the memory.



2. In the edit field you can specify the address you want to start viewing from.

2 Using the Assembler

Summary

This chapter describes the assembly process and explains how to call the assembler.

2.1 Introduction

The assembler converts hand-written or compiler-generated assembly language programs into machine language, resulting in object files in the IEEE-695 object format.

The assembler takes the following files for input and output:

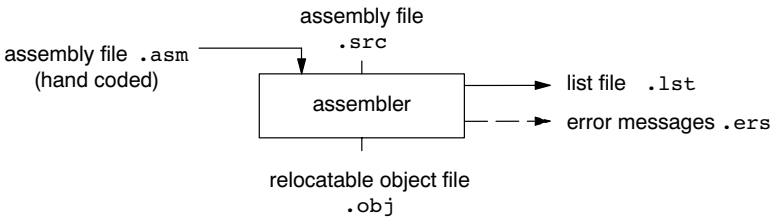


Figure 2-1: Assembler

The following information is described:

- The assembly process.
- How to call the assembler and how to use its options. An extensive list of all options and their descriptions is included in the reference manual.
- The various assembler optimizations.
- How to generate a list file
- Types of assmbler messages

2.2 Assembly Process

The assembler generates relocatable output files with the extension `.obj`. These files serve as input for the linker.

Phases of the assembly process

1. Parsing of the source file: preprocessing of assembler directives and checking of the syntax of instructions
2. Optimization (instruction size and generic instructions)
3. Generation of the relocatable object file and optionally a list file

The assembler integrates file inclusion and macro facilities. See section 1.9, *Macro Operations*, in Chapter *Assembly Language* for more information.

2.3 Calling the Assembler

Altium Designer uses a *makefile* to build your entire project. You can set options specific for the assembler. After you have built your project, the output files of the assembly step are available in your project directory, unless you specified an alternative output directory in the **Build Options** page of the *Project Options* dialog.

To assemble your program

Click either one of the following buttons:

(Compile Active Document)
Assembles the currently selected assembly file (`.asm` or `.src`). This results in a relocatable object file (`.obj`).

(Compile Active Project)
Builds your entire project but only updates files that are out-of-date or have been changed since the last build, which saves time.

Or select **Recompile Embedded Project** from the **Projects** menu.
Builds your entire project unconditionally. All steps necessary to obtain the final `.abs` file are performed.

Select the right toolset

First make sure you have selected the correct toolset for your target.

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Select the correct **Device**.

Select a target processor (core)

If you have selected a toolset that supports several processor cores, by means of a Generic device, you need to choose a processor type first.

To access the processor options:

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Processor** entry and select **Processor Definition**.
3. In the **Select Processor** box select a processor type.

Processor options affect the invocation of all tools in the toolset. In Altium Designer you only need to set them once.

To access the assembler options

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Assembler** entry.
3. Select the sub-entries and set the options in the various pages.

   The command line variant is shown simultaneously.

Invocation syntax on the command line (Windows Command Prompt)

The invocation syntax on the command line is:

```
astarget [ [option]... [file]... ]...
```

The input *file* must be an assembly source file (`.asm` or `.src`). **as***target* can be one of the supported assemblers. For example, **as165x** (for the TSK165x).

Example:

```
as165x test.asm
```

This assembles the file `test.asm` and generates the file `test.obj` which serves as input for the linker.

2.3.1 Overview of Assembler Options

You can set the following assembler options in Altium Designer.

Menu entry	Command line
Build Options	
Include files path	**–I***dir*
Processor » Processor Definition	
Select processor	**–C**[**tsk165a** | **tsk165b** | **tsk165c**]
Assembler » Preprocessing	
User macro	**–D***macro*[=*value*]
Include this file before source	**–H***file*
Assembler » Optimization	
Generic instructions	**–Og**
Jump chains	**–Oj**
Instruction size	**–Os**
Assembler » Debug Information	
Symbolic Debug Generation Automatic HLL or assembly level debug information Custom debug information No debug information	 **–gs** **–gAHLS**
Custom debug information Assembler source line information Pass HLL debug information	**–g***flags* **–ga** **–gh**
Assembler local symbols information	**–gl**
Assembler » List File	
Generate list file	**–l**
Display section information	**–tl**
List file format	**–L***flags*
Assembler » Diagnostics	
Warnings Report all warnings Suppress all warnings Suppress specific warnings	 *no option* **–w** **–w** **–w***num*[,*num*]...
Treat warnings as errors	**––warnings–as–errors**[=*n*,...]
Assembler » Miscellaneous	
Assemble case sensitive (required for C language)	**–c** (case *insensitive*)
Labels are by default: local (default) global	 **–il** **–ig**
Additional assembler options	*options*

Table 2–1: Altium Designer assembler options

The following assembler options are only available on the command line:

Description	Command line
Display invocation syntax	**--help**[=*item*,...]
Check source (check syntax without generating code)	**--check**
Show description of diagnostic(s)	**--diag**=[*fmt*:]{**all**|*nr*,...}
Emit local symbols	**--emit-locals**
Redirect diagnostic messages to a file	**--error-file**[=*file*]
Read options from *file*	**-f** *file*
Keep output file after errors	**-k**
Select TASKING preprocessor or no preprocessor	**-m**{**t**|**n**}
Specify name of output file	**-o** *file*
Verbose information	**-v**
Display version header only	**-V**

Table 2-2: Additional assembler options

For a complete overview of all options with extensive descriptions, see section 2.1, *Assembler Options*, of Chapter *Tool Options* of the reference manual.

2.4 How the Assembler Searches Include Files

When you use include files (with the `.INCLUDE` directive), you can specify their location in several ways. The assembler searches the specified locations in the following order:

1. If the `.INCLUDE` directive contains a path name, the assembler looks for this file. If no path is specified, the assembler looks in the same directory as the source file.
2. When the assembler did not find the include file, it looks in the directories that are specified in the **Build Options** page of the *Project Options* dialog (equivalent to the **-I** command line option).
3. When the assembler did not find the include file (because it is not in the specified include directory or because no directory is specified), it looks in the path(s) specified in the environment variable `AS`*`target`*`INC` (for example, `AS165XINC` for the TSK165x).
4. When the assembler still did not find the include file, it finally tries the default `include` directory relative to the installation directory.

Example

Suppose that the assembly source file `test.asm` contains the following lines:

```
.INCLUDE 'myinc.inc'
```

You can call the assembler as follows:

```
astarget -Imyinclude test.asm
```

First the assembler looks for the file `myinc.inc` in the directory where `test.asm` is located. If the file is not there the assembler searches in the directory `myinclude`. If it was still not found, the assembler searches in the environment variable and then in the default `include` directory.

2.5 Assembler Optimizations

The assembler performs various optimizations to reduce the size of assembled applications. There are two options available to influence the degree of optimization.

To enable or disable optimizations

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Assembler** entry and select **Optimization**.

You can enable or disable the optimizations described below. The command line option for each optimization is given in brackets.


See also option **--optimize (-O)** in section 2.1, *Assembler Options*, in Chapter *Tool Options* of the reference manual.

Allow generic instructions *(option **-Og**/**-OG**)*

When this option is enabled, you can use generic instructions in your assembly source. The assembler tries to replace instructions by faster or smaller instructions.

By default this option is enabled. If you turn off this optimization, generic instructions are not allowed. In that case you have to use hardware instructions.

Optimize jump chains *(option **-Oj**/**-OJ**)*

When this option is enabled, the assembler replaces chained jumps by a single jump instruction. For example, a jump from *a* to *b* immediately followed by a jump from *b* to *c*, is replaced by a jump from *a* to *c*. By default this option is disabled.

Optimize instruction size *(option **-Os**/**-OS**)*

When this option is enabled, the assembler tries to find the shortest possible operand encoding for instructions. By default this option is enabled.

2.6 Generating a List File

The list file is an additional output file that contains information about the generated code. You can customize the amount and form of information.

If the assembler generates errors or warnings, these are reported in the list file just below the source line that caused the error or warning.

To generate a list file

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Assembler** entry and select **List File**.
3. Select **Generate list file**.
4. (Optional) Enable the options to include that information in the list file.

Example on the command line (Windows Command Prompt)

The following command generates the list file `test.lst`:

```
astarget -l test.asm
```

2.7 Assembler Error Messages

The assembler produces error messages of the following types.

F (Fatal errors)

After a fatal error the assembler immediately aborts the assembly process.

E (Errors)

Errors are reported, but the assembler continues assembling. No output files are produced unless you have set the assembler option **--keep-output-files** (the resulting output file may be incomplete).

W (Warnings)

Warning messages do not result into an erroneous assembly output file. They are meant to draw your attention to assumptions of the assembler for a situation which may not be correct. You can control warnings in the **Assembler » Diagnostics** page of the **Project » Project Options...** menu (assembler option **--no-warnings**).

Display detailed information on diagnostics

1. From the **View** menu, select **Workspace Panels » System » Messages**.

   The Messages panel appears.

2. In the **Messages** panel, right-click on the message you want more information on.

   A popup menu appears.

3. Select **More Info**.

   A Message Info box appears with additional information.

On the command line you can use the assembler option **--diag** to see an explanation of a diagnostic message:

```
astarget --diag=[format:]{all | number,...]
```

See assembler option **--diag** in section 2.1, *Assembler Options* in Chapter *Tool Options* of the reference manual.

3 Using the Linker

Summary

This chapter describes the linking process, how to call the linker and how to control the linker with a script file.

