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MPLAB® XC16 C Compiler User's Guide

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Preface

NOTICE TO CUSTOMERS

All documentation becomes dated, and this manual is no exception. Microchip tools and documentation are constantly evolving to meet customer needs, so some actual dialogs and/or tool descriptions may differ from those in this document.

For the most up-to-date information on development tools, see the MPLAB® IDE or MPLAB X IDE Help. Select the Help menu and then "Topics" or "Help Contents" to open a list of available Help files.

For the most current PDFs, please refer to our web site (http://www.microchip.com). Documents are identified by "DSXXXXXA", where "XXXXX" is the document number and "A" is the revision level of the document. This number is located on the bottom of each page, in front of the page number.

INTRODUCTION

MPLAB XC16 C Compiler documentation and support information is discussed in the sections below:

- Document Layout
- Conventions Used
- Recommended Reading
- myMicrochip Personalized Notification Service
- The Microchip Web Site
- Microchip Forums
- Customer Support

DOCUMENT LAYOUT

This document describes how to use GNU language tools to write code for 16-bit applications. The document layout is as follows:

- **Chapter 1. "Compiler Overview"** – describes the compiler, development tools and feature set.
- **Chapter 3. "Compiler Command-Line Driver"** – describes how to use the compiler from the command line.
- **Chapter 5. "Differences Between MPLAB XC16 and ANSI C"** – describes the differences between the C language supported by the compiler syntax and the standard ANSI-89 C.
- **Chapter 4. "Device-Related Features"** – describes the compiler header and register definition files, as well as how to use with SFRs.
- **Chapter 6. "Supported Data Types and Variables"** – describes the compiler integer, floating point and pointer data types.
- **Chapter 7. "Memory Allocation and Access"** – describes the compiler run-time model, including information on sections, initialization, memory models, the software stack and much more.
- **Chapter 8. "Operators and Statements"** – discusses operators and statements.
- **Chapter 9. "Register Usage"** – explains how to access and use SFRs.
- **Chapter 10. "Functions"** – details available functions.
- **Chapter 11. "Interrupts"** – describes how to use interrupts.
- **Chapter 12. "Main, Runtime Startup and Reset"** – describes important elements of C code.
- **Chapter 14. "Library Routines"** – explains how to use libraries.
- **Chapter 13. "Mixing C and Assembly Code"** – provides guidelines to using the compiler with 16-bit assembly language modules.
- **Chapter 15. "Optimizations"** – describes optimization options.
- **Chapter 16. "Preprocessing"** – details preprocessing operation.
- **Chapter 17. "Linking Programs"** – explains how linking works.
- **Appendix A. "Implementation-Defined Behavior"** – details compiler-specific parameters described as implementation-defined in the ANSI standard.
- **Appendix B. "Diagnostics"** – lists error and warning messages generated by the compiler.
- **Appendix C. "MPLAB XC16 vs. MPLAB XC8"** – contains the ASCII character set.
- **Appendix C. "GNU Free Documentation License"** – usage license for the Free Software Foundation.
- **Appendix E. "Deprecated Features" –** details features that are considered obsolete.
- **Appendix F. "Built-in Functions"** – lists the built-in functions of the C compiler.
- **Appendix G. "XC16 Configuration Settings"** – information about configuration settings macros.

CONVENTIONS USED

The following conventions may appear in this documentation:

DOCUMENTATION CONVENTIONS

Description	Represents	Examples
Arial font:		
Italic characters	Referenced books	*MPLAB® IDE User's Guide*
	Emphasized text	...is the *only* compiler...
Initial caps	A window	the Output window
	A dialog	the Settings dialog
	A menu selection	select Enable Programmer
Quotes	A field name in a window or dialog	"Save project before build"
Underlined, italic text with right angle bracket	A menu path	*File>Save*
Bold characters	A dialog button	Click **OK**
	A tab	Click the **Power** tab
Text in angle brackets < >	A key on the keyboard	Press <Enter>, <F1>
Courier font:		
Plain Courier	Sample source code	`#define START`
	File names	`autoexec.bat`
	File paths	`c:\mcc18\h`
	Keywords	`_asm, _endasm, static`
	Command-line options	`-Opa+, -Opa-`
	Bit values	`0, 1`
	Constants	`0xFF, 'A'`
Italic Courier	A variable argument	*`file`*`.c`, where *`file`* can be any valid file name
Square brackets [ ]	Optional arguments	`mpasmwin [options]` *`file`* `[options]`
Curly brackets and pipe character: { | }	Choice of mutually exclusive arguments; an OR selection	`errorlevel {0|1}`
Ellipses...	Replaces repeated text	`var_name [, var_name...]`
	Represents code supplied by user	`void main (void)` `{ ...` `}`
Sidebar Text		
DD	Device Dependent. This feature is not supported on all devices. Devices supported will be listed in the title or text.	`xmemory` attribute

RECOMMENDED READING

This documentation describes how to use the MPLAB XC16 C Compiler. Other useful documents are listed below. The following Microchip documents are available and recommended as supplemental reference resources.

Release Notes (Readme Files)

For the latest information on Microchip tools, read the associated Release Notes (HTML files) included with the software.

MPLAB® Assembler, Linker and Utilities for PIC24 MCUs and dsPIC® DSCs User's Guide (DS51317)

A guide to using the 16-bit assembler, object linker, object archiver/librarian and various utilities.

16-Bit Language Tools Libraries (DS51456)

A descriptive listing of libraries available for Microchip 16-bit devices. This includes standard (including math) libraries and C compiler built-in functions. DSP and 16-bit peripheral libraries are described in Release Notes provided with each peripheral library type.

Device-Specific Documentation

The Microchip website contains many documents that describe 16-bit device functions and features. Among these are:

- Individual and family data sheets
- Family reference manuals
- Programmer's reference manuals

C Standards Information

American National Standard for Information Systems – *Programming Language – C*. American National Standards Institute (ANSI), 11 West 42nd. Street, New York, New York, 10036.

This standard specifies the form and establishes the interpretation of programs expressed in the programming language C. Its purpose is to promote portability, reliability, maintainability and efficient execution of C language programs on a variety of computing systems.

C Reference Manuals

Harbison, Samuel P. and Steele, Guy L., *C A Reference Manual*, Fourth Edition, Prentice-Hall, Englewood Cliffs, N.J. 07632.

Kernighan, Brian W. and Ritchie, Dennis M., *The C Programming Language*, Second Edition. Prentice Hall, Englewood Cliffs, N.J. 07632.

Kochan, Steven G., *Programming In ANSI C*, Revised Edition. Hayden Books, Indianapolis, Indiana 46268.

Plauger, P.J., *The Standard C Library*, Prentice-Hall, Englewood Cliffs, N.J. 07632.

Van Sickle, Ted., *Programming Microcontrollers in C*, First Edition. LLH Technology Publishing, Eagle Rock, Virginia 24085.

myMICROCHIP PERSONALIZED NOTIFICATION SERVICE

Microchip's personal notification service helps keep customers current on their Microchip products of interest. Subscribers will receive e-mail notification whenever there are changes, updates, revisions or errata related to a specified product family or development tool.

Please visit http://www.microchip.com/pcn to begin the registration process and select your preferences to receive personalized notifications. A FAQ and registration details are available on the page, which can be opened by selecting the link above.

When you are selecting your preferences, choosing “Development Systems” will populate the list with available development tools. The main categories of tools are listed below:

- **Compilers** – The latest information on Microchip C compilers, assemblers, linkers and other language tools. These include all MPLAB C compilers; all MPLAB assemblers (including MPASM™ assembler); all MPLAB linkers (including MPLINK™ object linker); and all MPLAB librarians (including MPLIB™ object librarian).
- **Emulators** – The latest information on Microchip in-circuit emulators.These include the MPLAB REAL ICE™ and MPLAB ICE 2000 in-circuit emulators
- **In-Circuit Debuggers** – The latest information on Microchip in-circuit debuggers. These include the MPLAB ICD 2 and 3 in-circuit debuggers and PICkit™ 2 and 3 debug express.
- **MPLAB® IDE/MPLAB X IDE** – The latest information on Microchip MPLAB IDE, the Windows® Integrated Development Environment, or MPLAB X IDE, the open source, cross-platform Integrated Development Environment. These lists focus on the IDE, Project Manager, Editor and Simulator, as well as general editing and debugging features.
- **Programmers** – The latest information on Microchip programmers. These include the device (production) programmers MPLAB REAL ICE in-circuit emulator, MPLAB ICD 3 in-circuit debugger, MPLAB PM3 and development (nonproduction) programmers MPLAB ICD 2 in-circuit debugger, PICSTART® Plus and PICkit 2 and 3.
- **Starter/Demo Boards** – These include MPLAB Starter Kit boards, PICDEM demo boards, and various other evaluation boards.

