

CC5X

*C Compiler for the
PICmicro Devices*

Version 3.1

User's Manual



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Trondheim - Norway

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COMPILER BUG REPORTS:

The compiler has been carefully tested and debugged. It is, however, not possible to guarantee a 100 % error free product.

If the compiler generates application code bugs, it is almost always possible to rewrite the program slightly in order to avoid the bug. *#pragma optimize* can be used to avoid optimization bugs. Other *#pragma* statements are also useful.

Please report cases of bad generated code and other serious program errors.

- 1) Investigate and describe the problem. If possible, please provide a short code sample which demonstrates the problem. A fragment of the generated assembly file (use cut and paste) is normally enough. Alternatively a short and complete C program (10 - 100 lines).
- 2) This service is intended for difficult compiler problems (not application problems).
- 3) Language: English
- 4) State the compiler version.
- 5) Send your report to support@bknd.com or by fax to (+47) 73 96 51 84.

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1 INTRODUCTION

Welcome to the CC5X C compiler for the Microchip PICmicro family of microcontrollers. The CC5X compiler enables programming using a subset of the C language. Assembly is no longer required. The reason for moving to C is clear. Assembly language is generally hard to read and errors are easily produced.

C enables the following advantages compared to assembly:

- Source code standardization
- Faster program development
- Improved source code readability
- Easier documentation
- Simplified maintenance
- Portable code

The CC5X compiler was designed to generate tight and optimized code. The optimizer automatically squeezes the code to a minimum. It is possible to write code that compiles into single instructions, but with C syntax. This means that the code can be optimized by rewriting C instead of rewriting assembly.

The design priority was not to provide full ANSI C support, but to enable best possible usage of the limited code and RAM resources. If the compiler generated less optimal code, this would force assembly to be used for parts of the code.

CC5X features

- Local and global variables of 1, 8, 16, 24 and 32 bits
- Efficient reuse of local variable space
- Generates tight and optimized code
- Produces binary, assembly, list, COD, error, function outline and variable files
- Automatic updating of the page selection bits
- Automatic updating of the bank selection bits
- Enhanced and compact support of bit operations, including bit functions
- Floating and fixed point math up to 32 bit
- Math libraries including functions like `sin()`, `log()`, `exp()`, `sqrt()`, etc.
- Supports standard C constant data and strings in program memory (`const`)
- Automatic storing of compressed 7 bit data in PIC16F87X devices
- Pointer models of 8 and 16 bits, mixed sizes in same application allowed
- RAM and/or ROM pointers
- The size of single pointers can be automatically chosen by the compiler
- Linker support (MPLINK), interfaces with assembly (MPASM) modules
- Extended call level by using `GOTO` instead of `CALL` when possible
- Inserts links to "hidden" subroutines
- Access to all assembly instructions through corresponding C statements
- Lookup tables: `#pragma return[] = "Hello world"`
- Integrated interrupt support
- Chip configuration information in source code

Size (in bits) of the variables supported by the different compiler editions:

	RED+FREE	STANDARD	EXTENDED
integer	8+16	8+16+24	8+16+24+32
fixed	-	8+16+24	8+16+24+32
float	24	24+32	16+24+32

1.1 Supported devices

12 bit core (PIC16C5X, PIC12C50X, etc.):

- up to 2048 words of code on 1 - 4 code pages
- up to 73 byte RAM in 1 - 4 banks

14 bit core (PIC12C67X, PIC14000, PIC16CXX, etc.):

- up to 8192 words of code on 1 - 4 code pages
- up to 512 byte RAM in 1 - 4 banks

1.2 Installation and System Requirements

The CC5X compiler uses 32 bit processing and runs on IBM-PC compatible machines using MSDOS or Windows (NT/95/98/2000).

Installing CC5X is done by first creating a directory/folder on the hard disk where the compiler files should be located. Then copy all CC5X files to this directory.