3.1 Introduction

The TASKING linker is a combined linker/locator. The linker phase combines relocatable object files (`.obj` files, generated by the assembler), and libraries into a single *relocatable linker object file* (`.out`). The locator phase assigns absolute addresses to the linker object file and creates an absolute object file which you can load into a target processor. From this point the term *linker* is used for the combined linker/locator.

The linker can simultaneously link and locate all programs for all cores available on a target board. The target board may be of arbitrary complexity. A simple target board may contain one standard processor with some external memory that executes one task. A complex target board may contain multiple standard processors and DSPs combined with configurable IP-cores loaded in an FPGA. Each core may execute a different program, and external memory may be shared by multiple cores.

The linker takes the following files for input and output:

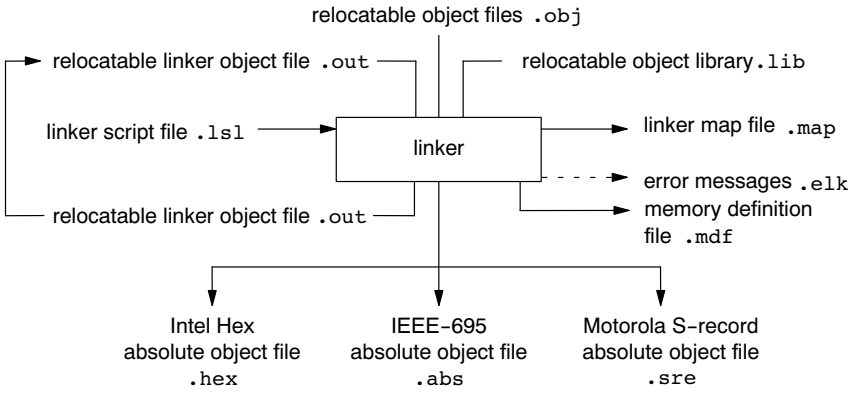


Figure 3-1: Linker

This chapter first describes the linking process. Then it describes how to call the linker and how to use its options. An extensive list of all options and their descriptions is included in section 2.2, *Linker Options*, of the reference manual.

To control the link process, you can write a script for the linker. This chapter shortly describes the purpose and basic principles of the *Linker Script Language* (LSL) on the basis of an example. A complete description of the LSL is included in Chapter 5, *Linker Script Language*, of the reference manual.

3.2 Linking Process

The linker combines and transforms relocatable object files (`.obj`) into a single absolute object file. This process consists of two phases: the linking phase and the locating phase.

In the first phase the linker combines the supplied relocatable object files and libraries into a single relocatable object file. In the second phase, the linker assigns absolute addresses to the object file so it can actually be loaded into a target.

Glossary of terms

Term	Definition
Absolute object file	Object code in which addresses have fixed absolute values, ready to load into a target.
Address	A specification of a location in an address space.
Address space	The set of possible addresses. A core can support multiple spaces, for example in a Harvard architecture the addresses that identify the location of an instruction refer to *code* space, whereas addresses that identify the location of a data object refer to a *data* space.
Architecture	A description of the characteristics of a core that are of interest for the linker. This encompasses the address space(s) and the internal bus structure. Given this information the linker can convert logical addresses into physical addresses.
Copy table	A section created by the linker. This section contains data that specifies how the startup code initializes the data sections. For each section the copy table contains the following fields: – action: defines whether a section is copied or zeroed – destination: defines the section's address in RAM – source: defines the sections address in ROM – length: defines the size of the section in MAUs of the destination space
Core	An instance of an architecture.
Derivative	The design of a processor. A description of one or more cores including internal memory and any number of buses.
Library	Collection of relocatable object files. Usually each object file in a library contains one symbol definition (for example, a function).
Logical address	An address as encoded in an instruction word, an address generated by a core (CPU).
LSL file	The set of linker script files that are passed to the linker.
MAU	Minimum Addressable Unit. For a given processor the number of bits between an address and the next address. This is not necessarily a byte or a word.
Object code	The binary machine language representation of the C source.
Physical address	An address generated by the memory system.
Processor	An instance of a derivative. Usually implemented as a (custom) chip, but can also be implemented in an FPGA, in which case the derivative can be designed by the developer.
Relocatable object file	Object code in which addresses are represented by symbols and thus relocatable.
Relocation	The process of assigning absolute addresses.
Relocation information	Information about how the linker must modify the machine code instructions when it relocates addresses.
Section	A group of instructions and/or data objects that occupy a contiguous range of addresses.
Section attributes	Attributes that define how the section should be linked or located.
Target	The hardware board on which an application is executing. A board contains at least one processor. However, a complex target may contain multiple processors and external memory and may be shared between processors.
Unresolved reference	A reference to a symbol for which the linker did not find a definition yet.

Table 3-1: Glossary of terms

3.2.1 Phase 1: Linking

The linker takes one or more relocatable object files and/or libraries as input. A relocatable object file, as generated by the assembler, contains the following information:

- *Header information*: Overall information about the file, such as the code size, name of the source file it was assembled from, and creation date.
- *Object code*: Binary code and data, divided into various named sections. Sections are contiguous chunks of code that have to be placed in specific parts of the memory. The program addresses start at zero for each section in the object file.
- *Symbols*: Some symbols are exported – defined within the file for use in other files. Other symbols are imported – used in the file but not defined (external symbols). Generally these symbols are names of routines or names of data objects.

- *Relocation information*: A list of places with symbolic references that the linker has to replace with actual addresses. When in the code an external symbol (a symbol defined in another file or in a library) is referenced, the assembler does not know the symbol's size and address. Instead, the assembler generates a call to a preliminary relocatable address (usually 0000), while stating the symbol name.
- *Debug information*: Other information about the object code that is used by a debugger. The assembler optionally generates this information and can consist of line numbers, C source code, local symbols and descriptions of data structures.

The linker resolves the external references between the supplied relocatable object files and/or libraries and combines the files into a single relocatable linker object file.

The linker starts its task by scanning all specified relocatable object files and libraries. If the linker encounters an unresolved symbol, it remembers its name and continues scanning. The symbol may be defined elsewhere in the same file, or in one of the other files or libraries that you specified to the linker. If the symbol is defined in a library, the linker extracts the object file with the symbol definition from the library. This way the linker collects all definitions and references of all of the symbols.

Next, the linker combines sections with the same section name and attributes into single sections. The linker also substitutes (external) symbol references by (relocatable) numerical addresses where possible. At the end of the linking phase, the linker either writes the results to a file (a single relocatable object file) or keeps the results in memory for further processing during the locating phase.

The resulting file of the linking phase is a single relocatable object file (`.out`). If this file contains unresolved references, you can link this file with other relocatable object files (`.obj`) or libraries (`.lib`) to resolve the remaining unresolved references.

With the linker command line option **--link-only**, you can tell the linker to only perform this linking phase and skip the locating phase. The linker complains if any unresolved references are left.

3.2.2 Phase 2: Locating

In the locating phase, the linker assigns absolute addresses to the object code, placing each section in a specific part of the target memory. The linker also replaces references to symbols by the actual address of those symbols. The resulting file is an absolute object file which you can actually load into a target memory. Optionally, when the resulting file should be loaded into a ROM device the linker creates a so-called copy table section which is used by the startup code to initialize the data sections.

Code modification

When the linker assigns absolute addresses to the object code, it needs to modify this code according to certain rules or *relocation expressions* to reflect the new addresses. These relocation expressions are stored in the relocatable object file. Consider the following snippet of x86 code that moves the contents of variable `a` to variable `b` via the `eax` register:

```
A1 3412 0000 mov a,%eax    (a defined at 0x1234, byte reversed)
A3 0000 0000 mov %eax,b    (b is imported so the instruction refers to
                              0x0000 since its location is unknown)
```

Now assume that the linker links this code so that the section in which `a` is located is relocated by 0x10000 bytes, and `b` turns out to be at 0x9A12. The linker modifies the code to be:

```
A1 3412 0100 mov a,%eax    (0x10000 added to the address)
A3 129A 0000 mov %eax,b    (0x9A12 patched in for b)
```

These adjustments affect instructions, but keep in mind that any pointers in the data part of a relocatable object file have to be modified as well.

Output formats

The linker can produce its output in different file formats. The default IEEE-696 format (`.abs`) contains an image of the executable code and data, and can contain additional debug information. The Intel-Hex format (`.hex`) and Motorola S-record format (`.sre`) only contain an image of the executable code and data. You can specify a format with the options **--output** (**-o**) and **--chip-output** (**-c**).

Controlling the linker

Via a so-called *linker script file* you can gain complete control over the linker. The script language is called the *Linker Script Language* (LSL). Using LSL you can define:

- The memory installed in the embedded target system:

To assign locations to code and data sections, the linker must know what memory devices are actually installed in the embedded target system. For each physical memory device the linker must know its start-address, its size, and whether the memory is read-write accessible (RAM) or read-only accessible (ROM).

- How and where code and data should be placed in the physical memory:

  Embedded systems can have complex memory systems. If for example on-chip and off-chip memory devices are available, the code and data located in internal memory is typically accessed faster and with dissipating less power. To improve the performance of an application, specific code and data sections should be located in on-chip memory. By writing your own LSL file, you gain full control over the locating process.

- The underlying hardware architecture of the target processor.

  To perform its task the linker must have a model of the underlying hardware architecture of the processor you are using. For example the linker must know how to translate an address used within the object file (a logical address) into an offset in a particular memory device (a physical address). In most linkers this model is hard coded in the executable and can not be modified. For the TASKING linker this hardware model is described in the linker script file. This solution is chosen to support configurable cores that are used in system-on-chip designs.