THE MICROCHIP WEB SITE

Microchip provides online support via our web site at http://www.microchip.com. This web site is used as a means to make files and information easily available to customers. Accessible by using your favorite Internet browser, the web site contains the following information:

- **Product Support** – Data sheets and errata, application notes and sample programs, design resources, user’s guides and hardware support documents, latest software releases and archived software
- **General Technical Support** – Frequently Asked Questions (FAQs), technical support requests, online discussion groups, Microchip consultant program member listing
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listing of seminars and events, listings of Microchip sales offices, distributors and factory representatives

MICROCHIP FORUMS

Microchip provides additional online support via our web forums at http://www.microchip.com/forums. Currently available forums are:

- Development Tools
- 8-bit PIC MCUs
- 16-bit PIC MCUs
- 32-bit PIC MCUs

CUSTOMER SUPPORT

Users of Microchip products can receive assistance through several channels:

- Distributor or Representative
- Local Sales Office
- Field Application Engineer (FAE)
- Technical Support

Customers should contact their distributor, representative or field application engineer (FAE) for support. Local sales offices are also available to help customers. A listing of sales offices and locations is included in the back of this document. See our web site for a complete, up-to-date listing of sales offices.

Technical support is available through the web site at http://support.microchip.com.

Documentation errors or comments may be emailed to docerrors@microchip.com.

DOCUMENT REVISION HISTORY

Revision A (April 2012)

Initial release of this document.

Revision B (July 2012)

- **Chapter 2. "Common C Interface"** was added.
- Figure 3-1 "Software Development Tools Data Flow" was updated.
- Table 3-16 "Linking Options" now includes the -fill option.
- Added the -pack_upper_byte qualifier information in **Section 6.10.4 "__pack_upper_byte Type Qualifier"** and **Section 7.8 "Packing Data Stored in Flash"**.
- Added DBRPAG/PSVPAG preservation bullet under **Section 10.8 "Function Call Conventions"**
- Fixed code syntax in **Section 11.4 "Specifying the Interrupt Vector"**.
- Fixed Eval Edition description under **Chapter 15. "Optimizations"**.
- Added "volatile" to SFR registers in **Appendix F. "Built-in Functions"**.
- Added built-in functions __builtin_write_CRYOTP and __builtin_write_NVM_secure in **Appendix F. "Built-in Functions"**.

Chapter 1. Compiler Overview

1.1 INTRODUCTION

The MPLAB XC16 C compiler is defined and described in the following topics:

- Device Description
- Compiler Description and Documentation
- Compiler and Other Development Tools

1.2 DEVICE DESCRIPTION

The MPLAB XC16 C compiler fully supports all Microchip 16-bit devices:

- The dsPIC® family of digital signal controllers combines the high performance required in digital signal processor (DSP) applications with standard microcontroller (MCU) features needed for embedded applications.
- The PIC24 family of MCUs are identical to the dsPIC DSCs with the exception that they do not have the digital signal controller module or that subset of instructions. They are a subset, and are high-performance MCUs intended for applications that do not require the power of the DSC capabilities.

1.3 COMPILER DESCRIPTION AND DOCUMENTATION

The MPLAB XC16 C compiler is a full-featured, optimizing compiler that translates standard ANSI C programs into 16-bit device assembly language source. The compiler also supports many command-line options and language extensions that allow full access to the 16-bit device hardware capabilities, and affords fine control of the compiler code generator.