CC5X is now ready to compile C files. Header and C source files have to be edited by a separate editor (not included), for instance in MPLAB.

If you are mainly working in a MSDOS window, it may be useful to modify PATH in the AUTOEXEC.BAT file to allow the operating system to find the compiler from any directory (PATH ...;C:\CC5X;...). This is not a required step.

The CC5X files can be deleted without any un-installation procedure.

Support for Long File Names

CC5X supports long file names. Currently, it is not possible to use spaces in file names or in directory names. The truncated short format must then be used.

The truncated form is decided by the file system according to some rules. The best guess consists of the 6 first characters of the long name plus ~1. The last number is different (~2) if the first 6 characters are equal to another name in the same directory.

If the path should be: "C:\Program Files\MPLAB\longfilename" the equivalent short format is often: C:\PROGRA~1\MPLAB\LONGFI~1

The name "C file" becomes CFILE~1 because spaces must be removed.

MPLAB use and display the short format only. The short format name can be found when using Open File and point-and-click to move along a particular path.

User Interface

The CC5X compiler is a command-line program. It requires a list of command line options to compile a C source file and produce the required files.

Starting CC5X from Windows can be done by selecting the Start->Run menu. Then type the full path name including cc5x (or use Browse). The list of compiler command line options are then written to the screen. The normal way of using CC5X is to use it as a tool from an integrate environment like MPLAB.

Compiling a program (in a MSDOS window) requires a file name and command line options:

```
cc5x -a sample1.c <enter>
```


1.3 MPLAB Support

CC5X can be selected as a tool in MPLAB which offers an integrated environment including editor and tool support (compilers, assemblers, simulators, emulators, device programmers). Compilation errors are easily handled. MPLAB supports point-and-click to go directly to the source line that needs correction. CC5X supports the COD file format used by MPLAB for program debugging. CC5X offers two modes of source file debugging is available: C or assembly mode. Thus, tracing programs in MPLAB can be done using assembly instructions or C statements. MPLAB is free, and can be downloaded from the Microchip Internet site.

Please refer to the supplied file **'install.txt'** for a description on how to install and use CC5X in the MPLAB environment.

1.4 Summary of Delivered Files

```

CC5X.EXE      : compiler

INTRO.TXT    : introduction
INSTALL.TXT  : installation guide and MPLAB setup
CC5X.TXT     : basic documentation on CC5X
PRAGMA.TXT  : the pragma statement
INLINE.TXT   : information on inline assembly syntax
DEBUG.TXT    : debugging details, MPLAB support
CHIP.TXT     : how to make new chip definitions
CONFIG.TXT   : the PICmicro configuration bits
CDATA.TXT    : info on the #pragma cdata statement
CONST.TXT    : standard C strings and constant data
GLOBDEF.TXT  : PICmicro registers
STARTUP.TXT  : special startup sequences
LINKER.TXT   : how to link several modules (C or asm)

INT16CXX.H   : interrupt header file
INLINE.H     : emulating inline instructions

CC5X.MTC     : MPLAB tool configuration file
TLCC5X.INI   : MPLAB tool configuration file

OP.INC       : command line options on a file
RELOC.INC    : options for object modules (MPLINK)

SAMPLE1.C    : minimal program example
IICBUS.C     : IIC-bus interface
IIC-COM.C    : IIC-bus communication
SERIAL.C     : serial communication (RS232, RS485)
STATE.C      : state machines
DELAY.C      : implementing delays
INT16XX.C    : simple interrupt example

MATH.TXT     : Math library support
MATH16.H     : 8-16 bit math library
MATH16M.H    : 8-16 bit multiply, speed

1) MATH24.H  : 8-24 bit math library
1) MATH24M.H : 8-24 bit multiply, speed
2) MATH32.H  : 8-32 bit math library
2) MATH32M.H : 8-32 bit multiply, speed