When you want to write your own linker script file, you can use the standard linker script files with architecture descriptions delivered with the product.

See also section 3.7, *Controlling the Linker with a Script*.

3.3 Calling the Linker

In Altium Designer you can set options specific for the linker. Altium Designer creates and uses a *makefile* to build your entire project. After you have build your project, the output files of the linking step are available in your project directory, unless you specified an alternative output directory in the **Build Options** page of the *Project Options* dialog.

To link your program

Click the following button:

(Compile Active Project)
Builds your entire project but only updates files that are out-of-date or have been changed since the last build, which saves time.

Or select **Recompile Embedded Project** from the **Projects** menu.
Builds your entire project unconditionally. All steps necessary to obtain the final `.abs` file are performed.

To access the linker options

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Linker** entry.
3. Select the sub-entries and set the options in the various pages.

   The command line variant is shown simultaneously.

Invocation syntax on the command line (Windows Command Prompt)

The invocation syntax on the command line is:

```
lk165x [ [option]... [file]... ]...
```

When you are linking multiple files, either relocatable object files (`.obj`) or libraries (`.lib`), it is important to specify the files in the right order. This is explained in Section 3.4, *Linking with Libraries*.

Example:

```
lk165x -d165x.lsl test.obj
```

This links and locates the file `test.obj` and generates the file `test.abs`.

3.3.1 Overview of Linker Options

You can set the following linker options in Altium Designer.

Menu entry	Command line
Build Options	
Library files path	**-L***dir*
Linker » Output Format	
Output format Absolute file for debuggers (.abs) Library for TASKING linker (.lib)	**-o**[*file*][**:***format*[**:***addr_size*]]...
Intel Hex records for EPROM programmers (.hex) Motorola S-records for EPROM programmers (.sre)	**-c**[*basename*]**:IHEX**[**:***addr_size*]**,**... **-c**[*basename*]**:SREC**[**:***addr_size*]**,**...
Linker » Optimization	
Optimization level No optimization Default optimization Full optimization Custom optimization	 **-O0** **-O1** **-O2**
Custom optimization	**-O***flags*
Linker » Map File	
Generate a memory map file (`.map`)	**-M**
Map file format	**-m***flags*
Linker » Diagnostics	
Error reporting Report all warnings Suppress all warnings Suppress specific warnings	 *no option* **-w** **-w** **-w***num*[,*num*]...
Treat warnings as errors	**--warnings-as-errors**
Linker » Miscellaneous	
Include symbolic debug information	**-S** (strips debug information)
Link case sensitive (required for C language)	**--case-insensitive**
Dump processor and memory info from LSL file	**--lsl-dump**[=*file*]
Use project specific LSL file	**-d***file*
Additional linker options	*options*

Table 3-2: Altium Designer Linker options

The following linker options are only available on the command line:

Description	Command line
Display invocation syntax	**--help**[=*item*,...]
Define preprocessor *macro*	**-D***macro*[=*def*]
Show description of diagnostic(s)	**--diag**=[*fmt*:]{**all**|*nr*,...}
Specify a symbol as unresolved external	**-e***symbol*
Redirect diagnostic messages to a file with extension `.elk`	**--error-file**[=*file*]
Read options from *file*	**-f** *file*
Scan libraries in given order	**--first-library-first**
Add *dir* to LSL include file search path	**-I***dir*
Search only in **-L** directories, not in default path	**--ignore-default-library-path**
Import a binary file containing raw data	**--import-object**=*file*,...
Keep output files after errors	**-k**
Link only, do not locate	**--link-only**
Check LSL file(s) and exit	**--lsl-check**
Do not generate ROM copy	**-N**
Locate all ROM sections in RAM	**--non-romable**
Link incrementally	**-r**
Display version header only	**-V**
Verbose / extra verbose information	**-v** / **-vv**

Table 3-3: Additional Linker options

For a complete overview of all options with extensive description, see section 2.2, *Linker Options*, of the reference manual.

3.4 Linking with Libraries

User library

You can create your own libraries. Section 4.4, *Librarian*, in Chapter *Using the Utilities*, describes how you can use the librarian to create your own library with object modules.

To link user libraries

1. From the **Project** menu, select **Add Existing to Project...**

   The Choose Documents to add to Project dialog box appears.

2. Select the libraries you want to add and click **Open**.
3. Click **OK** to accept the new project settings.

When you want to link user libraries from the command line, you must specify their filenames on the command line:

If the library resides in a sub-directory, specify that directory with the library name:

If you do not specify a directory, the linker searches the library in the current directory only.

Library order

The order in which libraries appear on the command line is important. By default the linker processes object files and libraries in the order in which they appear at the command line.

With the option **--first-library-first** you can tell the linker to scan the libraries from left to right, and extract symbols from the first library where the linker finds it. This can be useful when you want to use newer versions of a library routine:

If the file `test.obj` calls a function which is both present in `a.lib` and `b.lib`, normally the function in `b.lib` would be extracted. With this option the linker first tries to extract the symbol from the first library `a.lib`.

Note that routines in `b.lib` that call other routines that are present in both `a.lib` and `b.lib` are now also resolved from `a.lib`.

3.4.1 How the Linker Extracts Objects from Libraries

A library built with the TASKING librarian **tlb** always contains an index part at the beginning of the library. The linker scans this index while searching for unresolved externals. However, to keep the index as small as possible, only the defined symbols of the library members are recorded in this area.

When the linker finds a symbol that matches an unresolved external, the corresponding object file is extracted from the library and is processed. After processing the object file, the remaining library index is searched. If after a complete search of the library unresolved externals are introduced, the library index will be scanned again. After all files and libraries are processed, and there are still unresolved externals and you did not specify the linker option **--no-rescan**, all libraries are rescanned again. This way you do not have to worry about the library order on the command line and the order of the object files in the libraries.

The **--verbose** option shows how libraries have been searched and which objects have been extracted.

Resolving symbols

If you are linking from libraries, only the objects that contain symbols to which you refer, are extracted from the library. This implies that if you invoke the linker like:

nothing is linked and no output file will be produced, because there are no unresolved symbols when the linker searches through `mylib.lib`.

It is possible to force a symbol as external (unresolved symbol) with the option **--extern** (**-e**):

In this case the linker searches for the symbol `main` in the library and (if found) extracts the object that contains `main`. If this module contains new unresolved symbols, the linker looks again in `mylib.lib`. This process repeats until no new unresolved symbols are found.

3.5 Incremental Linking

With the TASKING linker it is possible to link *incrementally*. Incremental linking means that you link some, but not all `.obj` modules to a relocatable object file `.out`. In this case the linker does not perform the locating phase. With the second invocation, you specify both new `.obj` files as the `.out` file you had created with the first invocation.


Incremental linking is only possible on the command line.

```
lk165x -d165x.lsl -r test1.obj -otest.out
lk165x -d165x.lsl test2.obj test.out
```

This links the file `test1.obj` and generates the file `test.out`. This file is used again and linked together with `test2.obj` to create the file `test.abs` (the default name if no output filename is given in the default IEEE-695 format).

With incremental linking it is normal to have unresolved references in the output file until all `.obj` files are linked and the final `.out` or `.abs` file has been reached. The option **--incremental** (**-r**) for incremental linking also suppresses warnings and errors because of unresolved symbols.

3.6 Linker Optimizations

During the linking and locating phase, the linker looks for opportunities to optimize the object code. Both code size and execution speed can be optimized.

To enable or disable optimizations

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Linker** entry and select **Optimization**.

You can enable or disable the optimizations described below. The command line option for each optimization is given in brackets.


See also option **--optimize** (**-O**) in section 2.2, *Linker Options*, in Chapter *Tool Options* of the reference manual.

Delete unreferenced sections *(option **-Oc**/**-OC**)*

This optimization removes unused sections from the resulting object file. Because debug information normally refers to all sections, the optimization has no effect until you compile your project without debug information or use linker option **--strip-debug** to remove the debug information.

First fit decreasing *(option **-Ol**/**-OL**)*

When the physical memory is fragmented or when address spaces are nested it may be possible that a given application cannot be located although the size of the available physical memory is larger than the sum of the section sizes. Enable the first-fit-decreasing optimization when this occurs and re-link your application.

The linker's default behavior is to place sections in the order that is specified in the LSL file (that is, working from low to high memory addresses or vice versa). This also applies to sections within an unrestricted group. If a memory range is partially filled and a section must be located that is larger than the remainder of this range, then the section and all subsequent sections are placed in a next memory range. As a result of this gaps occur at the end of a memory range.

When the first-fit-decreasing optimization is enabled the linker will first place the largest sections in the smallest memory ranges that can contain the section. Small sections are located last and can likely fit in the remaining gaps.

Copy table compression *(option **-Ot**/**-OT**)*

The startup code initializes the application's data areas. The information about which memory addresses should be zeroed and which memory ranges should be copied from ROM to RAM is stored in the copy table.

When this optimization is enabled the linker will try to locate sections in such a way that the copy table is as small as possible thereby reducing the application's ROM image.

Delete duplicate code *(option **–Ox**/**–OX**)*
Delete duplicate constant data *(option **–Oy**/**–OY**)*

These two optimizations remove code and constant data that is defined more than once, from the resulting object file.

3.7 Controlling the Linker with a Script

With the options on the command line you can control the linker's behavior to a certain degree. From Altium Designer it is also possible to determine where your sections will be located, how much memory is available, which sorts of memory are available, and so on. Altium Designer passes these locating directions to the linker via a script file. If you want even more control over the locating process you can supply your own script.