The compiler is a port of the GNU Compiler Collection (GCC) compiler from the Free Software Foundation

This key features of the compiler are discussed in the following sections.

1.3.1 ANSI C Standard

The compiler is a fully validated compiler that conforms to the ANSI C standard as defined by the ANSI specification (ANSI x3.159-1989) and described in Kernighan and Ritchie's *The C Programming Language* (second edition). The ANSI standard includes extensions to the original C definition that are now standard features of the language. These extensions enhance portability and offer increased capability. In addition, language extensions for dsPIC DSC embedded-control applications are included.

1.3.2 Optimization

The compiler uses a set of sophisticated optimization passes that employ many advanced techniques for generating efficient, compact code from C source. The optimization passes include high-level optimizations that are applicable to any C code, as well as 16-bit device-specific optimizations that take advantage of the particular features of the device architecture.

For more on optimizations, see **Chapter 15. "Optimizations"**.

1.3.3 ANSI Standard Library Support

The compiler is distributed with a complete ANSI C standard library. All library functions have been validated, and conform to the ANSI C library standard. The library includes functions for string manipulation, dynamic memory allocation, data conversion, time-keeping and math functions (trigonometric, exponential and hyperbolic). The standard I/O functions for file handling are also included, and, as distributed, they support full access to the host file system using the command-line simulator. The fully functional source code for the low-level file I/O functions is provided in the compiler distribution, and may be used as a starting point for applications that require this capability.

1.3.4 Flexible Memory Models

The compiler supports both large and small code and data models. The small code model takes advantage of more efficient forms of call and branch instructions, while the small data model supports the use of compact instructions for accessing data in SFR space.

The compiler supports two models for accessing constant data. The "constants in data" model uses data memory, which is initialized by the run-time library. The "constants in code" model uses program memory, which is accessed through the Program Space Visibility (PSV) window.

1.3.5 Attributes and Qualifiers

The compiler keyword `__attribute__` allows you to specify special attributes of variables, structure fields or functions. This keyword is followed by an attribute specification inside double parentheses, as in:

```
int last_mode __attribute__ ((persistent));
```

In other compilers, qualifiers are used to create qualified types:

```
persistent int last_mode;
```

The MPLAB XC16 C Compiler does have some non-standard qualifiers described in **Section 6.10 "Compiler-Specific type Qualifiers"**.

Generally speaking, qualifiers indicate how an object should be accessed, whereas attributes indicate where objects are to be located. Attributes also have many other purposes.

1.3.6 Compiler Driver

The compiler includes a powerful command-line driver program. Using the driver program, application programs can be compiled, assembled and linked in a single step.

1.3.7 Documentation

The compiler is supported under both the MPLAB IDE v8.xx and above, and the MPLAB X IDE. For simplicity, both IDEs are referred to throughout the book as simply MPLAB IDE.

Features that are unique to specific devices, and therefore specific compilers, are noted with a "DD" icon next to the section and text that identifies the specific devices to which the information applies (see the **Preface**).

1.4 COMPILER AND OTHER DEVELOPMENT TOOLS

The compiler works with many other Microchip tools including:

- MPLAB XC16 Assembler and Linker - see the *MPLAB Assembler, Linker and Utilities for PIC24 MCUs and dsPIC DSCs User's Guide (DS51317)*.
- MPLAB IDE v8.xx and MPLAB X IDE
- The MPLAB SIM Simulator and MPLAB X Simulator
- All Microchip debug tools and programmers
- Demonstration boards and Starter kits that support 16-bit devices

NOTES:

Chapter 2. Common C Interface

2.1 INTRODUCTION

The Common C Interface (CCI) is available with all MPLAB XC C compilers and is designed to enhance code portability between these compilers. For example, CCI-conforming code would make it easier to port from a PIC18 MCU using the MPLAB XC8 C compiler to a PIC24 MCU using the MPLAB XC16 C compiler.

The CCI assumes that your source code already conforms to the ANSI Standard. If you intend to use the CCI, it is your responsibility to write code that conforms. Legacy projects will need to be migrated to achieve conformance. A compiler option must also be set to ensure that the operation of the compiler is consistent with the interface when the project is built.