```

```

1) MATH16X.H : 16 bit fixed point library
1) MATH24X.H : 24 bit fixed point library
2) MATH32X.H : 32 bit fixed point library

2) MATH16F.H : 16 bit floating point library
   MATH24F.H : 24 bit floating point library
1) MATH32F.H : 32 bit floating point library

   MATH24LB.H : 24 bit floating point functions
                 (log,sqrt,cos,..)
1) MATH32LB.H : 32 bit floating point functions
                 (log,sqrt,cos,..)

12C508.H .. 16C924.H : PICmicro header files

NEWS.TXT      : Recent added features
README.TXT

```

1) Not available on the RED and FREE editions

2) Not available on the RED, STANDARD and FREE editions

1.5 Short Program Example

```

/* global variables */
char a;
bit b1, b2;

/* assign names to port pins */
#pragma bit in @ PORTB.0
#pragma bit out @ PORTB.1

void sub( void)
{
    char i;      /* a local variable */

    /* generate 20 pulses */
    for ( i = 0; i < 20; i++) {
        out = 1;
        nop();
        out = 0;
    }
}

void main( void)
{
    // if (TO == 1 && PD == 1 /* power up */) {
    //     WARM_RESET:
    //     clearRAM(); // clear all RAM
    // }

    /* first decide the initial output level
    on the output port pins, and then
    define the input/output configuration.
    This avoids spikes at the output pins. */

```

```

PORTA =      0b.0010; /* out = 1 */
TRISA = 0b.1111.0001; /* xxxxx 0001 */

a = 9; /* value assigned to global variable */

do {
    if (in == 0) /* stop if 'in' is low */
        break;
    sub();
} while ( -- a > 0); /* 9 iterations */

// if (some condition)
//     goto WARM_RESET;

/* main is terminated by a SLEEP instruction */
}

```

1.6 Defining the PICmicro Device

CC5X offers 3 ways to select the PICmicro device in an application:

1) By a command line option. In MPLAB, the device command line option is selected in Project->Edit Project..(target)..Node Properties.

```

-p16C73
-pPIC16F877

```

2) By a pragma statement in the source code:

```

#pragma chip PIC16F84

```

3) By an include file.

```

#include "16c73.h"

```

NOTE 1: When using a pragma statement or header files, remember to use this the beginning of the C program so that it is compiled first. However, some preprocessor statements like *#define* and *#if* may proceed the *#include/#pragma* statement.

NOTE 2: When using the command line option or the pragma statement, CC5X will use the internal definitions for some devices. If the device is not known internally, **automatic** include of a header file is started. The internal known devices are: 16C54,55,56,57,58, 61,64,65, 71,73,74, 84, 620,621,622.

NOTE 3: If the header file does not reside in the default project folder, then the path name is required. This can be supplied by a command line option as an include folder/directory (-Ipath).

NOTE 4: New header files can be defined according to file 'chip.txt'.

NOTE 5: ICD debugging requires defining a symbol first:

a) Command line options:

```

-DICD_DEBUG -p16F877

```

b)

```

#define ICD_DEBUG // or by command line -DICD_DEBUG
#pragma chip PIC16F877

```

c)

```
#define ICD_DEBUG // or by command line -DICD_DEBUG
#include "16F877.H"
```

1.7 What to do next

It is important to know the PICmicro family and the tools well. The easiest way to start is to read the available documentation and experiment with the examples. Then move on to a simple project. Some suggestions:

- study the supplied program samples
- compile code fragments and check out what the compiler accepts
- study the optional assembly file produced by the compiler

Note that using more than one ram bank or code page requires pragma instructions.

Typical steps when developing programs is as follows:

- describe the system, make requirements
- suggest solutions that satisfy these requirements
- write detailed code in the C language
- compile the program using the CC5X compiler
- test the program on a prototype or a simulator

Writing programs for the PICmicro microcontroller family requires careful planning. Program and RAM space are limited, and the key question is often: *Will the application code fit into the selected controller?*

Important:

File '**readme.txt**' contains information on how to write code that can be compiled by CC5X.