The language for the script is called the *Linker Script Language*, or shortly LSL. You can specify the script file to the linker, which reads it and locates your application exactly as defined in the script. If you do not specify your own script file, the linker always reads a standard script file which is supplied with the toolset.

3.7.1 Purpose of the Linker Script Language

The Linker Script Language (LSL) serves three purposes:

1. It provides the linker with a definition of the target's core architecture. This definition is supplied with the toolset.
2. It provides the linker with a specification of the memory attached to the target processor.
3. It provides the linker with information on how your application should be located in memory. This gives you, for example, the possibility to create overlaying sections.

The linker accepts multiple LSL files. You can use the specifications of the core architectures that Altium has supplied in the `include.lsl` directory. Do not change these files.

If you use a different memory layout than described in the LSL file supplied for the target core, you must specify this in a separate LSL file and pass both the LSL file that describes the core architecture and your LSL file that contains the memory specification to the linker. Next you may want to specify how sections should be located and overlaid. You can do this in the same file or in another LSL file.

LSL has its own syntax. In addition, you can use the standard C preprocessor keywords, such as `#include` and `#define`, because the linker sends the script file first to the C preprocessor before it starts interpreting the script.


The complete syntax is described in Chapter 5, *Linker Script Language*, in the reference manual.

3.7.2 Altium Designer and LSL

In Altium Designer you can specify the size of the stack and heap; the physical memory attached to the processor; identify that particular address ranges are reserved; and specify which sections are located where in memory. Altium Designer translates your input into an LSL file that is stored in the project directory under the name *`project`*`.lsl` and passes this file to the linker.

If you want to learn more about LSL you can inspect the generated file *`project`*`.lsl`.

To change the LSL settings

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.
2. Open the **Configure Memory** tab.
3. Make your changes to the memory layout.
4. Open the **Sections**/**Reserved Areas** tab.
5. Make your changes to the list of sections and/or reserved areas.

Each time you close the *Project Options* dialog the file *`project`*`.lsl` is updated and you can immediately see how your settings are encoded in LSL.

Note that Altium Designer supports ChromaCoding (applying color coding to text) and template expansion when you edit LSL files.

3.7.3 Structure of a Linker Script File

A script file consists of several definitions. The definitions can appear in any order.

The architecture definition (required)

In essence an *architecture definition* describes how the linker should convert logical addresses into physical addresses for a given type of core. If the core supports multiple address spaces, then for each space the linker must know how to perform this conversion. In this context a physical address is an offset on a given internal or external bus. Additionally the architecture definition contains information about items such as the (hardware) stack and the vector table.

This specification is normally written by Altium. Altium supplies LSL files in the `include.lsl` directory. The architecture definition of the LSL file should not be changed by you unless you also modify the core's hardware architecture. If the LSL file describes a multi-core system an architecture definition must be available for each different type of core.

The linker uses the architecture name in the LSL file to identify the target. For example, the default library search path can be different for each core architecture.

The derivative definition

The *derivative definition* describes the configuration of the internal (on-chip) bus and memory system. Basically it tells the linker how to convert offsets on the buses specified in the architecture definition into offsets in internal memory. Microcontrollers and DSPs often have internal memory and I/O sub-systems apart from one or more cores. The design of such a chip is called a *derivative*.

When you design an FPGA together with a PCB, the components on the FPGA become part of the board design and there is no need to distinguish between internal and external memory. For this reason you probably do not need to work with derivative definitions at all. There are, however, two situations where derivative definitions are useful:

1. When you re-use an FPGA design for several board designs it may be practical to write a derivative definition for the FPGA design and include it in the project LSL file.
2. When you want to use multiple cores of the same type, you must instantiate the cores in a derivative definition, since the linker automatically instantiates only a single core for an unused architecture.

The processor definition

The *processor definition* describes an instance of a derivative. A processor definition is only needed in a multi-processor embedded system. It allows you to define multiple processors of the same type.

If for a derivative 'A' no processor is defined in the LSL file, the linker automatically creates a processor named 'A' of derivative 'A'. This is why for single-processor applications it is enough to specify the derivative in the LSL file.

The memory and bus definitions (optional)

Memory and bus definitions are used within the context of a derivative definition to specify internal memory and on-chip buses. In the context of a board specification the memory and bus definitions are used to define external (off-chip) memory and buses. Given the above definitions the linker can convert a logical address into an offset into an on-chip or off-chip memory device.

The board specification

The processor definition and memory and bus definitions together form a *board specification*. LSL provides language constructs to easily describe single-core and heterogeneous or homogeneous multi-core systems. The board specification describes all characteristics of your target board's system buses, memory devices, I/O sub-systems, and cores that are of interest to the linker. Based on the information provided in the board specification the linker can for each core:

- convert a logical address to an offset within a memory device
- locate sections in physical memory
- maintain an overall view of the used and free physical memory within the whole system while locating

The section layout definition (optional)

The optional *section layout definition* enables you to exactly control where input sections are located. Features are provided such as: the ability to place sections at a given address, to place sections in a given order, and to overlay code and/or data sections.

Example: Skeleton of a Linker Script File

A linker script file that defines a derivative ”X”' based on the c165x architecture, its external memory and how sections are located in memory, may have the following skeleton:

```
architecture c165x
{
    // Specification of the c165x core architecture.
    // Written by Altium.
}

derivative X            // derivative name is arbitrary
{
    // Specification of the derivative.
    // Written by Altium.
    core c165x          // always specify the core
    {
       architecture = c165x;
    }

    bus data_bus        // data bus
    {
       // maps to data_bus in ”c165x” core
    }

    // internal memory
}

processor proc1        // processor name is arbitrary
{
    derivative = X;

    // You can omit this part, except if you use a
    // multi-core system.
}

memory ext_name
{
    // external memory definition
}

section_layout proc1:c165x:data    // section layout
{
    // section placement statements

    // sections are located in address space ’data’
    // of core ’c165x’ of processor ’proc1’
}
```

3.7.4 The Architecture Definition

Although you will probably not need to program the architecture definition (unless you are building your own processor core) it helps to understand the Linker Script Language and how the definitions are interrelated.

Within an *architecture definition* the characteristics of a target processor core that are important for the linking process are defined. These include:

- space definitions: the logical address spaces and their properties
- bus definitions: the I/O buses of the core architecture
- mappings: the address translations between logical address spaces, the connections between logical address spaces and buses and the address translations between buses

Address spaces

A logical address space is a memory range for which the core has a separate way to encode an address into instructions. Most microcontrollers and DSPs support multiple address spaces. For example, separate spaces for code and data. Normally, the size of an address space is 2^N, with *N* the number of bits used to encode the addresses.

The relation of an address space with another address space can be one of the following:

- one space is a subset of the other. These are often used for ”small” absolute, and relative addressing.
- the addresses in the two address spaces represent different locations so they do not overlap. This means the core must have separate sets of address lines for the address spaces. For example, in Harvard architectures we can identify at least a code and a data memory space.

Address spaces (even nested) can have different minimal addressable units (MAU), alignment restrictions, and page sizes. All address spaces have a number that identifies the logical space (id). The following table lists the different address spaces.

Space	Id	MAU	Description
data	1	8	Data space (4 banks of 32 bytes)
code	2	12	Code address space
bit	3	1	Bit addressable data (data space)

Table 3-4: TSK165x address spaces

The TSK165x architecture in LSL notation

The best way to program the architecture definition, is to start with a drawing. The figure below shows a part of the TSK165x architecture `c165x` (sizes are for the TSK165B):

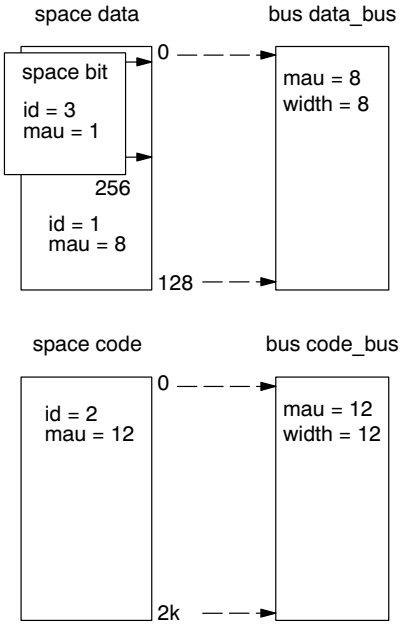


Figure 3-2: Scheme of the c165x architecture

The figure shows three address spaces called `data`, `bit` and `code`. The address space `bit` is a subset of the address space `data`. All address spaces have attributes like a number that identifies the logical space (id), a MAU and an alignment. In LSL notation the definition of these address spaces look as follows:

```
space data
{
  id  = 1;
  mau = 8;
  map (src_offset=0x00, dest_offset=0x00, size=0x10, dest=bus:data_bus);
  map (src_offset=0x10, dest_offset=0x10, size=0x10, dest=bus:data_bus);
  map (src_offset=0x20, dest_offset=0x00, size=0x10, dest=bus:data_bus);
  map (src_offset=0x30, dest_offset=0x30, size=0x10, dest=bus:data_bus);
  map (src_offset=0x40, dest_offset=0x00, size=0x10, dest=bus:data_bus);
  map (src_offset=0x50, dest_offset=0x50, size=0x10, dest=bus:data_bus);
  map (src_offset=0x60, dest_offset=0x00, size=0x10, dest=bus:data_bus);
  map (src_offset=0x70, dest_offset=0x70, size=0x10, dest=bus:data_bus);
}

space bit
{
  id  = 3;
  mau = 1;
  map (size=0x100, dest=space:data);
}

space code
{
  id  = 2;
  mau = 12;
  map (size=2k, dest=bus:code_bus);
}
```

The keyword `map` corresponds with the arrows in the drawing. You can map:

- address space => address space
- address space => bus
- memory => bus (not shown in the drawing)
- bus => bus (not shown in the drawing)

Next the two internal buses named `data_bus` and `code_bus` must be defined in LSL:

```
bus data_bus
{
    mau = 8;
    width = 8;  // there are 8 data lines on the bus
}

bus code_bus
{
    mau = 12;
    width = 12;
}
```

This completes the LSL code in the architecture definition. Note that all code above goes into the architecture definition, thus between:

```
architecture c165x
{
    All code above goes here.
}
```

3.7.5 The Derivative Definition

When you are building a personal ASIC (using FPGAs) you will probably not need to program the derivative definition (unless you are using multiple cores), but the description below helps to understand the Linker Script Language and how the definitions are interrelated.