The following topics are examined in this chapter of the MPLAB XC16 C Compiler User's Guide:

- ANSI Standard Extensions
- Using the CCI
- ANSI Standard Refinement
- ANSI Standard Extensions

2.2 BACKGROUND – THE DESIRE FOR PORTABLE CODE

All programmers want to write portable source code.

Portability means that the same source code can be compiled and run in a different execution environment than that for which it was written. Rarely can code be one hundred percent portable, but the more tolerant it is to change, the less time and effort it takes to have it running in a new environment.

Embedded engineers typically think of code portability as being across target devices, but this is only part of the situation. The same code could be compiled for the same target but with a different compiler. Differences between those compilers might lead to the code failing at compile time or runtime, so this must be considered as well.

You may only write code for one target device and only use one brand of compiler, but if there is no regulation of the compiler's operation, simply updating your compiler version may change your code's behavior.

Code must be portable across targets, tools, and time to be truly flexible.

Clearly, this portability cannot be achieved by the programmer alone, since the compiler vendors can base their products on different technologies, implement different features and code syntax, or improve the way their product works. Many a great compiler optimization has broken many an unsuspecting project.

Standards for the C language have been developed to ensure that change is managed and code is more portable. The American National Standards Institute (ANSI) publishes standards for many disciplines, including programming languages. The ANSI C Standard is a universally adopted standard for the C programming language.

2.2.1 The ANSI Standard

The ANSI C Standard has to reconcile two opposing goals: freedom for compilers vendors to target new devices and improve code generation, with the known functional operation of source code for programmers. If both goals can be met, source code can be made portable.

The standard is implemented as a set of rules which detail not only the syntax that a conforming C program must follow, but the semantic rules by which that program will be interpreted. Thus, for a compiler to conform to the standard, it must ensure that a conforming C program functions as described by the standard.

The standard describes *implementation*, the set of tools and the runtime environment on which the code will run. If any of these change, e.g., you build for, and run on, a different target device, or if you update the version of the compiler you use to build, then you are using a different implementation.

The standard uses the term *behavior* to mean the external appearance or action of the program. It has nothing to do with how a program is encoded.

Since the standard is trying to achieve goals that could be construed as conflicting, some specifications appear somewhat vague. For example, the standard states that an `int` type must be able to hold at least a 16-bit value, but it does not go as far as saying what the size of an `int` actually is; and the action of right-shifting a signed integer can produce different results on different implementations; yet, these different results are still ANSI C compliant.

If the standard is too strict, device architectures may not allow the compiler to conform.[1] But, if it is too weak, programmers would see wildly differing results within different compilers and architectures, and the standard would loose its effectiveness.

The standard organizes source code whose behavior is not fully defined into groups that include the following behaviors:

Implementation-defined behavior

This is unspecified behavior where each implementation documents how the choice is made.

Unspecified behavior

The standard provides two or more possibilities and imposes no further requirements on which possibility is chosen in any particular instance.

Undefined behavior

This is behavior for which the standard imposes no requirements.

Code that strictly conforms to the standard does not produce output that is dependent on any unspecified, undefined, or implementation-defined behavior. The size of an `int`, which we used as an example earlier, falls into the category of behavior that is defined by implementation. That is to say, the size of an `int` is defined by which compiler is being used, how that compiler is being used, and the device that is being targeted.

All the MPLAB XC compilers conform to the ANS X3.159-1989 Standard for programming languages (with the exception of the XC8 compiler's inability to allow recursion, as mentioned in the footnote). This is commonly called the C89 Standard. Some features from the later standard, C99, are also supported.

1. Case in point: The mid-range PIC® microcontrollers do not have a data stack. Because a compiler targeting this device cannot implement recursion, it (strictly speaking) cannot conform to the ANSI C Standard. This example illustrate a situation in which the standard is too strict for mid-range devices and tools.

For freestanding implementations – or for what we typically call embedded applications – the standard allows non-standard extensions to the language, but obviously does not enforce how they are specified or how they work. When working so closely to the device hardware, a programmer needs a means of specifying device setup and interrupts, as well as utilizing the often complex world of small-device memory architectures. This cannot be offered by the standard in a consistent way.