2 VARIABLES

The compiler prints information on the screen when compiling. Most important are error messages, and how much RAM and PROGRAM space the program requires. The compiler output information is also written to file *.occ. Example:

```
delay.c:
Chip = 16C74
RAM: 00h : -----
RAM: 20h : ==.*****
RAM: 40h : *****
RAM: 60h : *****
RAM: 80h : -----
RAM: A0h : *****
RAM: C0h : *****
RAM: E0h : *****
Optimizing - removed 11 instructions (-14 %)
File 'delay.asm'
Codepage 0 has 68 word(s) : 3 %
Codepage 1 has 0 word(s) : 0 %
File 'delay.hex'
Total of 68 instructions (1 %)
```

2.1 Information on RAM allocation

The compiler prints information on RAM allocation. This map is useful to check out which RAM locations are still free. The map for the 16C57 chip may look like this:

```
Mapped RAM: 00h : ----- .7.-*****
Bank 0 RAM: 10h : ====4==* *****
Bank 1 RAM: 30h : ..6*****
Bank 2 RAM: 50h : *****
Bank 3 RAM: 70h : -7*****
```

Symbols:

```
* : free location
- : predefined or pragma variable
= : local variable(s)
. : global variable
7 : 7 free bits in this location
```

16C71 map:

```
RAM: 00h : ----- ===== ==3.7... *****
RAM: 20h : *****
```

2.2 Defining Variables

CC5X supports integer, fixed and floating point variables. The variable sizes are 1, 8, 16, 24 and 32 bit. The default *int* size is 8 bit, and *long* is 16 bit. Char variables are unsigned by default and thus range from 0 to 255. Note that 24 and 32 bit variables are not supported by all CC5X editions.

Math libraries have to be included for math operations (Section 6.5 *Library Support*).

CC5X uses (stores) LOW ORDER FIRST. This means that the least significant byte of a variable is assigned to the lowest address. All variables are allocated from low RAM addresses and upwards. Each

RAM location can contain 8 bit variables. Address regions used for special purpose registers are not available for normal allocation. An error message is produced when there is no space left.

Special purpose registers are either predefined or defined in chip-specific header files. This applies to W, INDF, TMR0, PCL, STATUS, FSR, Carry, PD, TO, etc.

Integer variables

```

unsigned a8;           // 8 bit unsigned
char a8;              // 8 bit unsigned
unsigned long i16;    // 16 bit unsigned

char varX;
char counter, L_byte, H_byte;
bit ready; // 0 or 1
bit flag, stop, semafor;

int i;                // 8 bit signed
signed char sc; // 8 bit signed
long i16;             // 16 bit signed

uns8 u8; // 8 bit unsigned
uns16 u16; // 16 bit unsigned
uns24 u24; // 24 bit unsigned
uns32 u32; // 32 bit unsigned

int8 s8; // 8 bit signed
int16 s16; // 16 bit signed
int24 s24; // 24 bit signed
int32 s32; // 32 bit signed

```

The bitfield syntax can also be used:

```

unsigned x : 24; // 24 bit unsigned
int y : 16; // 16 bit signed

```

The value range of the variables are:

TYPE	SIZE	MIN	MAX
----	----	---	---
int8	1	-128	127
int16	2	-32768	32767
int24	3	-8388608	8388607
int32	4	-2147483648	2147483647
uns8	1	0	255
uns16	2	0	65535
uns24	3	0	16777215
uns32	4	0	4294967295

Floating point

The compiler supports 16, 24 and 32 bit floating point. The 32 bit floating point can be converted to and from IEEE754 by 3 instructions (macro in math32f.h).