A *derivative* is the design of a processor, as implemented on an FPGA. It comprises one or more cores and on-chip memory. The derivative definition includes:

- core definition: an instance of a core architecture
- bus definition: the I/O buses of the core architecture
- memory definitions: internal (or on-chip) memory

Core

Each derivative must have at least one core and each core must have a specification of its core architecture. This core architecture must be defined somewhere in the LSL file(s).

```
core c165x
{
   architecture = c165x;
}
```

Bus

Each derivative can contain a bus definition for connecting external memory. In this example, the bus `data_bus` maps to the bus `data_bus` defined in the architecture definition of core `c165x`:

```
bus data_bus
{
   mau = 8;
   width = 8;
   map (dest=bus:c165x:data_bus, dest_offset=0, size=128);
}
```

Memory

Memory is usually described in a separate memory definition, but you can specify on-chip memory for a derivative. For example:

```
memory internal_code_rom
{
     type = rom;
     size = 2k;
     mau = 8;
     map(dest = bus:code_bus, size=2k,
         dest_offset = 0x00);  // src_offset is zero by default)
}
```

This completes the LSL code in the derivative definition. Note that all code above goes into the derivative definition, thus between:

```
derivative X    // name of derivative
{
    All code above goes here.
}
```

If you create a derivative and you want to use Altium Designer to select sections, the derivative must be called ”c165x” for the TSK165x, since Altium Designer uses this name in the generated LSL file. If you want to specify memory in Altium Designer, the custom derivative must contain the buses ”data_bus” and ”code_bus” for the same reasons.

3.7.6 The Processor Definition: Using Multi-Processor Systems

The processor definition is only needed when you write an LSL file for a multi-processor embedded system. The processor definition explicitly instantiates a derivative, allowing multiple processors of the same type.

```
processor proc_name
{
   derivative = deriv_name;
}
```

If no processor definition is available that instantiates a derivative, a processor is created with the same name as the derivative.

3.7.7 The Memory Definition

Once the core architecture is defined in LSL, you may want to extend the processor with memory. You need to specify the location and size of the physical external memory devices in the target system.

The principle is the same as defining the core's architecture but now you need to fill the memory definition:

```
memory name
{
    memory definitions.
}
```

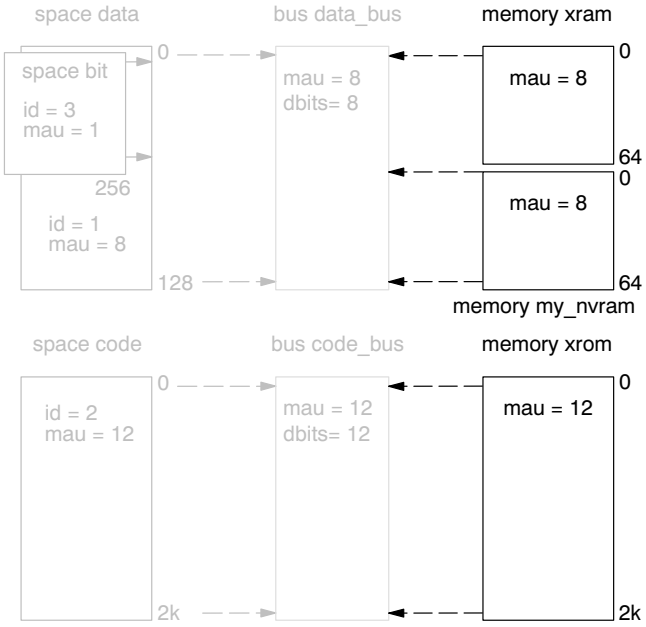


Figure 3-3: Adding external memory to the c165x architecture

Suppose your embedded system has 64 bytes of internal RAM, named `xram` and 64 bytes of external NVRAM, named `my_nvram` and 2k of external ROM, named `xrom` (see figure above.) `xram` and `my_nvram` are connected to the bus `data_bus` and `xrom` is connected to the bus `code_bus`. In LSL this looks like follows:

```
memory xram
{
     mau = 8;
     type = ram;
     size = 64;
     map (dest = bus:X:data_bus, src_offset = 0, dest_offset = 0,
          size=64);
}
```

```
memory my_nvram
{
     mau = 8;
     type = ram;
     size = 64;
     map (dest = bus:X:data_bus, src_offset = 0, dest_offset = 64,
          size=64);
}

memory xrom
{
     mau = 12;
     type = rom;
     size = 2k;
     map (dest = bus:X:code_bus, src_offset = 0, dest_offset = 0,
          size=2k);
}
```

If you use a different memory layout than described in the LSL file supplied for the target core, you can specify this in Altium Designer or you can specify this in a separate LSL file and pass both the LSL file that describes the core architecture and your LSL file that contains the memory specification to the linker.

In order to bypass the default memory setup, your memory definition file must contain a `#define __MEMORY`, and you must specify this file *before* the core architecture LSL file.

Adding memory using Altium Designer

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Open the **Configure Memory** tab.
3. Disable the check box **Automatically import when compiling FPGA project**.
4. Right-click in the tab and select **Add Memory...**

   The Processor Memory Definition dialog box appears.

5. Specify a new physical memory device, for example `my_nvram`.

3.7.8 The Section Layout Definition: Locating Sections

Once you have defined the internal core architecture and optional memory, you can actually define where your application must be located in the physical memory.

Sections have a name, an indication (section type) in which address space it should be located and attributes like writable or read-only.

In the section layout definition you can exactly define how input sections are placed in address spaces, relative to each other, and what their absolute run-time and load-time addresses will be.

Example: section propagation through the toolset

As an example consider the following assembly part:

```
        .section  non_volatile, data, clear
        .global  _battery_backup_invok
_battery_backup_invok:
        .ds      2
```

This defines a section with the name ”non_volatile” of section type ”data” carrying section attribute ”clear”. The section type and attributes tell the linker to locate the section in address space `data` and that the section content should be filled with zeros at startup.

Section placement

The data of the example should be saved in non-volatile (battery back-upped) memory. This is the memory `my_nvram` from the example in section 3.7.7, *The Memory Definition*.

To control the locating of sections, you need to write one or more section definitions in the LSL file. At least one for each address space where you want to change the default behavior of the linker. In our example, we need to locate sections in the address space `data`:

```
section_layout ::data
{
    Section placement statements
}
```

To locate sections, you must create a group in which you select sections from your program. For the battery back-up example, we need to define one group, which contains the section `non_volatile`. All other sections are located using the defaults specified in the architecture definition. Section `non_volatile` should be placed in non-volatile ram. To achieve this, the run address refers to our non-volatile memory called `my_nvram`. Furthermore, the section should not be cleared and therefore the attribute **s** (scratch) is assigned to the group:

```
group ( ordered, run_addr = mem:my_nvram, attributes = rws )
{
     select "non_volatile";
}
```

Section placement from Altium Designer

To specify the above settings using Altium Designer, follow these steps:

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Open the **Sections/Reserved Areas** tab.

3. Click **Add Section**.

   The Section dialog box appears.

4. In the **Name** field, enter `non_volatile`

5. In the **Space** field, select **data**

6. In the **Location** field, enter `mem:my_nvram`

This completes the LSL file for the sample architecture and sample program. You can now invoke the linker with this file and the sample program to obtain an application that works for this architecture.

For a complete description of the Linker Script Language, refer to Chapter 5, *Linker Script Language*, in the reference manual.

3.8 Linker Labels

The linker creates labels that you can use to refer to from within the application software. Some of these labels are real labels at the beginning or the end of a section. Other labels have a second function, these labels are used to address generated data in the locating phase. The data is only generated if the label is used.

Linker labels are labels starting with **__lc_**. The linker assigns addresses to the following labels when they are referenced:

Label	Description
`__lc_ub_`*name* `__lc_b_`*name*	Begin of section *name*. Also used to mark the begin of the stack or heap or copy table.
`__lc_ue_`*name* `__lc_e_`*name*	End of section *name*. Also used to mark the end of the stack or heap.
`__lc_cb_`*name*	Start address of an overlay section in ROM.

Label	Description
`__lc_ce_`*name*	End address of an overlay section in ROM.
`__lc_gb_`*name*	Begin of group *name*. This label appears in the output file even if no reference to the label exists in the input file.
`__lc_ge_`*name*	End of group *name*. This label appears in the output file even if no reference to the label exists in the input file.

Table 3-5: Linker labels

The linker only allocates space for the stack and/or heap when a reference to either of the section labels exists in one of the input object files.

Additionally, the linker script file defines the following symbols:

Symbol	Description
`__init`	Start of initialization routine. Same as `__lc_ub_dinit`.


See also section 5.9.4, *Creating Symbols*, in Chapter 5, *Linker Script Language* of the reference manual.