While the ANSI C Standard provides a mutual understanding for programmers and compiler vendors, programmers need to consider the implementation-defined behavior of their tools and the probability that they may need to use extensions to the C language that are non-standard. Both of these circumstances can have an impact on code portability.

2.2.2 The Common C Interface

The Common C Interface (CCI) supplements the ANSI C Standard and makes it easier for programmers to achieve consistent outcomes on all Microchip devices when using any of the MPLAB XC C compilers.

It delivers the following improvements, all designed with portability in mind.

Refinement of the ANSI C Standard

The CCI documents specific behavior for some code in which actions are implementation-defined behavior under the ANSI C Standard. For example, the result of right-shifting a signed integer is fully defined by the CCI. Note that many implementation-defined items that closely couple with device characteristics, such as the size of an `int`, are not defined by the CCI.

Consistent syntax for non-standard extensions

The CCI non-standard extensions are mostly implemented using keywords with a uniform syntax. They replace keywords, macros and attributes that are the native compiler implementation. The interpretation of the keyword may differ across each compiler, and any arguments to the keywords may be device specific.

Coding guidelines

The CCI may indicate advice on how code should be written so that it can be ported to other devices or compilers. While you may choose not to follow the advice, it will not conform to the CCI.

2.3 USING THE CCI

The CCI allows enhanced portability by refining implementation-defined behavior and standardizing the syntax for extensions to the language.

The CCI is something you choose to follow and put into effect, thus it is relevant for new projects, although you may choose to modify existing projects so they conform.

For your project to conform to the CCI, you must do the following things.

Enable the CCI

Select the MPLAB IDE widget *Use CCI Syntax* in your project, or use the command-line option that is equivalent.

Include <xc.h> in every module

Some CCI features are only enabled if this header is seen by the compiler.

Ensure ANSI compliance

Code that does not conform to the ANSI C Standard does not confirm to the CCI.

Observe refinements to ANSI by the CCI

Some ANSI implementation-defined behavior is defined explicitly by the CCI.

Use the CCI extensions to the language

Use the CCI extensions rather than the native language extensions

The next sections detail specific items associated with the CCI. These items are segregated into those that refine the standard, those that deal with the ANSI C Standard extensions, and other miscellaneous compiler options and usage. Guidelines are indicated with these items.

If any implementation-defined behavior or any non-standard extension is not discussed in this document, then it is not part of the CCI. For example, GCC case ranges, label addresses and 24-bit `short long` types are not part of the CCI. Programs which use these features do not conform to the CCI. The compiler may issue a warning or error to indicate when you use a non-CCI feature and the CCI is enabled.

2.4 ANSI STANDARD REFINEMENT

The following topics describe how the CCI refines the implementation-defined behaviors outlined in the ANSI C Standard.

2.4.1 Source File Encoding

Under the CCI, a source file must be written using characters from the 7-bit ASCII set. Lines may be terminated using a *line feed* ('\n') or *carriage return* ('\r') that is immediately followed by a *line feed*. Escaped characters may be used in character constants or string literals to represent extended characters not in the basic character set.

2.4.1.1 EXAMPLE

The following shows a string constant being defined that uses escaped characters.

```
const char myName[] = "Bj\370rk\n";
```

2.4.1.2 DIFFERENCES

All compilers have used this character set.

2.4.1.3 MIGRATION TO THE CCI

No action required.

2.4.2 The Prototype for `main`

The prototype for the `main()` function is

```
int main(void);
```

2.4.2.1 EXAMPLE

The following shows an example of how `main()` might be defined

```
int main(void)
{
    while(1)
        process();
}
```

2.4.2.2 DIFFERENCES

The 8-bit compilers used a `void` return type for this function.

2.4.2.3 MIGRATION TO THE CCI

Each program has one definition for the `main()` function. Confirm the return type for `main()` in all projects previously compiled for 8-bit targets.

2.4.3 Header File Specification

Header file specifications that use directory separators do not conform to the CCI.

2.4.3.1 EXAMPLE

The following example shows two conforming include directives.

```
#include <usb_main.h>
#include "global.h"
```