Example: refer to the stack

Suppose in an LSL file you have defined a stack section with the name ”`stack`” (with the keyword **`stack`**). You can refer to the end of the stack from your assembly source as follows:

```
.extern __lc_ue_stack   ; end of stack
```

3.9 Generating a Map File

The map file is an additional output file that contains information about the location of sections and symbols. You can customize the type of information that should be included in the map file.

To generate a map file

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Linker** entry and select **Map File**.
3. Select **Generate a memory map file (.map)**
4. (Optional) Enable the options to include that information in the map file.

Example on the command line (Windows Command Prompt)

```
lktarget -M test.obj
```

With this command the map file `test.map` is created.

See section 3.2, *Linker Map File Format*, in Chapter *List File Formats* of the reference manual for an explanation of the format of the map file.

Linker option **--map-file** (**-M**) (Generate task related map file)

Linker option **--map-file-format** (**-m**) (Map file formatting)

3.10 Linker Error Messages

The linker produces error messages of the following types:

F Fatal errors

After a fatal error the linker immediately aborts the link/locate process.

E Errors

Errors are reported, but the linker continues linking and locating. No output files are produced unless you have set the linker option **--keep-output-files**.

W Warnings

Warning messages do not result into an erroneous output file. They are meant to draw your attention to assumptions of the linker for a situation which may not be correct. You can control warnings in the **Linker » Diagnostics** page of the **Project » Project Options...** menu (linker option **--no-warnings**).

I Information

Verbose information messages do not indicate an error but tell something about a process or the state of the linker. To see verbose information, use the linker option **--verbose**.

S System errors

System errors occur when internal consistency checks fail and should never occur. When you still receive the system error message

```
S6##: message
```

please report the error number and as many details as possible about the context in which the error occurred.

Display detailed information on diagnostics

1. From the **View** menu, select **Workspace Panels » System » Messages**.

   The Messages panel appears.

2. In the **Messages** panel, right-click on the message you want more information on.

   A popup menu appears.

3. Select **More Info**.

   A Message Info box appears with additional information.

On the command line you can use the linker option **--diag** you can see an explanation of a diagnostic message:

```
lktarget --diag=[format:]{all | number,...]
```

See linker option **--diag** in section 2.2, *Linker Options* in Chapter *Tool Options* of the reference manual.

4 Using the Utilities

Summary

This chapter describes the utilities that are delivered with the product.

4.1 Introduction

The TASKING toolset comes with a number of utilities that are only available as command line tools.

cc*target* A control program. The control program invokes all tools in the toolset and lets you quickly generate an absolute object file from C and/or assembly source input files.

tmk A utility program to maintain, update, and reconstruct groups of programs. The make utility looks whether files are out of date, rebuilds them and determines which other files as a consequence also need to be rebuilt.

tlb A librarian. With this utility you create and maintain library files with relocatable object modules (`.obj`) generated by the assembler.

4.2 Control Program

The control program is a tool that invokes all tools in the toolset for you. It provides a quick and easy way to generate the final absolute object file out of your C sources without the need to invoke the assembler and linker manually.

4.2.1 Calling the Control Program

You can only call the control program from the command line. The invocation syntax is:

cc*target* [[*option*]... [*file*]...]...

where, *target* is the target you are building for.

Recognized input files

The control program recognizes the following input files:

- Files with a `.asm` suffix are interpreted as hand-written assembly source files which have to be passed to the assembler.
- Files with a `.src` suffix are interpreted as compiled assembly source files. They are directly passed to the assembler.
- Files with a `.lib` suffix are interpreted as library files and are passed to the linker.
- Files with a `.obj` suffix are interpreted as object files and are passed to the linker.
- Files with a `.out` suffix are interpreted as linked object files and are passed to the locating phase of the linker. The linker accepts only one `.out` file in the invocation.
- An argument with a `.lsl` suffix is interpreted as a linker script file and is passed to the linker.

Options

The control program accepts several command line options. If you specify an unknown option to the control program, the control program looks if it is an option for a specific tool. If so, it passes the option directly to the tool. However, for directly passing an option to the assembler or linker, it is recommended to use the control program options **--pass-assembler**, **--pass-linker**.

Example with verbose output

```
cc165x -v test.asm
```

The control program calls all tools in the toolset and generates the absolute object file `test.abs`. With option **--verbose** (**-v**) you can see how the control program calls the tools:

```
+ path\as165x -o cc1692b.obj test.asm
+ path\lk165x cc1692b.obj -o test.abs -d165x.lsl -M
```

The control program produces unique filenames for intermediate steps in the compilation process (such as `cc1692b.obj` in the example above) which are removed afterwards, unless you specify command line option **--keep-temporary-files** (**-t**).

Example with argument passing to a tool

```
cc165x -Wa-Ogs test.asm
```

The option **-Ogs** is directly passed to the assembler.

4.2.2 Overview of Control Program Options

The following control program options are available:

Description	Option
Information	
Display invocation options	**--help** / **-?**
Display version header	**--version** / **-V**
Show description of diagnostics	**--diag**=[*fmt*:]{**all**|*nr*}
Check the source, but do not generate code	**--check**
Verbose output	**--verbose** / **-v**
Verbose output and suppress execution	**--dry-run** / **-n**
Suppress all or specific warnings	**--no-warnings**[=*num*] / **-w**
Treat warnings as errors	**--warnings-as-errors**
Preprocessing	
Define preprocessor *macro*	**--define**=*macro*[=*def*] / **-D**
Code generation	
Select target CPU	**--cpu**=*cpu*
Generate symbolic debug information	**--debug-info** / **-g**
Pass arguments	
Pass arguments directly to the:	
Assembler	**--pass-assembler**=*option*
Linker	**--pass-linker**=*option*
Input files	
Specify linker script file	**--lsl-file**=*file* / **-d**
Read options from file	**--option-file**=*file* / **-f**
Add include directory	**--include-directory**=*dir* / **-I**
Output files	
Redirect diagnostic messages to a file	**--error-file**
Select final output file:	
relocatable output file	**--create=relocatable**
object file(s)	**--create=object**
Specify linker output format (IEEE, ELF, IHEX, SREC)	**--format**=*type*
Set the address size for linker IHEX/SREC files	**--address-size**=*n*
Keep output file(s) after errors	**--keep-output-files** / **-k**
Generate assembler list files	**--list-files**[=*name*]
Do not generate linker map file	**--no-map-file**
Specify name of output file	**--output**=*file* / **-o**
Do not delete intermediate (temporary) files	**--keep-temporary-files** / **-t**

Table 4-1: Overview of control program options

For a complete list and description of all control program options, see section 2.3, *Control Program Options*, in Chapter *Tool Options* of the reference manual.

4.3 Make Utility

If you are working with large quantities of files, or if you need to build several targets, it is rather time-consuming to call the individual tools to compile, assemble, link and locate all your files.

You save already a lot of typing if you use the control program **cc***target* and define an options file. You can even create a batch file or script that invokes the control program for each target you want to create. But with these methods all files are completely compiled, assembled and linked to obtain the target file, even if you changed just one C source. This may demand a lot of (CPU) time on your host.

The make utility **tmk** is a tool to maintain, update, and reconstruct groups of programs. The make utility looks which files are out-of-date and only recreates these files to obtain the updated target.

Make process

In order to build a target, the make utility needs the following input:

- the target it should build, specified as argument on the command line
- the rules to build the target, stored in a file usually called `makefile`

In addition, the make utility also reads the file `tmk.mk` which contains predefined rules and macros. See section 4.3.3, *Writing a Makefile*.

The makefile contains the relationships among your files (called *dependencies*) and the commands that are necessary to create each of the files (called *rules*). Typically, the absolute object file (`.abs`) is updated when one of its dependencies has changed. The absolute file depends on `.obj` files and libraries that must be linked together. The `.obj` files on their turn depend on `.asm` files that must be assembled. In the makefile `makefile` this looks like:

```
test.obj : test.asm                  # dependency
           as165x test.asm           # rule

test.abs : test.obj
           lk165x test.obj -o test.abs -d165x.lsl -M
```

You can use any command that is valid on the command line as a rule in the `makefile`. So, rules are not restricted to invocation of the toolset.

Example

To build the target `test.abs`, call **tmk** with one of the following lines:

```
tmk test.abs

tmk -f mymake.mak test.abs
```

By default the make utility reads `makefile` so you do not need to specify it on the command line. If you want to use another name for the makefile, use the option **–f** *my_makefile*.

If you do not specify a target, **tmk** uses the first target defined in the makefile. In this example it would build `test.obj` instead of `test.abs`.

The make utility now tries to build `test.abs` based on the `makefile` and peforms the following steps:

1. From the `makefile` the make utility reads that `test.abs` depends on `test.obj`.
2. If `test.obj` does not exist or is out-of-date, the make utility first tries to build this file and reads from the makefile that `test.obj` depends on `test.src`.
3. There are no other files necessary to create `test.abs` so the make utility now can use `test.obj` to create `test.abs` by executing the rule `test.obj -o test.abs .....`.

The make utility has now built `test.abs` but it only used the assembler to update `test.obj` and the linker to create `test.abs`.

If you compare this to the control program:

```
cc165x test.asm
```

This invocation has the same effect but now *all* files are recompiled (assembled, linked and located).

4.3.1 Calling the Make Utility

You can only call the make utility from the command line. The invocation syntax is:

```
tmk [ [option]... [target]... [macro=def]... ]
```

For example:

```
tmk test.abs
```

target You can specify any target that is defined in the makefile. A target can also be one of the intermediate files specified in the makefile.

macro=def Macro definition. This definition remains fixed for the **tmk** invocation. It overrides any regular definitions for the specified macro within the makefiles and from the environment. It is inherited by subordinate **tmk**'s but act as an environment variable for these. That is, depending on the **–e** setting, it may be overridden by a makefile definition.

Exit status

tmk returns an exit status of 1 when it halts as a result of an error. Otherwise it returns an exit status of 0.

4.3.2 Overview of Make Utility Options

The following make utility options are available:

Description	Option
Information	
Display invocation options	**–?**
Display version header only	**–V**
Print makefile lines while being read	**–D**/**–DD**
Display time comparisons which indicate a target is out of date	**–d**/**–dd**
Verbose option: show commands without executing (dry run)	**–n**
Do not show commands before execution	**–s**
Do not build, only indicate whether target is up–to–date	**–q**
Input files	
Use *makefile* instead of the standard `makefile`	**–f** *makefile*
Change to directory before reading the makefile	**–G** *path*
Read options from *file*	**–m** *file*
Do not read the `tmk.mk` file	**–r**
Process	
Always rebuild target without checking whether it is out–of–date	**–a**
Run as a child process	**–c**
Environment variables override macro definitions	**–e**
Do not remove temporary files	**–K**
On error, only stop rebuilding current target	**–k**
Overrule the option **–k** (only stop building current target)	**–S**
Touch the target files instead of rebuilding them	**–t**
Treat *target* as if it has just been reconstructed	**–W** *target*
Error messages	
Redirect error messages and verbose messages to a file	**–err** *file*
Ignore error codes returned by commands	**–i**

Description	Option
Redirect messages to standard out instead of standard error	**–w**
Show extended error messages	**–x**

Table 4-2: Overview of control program options

For a complete list and description of all make utility options, see section 2.4, *Make Utility Options*, in Chapter *Tool Options* of the reference manual.

4.3.3 Writing a MakeFile

In addition to the standard makefile `makefile`, the make utility always reads the makefile `tmk.mk` before other inputs. This system makefile contains implicit rules and predefined macros that you can use in the makefile `makefile`.

With the option **–r** (Do not read the `tmk.mk` file) you can prevent the make utility from reading `tmk.mk`.

The default name of the makefile is `makefile` in the current directory. If you want to use other makefiles, use the option **–f** *my_makefile*.

The makefile can contain a mixture of:

- targets and dependencies
- rules
- macro definitions or functions
- comment lines
- include lines
- export lines

To continue a line on the next line, terminate it with a backslash (\):

```
# this comment line is continued\
on the next line
```

If a line must end with a backslash, add an empty macro.

```
# this comment line ends with a backslash \$(EMPTY)
# this is a new line
```

Targets and dependencies

The basis of the makefile is a set of targets, dependencies and rules. A target entry in the makefile has the following format:

```
target ... : [dependency ...] [; rule]
       [rule]
        ...
```

Target lines must always start at the beginning of a line, leading white spaces (tabs or spaces) are not allowed. A target line consists of one or more targets, a semicolon and a set of files which are required to build the target (*dependencies*). The target itself can be one or more filenames or symbolic names:

```
all:                    demo.abs final.abs

demo.abs final.abs:     test.obj demo.obj final.obj
```

You can now can specify the target you want to build to the make utility. The following three invocations all have the same effect:

```
tmk
tmk all
tmk demo.abs final.abs
```

If you do *not* specify a target, the first target in the makefile (in this example `all`) is built. The target `all` depends on `demo.abs` and `final.abs` so the second and third invocation have the same effect and the files `demo.abs` and `final.abs` are built.

You can normally use colons to denote drive letters. The following works as intended:

```
c:foo.obj : a:foo.c
```

If a target is defined in more than one target line, the dependencies are added to form the target's complete dependency list:

```
all:  demo.abs   # These two lines are equivalent with:
all:  final.abs  # all: demo.abs final.abs
```

For target lines, macros and functions are expanded at the moment they are read by the make utility. Normally macros are not expanded until the moment they are actually used.

Special targets

There are a number of special targets. Their names begin with a period.

Target	Description
`.DEFAULT`	If you call the make utility with a target that has no definition in the makefile, this target is built.
`.DONE`	When the make utility has finished building the specified targets, it continues with the rules following this target.
`.IGNORE`	Non-zero error codes returned from commands are ignored. Encountering this in a makefile is the same as specifying the option **–i** on the command line.
`.INIT`	The rules following this target are executed before any other targets are built.
`.PRECIOUS`	Dependency files mentioned for this target are never removed. Normally, if a command in a rule returns an error or when the target construction is interrupted, the make utility removes that target file.
`.SILENT`	Commands are not echoed before executing them. Encountering this in a makefile is the same as specifying the option **–s** on the command line.
`.SUFFIXES`	This target specifies a list of file extensions. Instead of building a completely specified target, you now can build a target that has a certain file extension. Implicit rules to build files with a number of extensions are included in the system makefile `tmk.mk`. If you specify this target with dependencies, these are added to the existing `.SUFFIXES` target in `tmk.mk`. If you specify this target without dependencies, the existing list is cleared.

Rules

A line with leading white space (tabs or spaces) is considered as a rule and associated with the most recently preceding dependency line. A *rule* is a line with commands that are executed to build the associated target. A target-dependency line can be followed by one or more rules.

```
final.obj : final.asm                # target and dependency
            move test.asm final.asm  # rule1
            as165x final.asm         # rule2
```

You can precede a rule with one or more of the following characters:

@ does not echo the command line, except if **–n** is used.

- the make utility ignores the exit code of the command (ERRORLEVEL in MS-DOS). Normally the make utility stops if a non-zero exit code is returned. This is the same as specifying the option **–i** on the command line or specifying the special `.IGNORE` target.

\+ The make utility uses a shell or COMMAND.COM to execute the command. If the '+' is not followed by a shell line, but the command is a DOS command or if redirection is used (<, |, >), the shell line is passed to COMMAND.COM anyway.

You can force **tmk** to execute multiple command lines in one shell environment. This is accomplished with the token combination ';\'. For example:

```
cd c:\Tasking\bin ;\
tmk -V
```

Note that the ';' must always directly be followed by the '\' token. Whitespace is not removed when it is at the end of the previous command line or when it is in front of the next command line. The use of the ';' as an operator for a command (like a semicolon ';' separated list with each item on one line) and the '\' as a layout tool is not supported, unless they are separated with whitespace.

Inline temporary files

The make utility can generate inline temporary files. If a line contains **<<***LABEL* (no whitespaces!) then all subsequent lines are placed in a temporary file until the line *LABEL* is encountered. Next, **<<***LABEL* is replaced by the name of the temporary file.

Example:

```
 -o $@ -f <<EOF
     $(separate "\n" $(match .obj $!))
     $(separate "\n" $(match .lib $!))
     $(LKFLAGS)
EOF
```

The three lines between <<EOF and EOF are written to a temporary file (for example mkce4c0a.tmp), and the rule is rewritten as -o $@ -f mkce4c0a.tmp.

Suffix targets

Instead of specifying a specific target, you can also define a general target. A general target specifies the rules to generate a file with extension *.ex1* to a file with extension *.ex2*. For example:

```
.SUFFIXES:  .asm
.asm.obj :
            as165x $<
```

Read this as: to build a file with extension .obj out of a file with extension .asm, call the assembler with $<. $< is a predefined macro that is replaced with the basename of the specified file. The special target .SUFFIXES: is followed by a list of file extensions of the files that are required to build the target.

Implicit rules

Implicit rules are stored in the system makefile tmk.mk and are intimately tied to the .SUFFIXES special target. Each dependency that follows the .SUFFIXES target, defines an extension to a filename which must be used to build another file. The implicit rules then define how to actually build one file from another. These files share a common basename, but have different extensions.

If the specified target on the command line is not defined in the makefile or has not rules in the makefile, the make utility looks if there is an implicit rule to build the target.

Example:

This makefile says that prog.abs depends on two files prog.obj and sub.obj, and that they in turn depend on their corresponding source files (prog.asm and sub.asm) along with the common file gen.inc.

```
LSL  =     -d165x.lsl    # macro

prog.abs:  prog.obj sub.obj
     lk165x prog.obj sub.obj $(LSL) -o prog.abs

prog.obj:  prog.asm gen.inc
     as165x prog.asm

sub.obj:  sub.asm gen.inc
     as165x sub.asm
```

The following makefile uses implicit rules (from tmk.mk) to perform the same job.

```
LKFLAGS = -d165x.lsl                  # macro used by implicit rules
prog.abs: prog.obj sub.obj            # implicit rule used
prog.obj: prog.asm gen.inc            # implicit rule used
sub.obj:  sub.asm gen.inc             # implicit rule used
```

Macro definitions

A *macro* is a symbol name that is replaced with its definition before the makefile is executed. Although the macro name can consist of lower case or upper case characters, upper case is an accepted convention. The general form of a macro definition is:

```
MACRO = text and more text
```

Spaces around the equal sign are not significant.

To use a macro, you must access its contents:

```
$(MACRO)        # you can read this as
${MACRO}        # the contents of macro MACRO
```

If the macro name is a single character, the parentheses are optional. Note that the expansion is done recursively, so the body of a macro may contain other macros. These macros are expanded when the macro is actually used, not at the point of definition:

```
FOOD = $(EAT) and $(DRINK)
EAT = meat and/or vegetables
DRINK = water
export FOOD
```

The macro `FOOD` is expanded as `meat and/or vegetables and water` at the moment it is used in the export line line and the environment variable `FOOD` is set accordingly.

Predefined macros

Macro	Description
`MAKE`	Holds the value `tmk`. Any line which uses `MAKE`, temporarily overrides the option **–n** (Show commands without executing), just for the duration of the one line. This way you can test nested calls to `MAKE` with the option **–n**.
`MAKEFLAGS`	Holds the set of options provided to **tmk** (except for the options **–f** and **–d**). If this macro is exported to set the environment variable `MAKEFLAGS`, the set of options is processed before any command line options. You can pass this macro explicitly to nested **tmk**'s, but it is also available to these invocations as an environment variable.

`PRODDIR`	Holds the name of the directory where **tmk** is installed. You can use this macro to refer to files belonging to the product, for example a library source file.
	`DOPRINT = $(PRODDIR)/lib/src/_doprint.c`
	When **tmk** is installed in the directory `c:/Tasking/bin` this line expands to:
	`DOPRINT = c:/Tasking/lib/src/_doprint.c`

`SHELLCMD`	Holds the default list of commands which are local to the SHELL. If a rule is an invocation of one of these commands, a SHELL is automatically spawned to handle it.
`$`	This macro translates to a dollar sign. Thus you can use "$$" in the makefile to represent a single "$".

Dynamically maintained macros

There are several dynamically maintained macros that are useful as abbreviations within rules. It is best not to define them explicitly.

Macro	Description
`$*`	The basename of the current target.
`$<`	The name of the current dependency file.
`$@`	The name of the current target.
`$?`	The names of dependents which are younger than the target.
`$!`	The names of all dependents.

The $< and $* macros are normally used for implicit rules. They may be unreliable when used within explicit target command lines. All macros may be suffixed with **F** to specify the Filename components (e.g. `${*F}`, `${@F}`). Likewise, the macros $*, $< and $@ may be suffixed by **D** to specify the Directory component.

The result of the $* macro is always without double quotes ("), regardless of the original target having double quotes (") around it or not.

The result of using the suffix **F** (Filename component) or **D** (Directory component) is also always without double quotes ("), regardless of the original contents having double quotes (") around it or not.

Makefile: Functions

A function not only expands but also performs a certain operation. Functions syntactically look like macros but have embedded spaces in the macro name, e.g. '`$(match arg1 arg2 arg3 )`'. All functions are built-in and currently there are five of them: `match`, `separate`, `protect`, `exist` and `nexist`.

match

The `match` function yields all arguments which match a certain suffix:

```
$(match .obj prog.obj sub.obj mylib.lib)
```

yields:

```
prog.obj sub.obj
```

separate

The `separate` function concatenates its arguments using the first argument as the separator. If the first argument is enclosed in double quotes then '\n' is interpreted as a newline character, '\t' is interpreted as a tab, '*ooo*' is interpreted as an octal value (where, *ooo* is one to three octal digits), and spaces are taken literally. For example:

```
$(separate "\n" prog.obj sub.obj)
```

results in:

```
prog.obj
sub.obj
```

Function arguments may be macros or functions themselves. So,

```
$(separate "\n" $(match .obj $!))
```

yields all object files the current target depends on, separated by a newline string.

protect

The `protect` function adds one level of quoting. This function has one argument which can contain white space. If the argument contains any white space, single quotes, double quotes, or backslashes, it is enclosed in double quotes. In addition, any double quote or backslash is escaped with a backslash.

Example:

```
echo $(protect I'll show you the "protect" function)
```

yields:

```
echo "I'll show you the \"protect\" function"
```

exist

The `exist` function expands to its second argument if the first argument is an existing file or directory.

Example:

```
$(exist test.asm cc165x test.asm)
```

When the file `test.asm` exists, it yields:

```
$(exist test.asm cc165x test.asm)
```

When the file `test.asm` does not exist nothing is expanded.

nexist

The `nexist` function is the opposite of the exist function. It expands to its second argument if the first argument is not an existing file or directory.

Example:

```
$(nexist test.obj cc165x test.asm)
```

Conditional processing

Lines containing `ifdef`, `ifndef`, `else` or `endif` are used for conditional processing of the makefile. They are used in the following way:

`ifdef` *macro-name*
if-lines
`else`
else-lines
`endif`

The *if-lines* and *else-lines* may contain any number of lines or text of any kind, even other `ifdef`, `ifndef`, `else` and `endif` lines, or no lines at all. The `else` line may be omitted, along with the *else-lines* following it.

First the *macro-name* after the `if` command is checked for definition. If the macro is defined then the *if-lines* are interpreted and the *else-lines* are discarded (if present). Otherwise the *if-lines* are discarded; and if there is an `else` line, the *else-lines* are interpreted; but if there is no `else` line, then no lines are interpreted.

When using the `ifndef` line instead of `ifdef`, the macro is tested for not being defined. These conditional lines can be nested up to 6 levels deep.


See also *Defining Macros* in section 2.4, *Make Utility Options*, in Chapter *Tools Options* of the reference manual.

Comment lines

Anything after a ”#” is considered as a comment, and is ignored. If the ”#” is inside a quoted string, it is not treated as a comment. Completely blank lines are ignored.

```
test.obj  : test.asm         # this is comment and is
            cc165x test.asm  # ignored by the make utility
```

Include lines

An *include* line is used to include the text of another makefile (like including a .h file in a C source). Macros in the name of the included file are expanded before the file is included. Include files may be nested.

```
include makefile2
```

Export lines

An *export* line is used to export a macro definition to the environment of any command executed by the make utility.

```
GREETING = Hello
export GREETING
```

This example creates the environment variable `GREETING` with the value `Hello`. The macros is exported at the moment the export line is read so the macro definition has to proceed the export line.

4.4 Librarian

The librarian **tlb** is a program to build and maintain your own library files. A library file is a file with extension `.lib` and contains one or more object files (`.obj`) that may be used by the linker.

The librarian has five main functionalities:

- Deleting an object module from the library
- Moving an object module to another position in the library file
- Replacing an object module in the library or add a new object module
- Showing a table of contents of the library file
- Extracting an object module from the library

The librarian takes the following files for input and output:

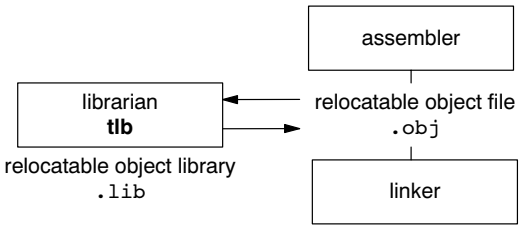


Figure 4-1: Librarian

The linker optionally includes object modules from a library if that module resolves an external symbol definition in one of the modules that are read before.

4.4.1 Calling the Librarian

You can only call the librarian from the command line. The invocation syntax is:

`tlb` *`key_option`* `[sub_option...]` *`library`* `[object_file]`

key_option With a key option you specify the main task which the librarian should perform. You must *always* specify a key option.

sub_option Sub-options specify into more detail how the librarian should perform the task that is specified with the key option. It is not obligatory to specify sub-options.

library The name of the library file on which the librarian performs the specified action. You must always specify a library name, except for the option **-?** and **-V**. When the library is not in the current directory, specify the complete path (either absolute or relative) to the library.

object_file The name of an object file. You must always specify an object file name when you add, extract, replace or remove an object file from the library.

4.4.2 Overview of Librarian Options

The following librarian options are available:

Description	Option	Sub-option
Main functions (key options)		
Replace or add an object module	**-r**	**-a -b -c -u -v**
Extract an object module from the library	**-x**	**-v**
Delete object module from library	**-d**	**-v**
Move object module to another position	**-m**	**-a -b -v**
Print a table of contents of the library	**-t**	**-s0 -s1**
Print object module to standard output	**-p**	
Sub-options		
Append or move new modules after existing module *name*	**-a** *name*	

Description	Option	Sub-option
Append or move new modules before existing module *name*	**-b** *name*	
Create library without notification if library does not exist	**-c**	
Preserve last-modified date from the library	**-o**	
Print symbols in library modules	**-s**{**0**|**1**}	
Replace only newer modules	**-u**	
Verbose	**-v**	
Miscellaneous		
Display options	**-?**	
Display version header	**-V**	
Read options from *file*	**-f** *file*	
Suppress warnings above level *n*	**-w***n*	

Table 4-3: Overview of librarian options and sub-options

For a complete list and description of all librarian options, see section 2.5, *Librarian Options*, in Chapter *Tool Options* of the reference manual.

4.4.3 Examples

Create a new library

If you add modules to a library that does not yet exist, the library is created. To create a new library with the name `mylib.lib` and add the object modules `cstart.obj` and `calc.obj` to it:

```
tlb -r mylib.lib cstart.obj calc.obj
```

Add a new module to an existing library

If you add a new module to an existing library, the module is added at the end of the module. (If the module already exists in the library, it is replaced.)

```
tlb -r mylib.lib mod3.obj
```

Print a list of object modules in the library

To inspect the contents of the library:

```
tlb -t mylib.lib
```

The library has the following contents:

```
cstart.obj
calc.obj
mod3.obj
```

Move an object module to another position

To move `mod3.obj` to the beginning of the library, position it just before `cstart.obj`:

```
tlb -mb cstart.obj mylib.lib mod3.obj
```

Delete an object module from the library

To delete the object module `cstart.obj` from the library `mylib.lib`:

```
tlb -d mylib.lib cstart.obj
```

Extract all modules from the library

Extract all modules from the library `mylib.lib`:

```
tlb -x mylib.lib
```

Index

M

O

P

R

S

T

U

V