Supported floating point types:

```
float16      : 16 bit floating point
float, float24 : 24 bit floating point
double, float32 : 32 bit floating point
```

Format	Resolution	Range
16 bit	2.4 digits	+/- 3.4e38, +/- 1.1e-38
24 bit	4.8 digits	+/- 3.4e38, +/- 1.1e-38
32 bit	7.2 digits	+/- 3.4e38, +/- 1.1e-38

Note that 16 bit floating point is intended for special use where accuracy is less important. More details on the floating point formats is found in **'math.txt'**. Information on floating point libraries is found in Section 6.5 *Library Support*.

Floating point exception flags

The floating point flags are accessible in the application program. At program startup the flags should be initialized:

```
FpFlags = 0;    // reset all flags, disable rounding
FpRounding = 1; // enable rounding
```

Also, after an exception is detected and handled in the application, the exception bit should be cleared so that new exceptions can be detected. Exceptions can be ignored if this is most convenient. New operations are not affected by old exceptions. This also enables delayed handling of exceptions. Only the application program can clear exception flags.

```
char FpFlags; // contains the floating point flags

bit FpOverflow    @ FpFlags.1; // fp overflow
bit FpUnderFlow  @ FpFlags.2; // fp underflow
bit FpDiv0        @ FpFlags.3; // fp divide by zero
bit FpDomainError @ FpFlags.5; // domain error
bit FpRounding    @ FpFlags.6; // fp rounding
// FpRounding=0: truncation
// FpRounding=1: unbiased rounding to nearest LSB
```

IEEE754 interoperability

The floating point format used is not equivalent to the IEEE754 standard, but the difference is very small. The reason for using a different format is code efficiency. IEEE compatibility is needed when floating point values are exchanged with the outside world. It may also happen that inspecting variables during debugging requires the IEEE754 format on some emulators/debuggers. Macros for converting to and from IEEE754 is available:

```
math32f.h:
// before sending a floating point value:
float32ToIEEE754(floatVar);
// change to IEEE754 (3 instr.)

// before using a floating point value received:
IEEE754ToFloat32(floatVar);
// change from IEEE754 (3 instr.)

math24f.h:
float24ToIEEE754(floatVar);
// change to IEEE754 (3 instr.)
```

```
IEEE754ToFloat24(floatVar);
// change from IEEE754 (3 instr.)
```

Fixed point variables

Fixed point can be used instead of floating point, mainly to save program space. Fixed point math use formats where the decimal point is permanently set at byte boundaries. For example, fixed8_8 use one byte for the integer part and one byte for the decimal part. Fixed point operations maps nicely to integer operations except for multiplication and division which are supported by library functions. Information on fixed point libraries is found in Section 6.5 *Library Support*.

```
fixed8_8 fx;

fx.low8  : Least significant byte, decimal part
fx.high8 : Most significant byte, integer part

MSB LSB  1/256 = 0.00390625
07 01 : 7 + 0x01*0.00390625 = 7.0039625
07 80 : 7 + 0x80*0.00390625 = 7.5
07 FF : 7 + 0xFF*0.00390625 = 7.99609375
00 00 : 0
FF 00 : -1
FF FF : -1 + 0xFF*0.00390625 = -0.0039625
7F 00 : +127
7F FF : +127 + 0xFF*0.00390625 = 127.99609375
80 00 : -128
```

Convention: fixed<S><I>_<D> :

- <S> : 'U' : unsigned
- <none>: signed
- <I> : number of integer bits
- <D> : number of decimal bits

Thus, fixed16_8 uses 16 bits for the integer part plus 8 bits for the decimals, a total of 24 bits. The resolution for fixed16_8 is $1/256=0.0039$ which is the lowest possible increment. This is equivalent to 2 decimal digits (actually 2.4 decimal digits).

Built in fixed point types:

Type:	#bytes	Range	Resolution
fixed8_8	2 (1+1)	-128, +127.996	0.00390625
fixed8_16	3 (1+2)	-128, +127.99998	0.000015259
fixed8_24	4 (1+3)	-128, +127.99999994	0.000000059605
fixed16_8	3 (2+1)	-32768, +32767.996	0.00390625
fixed16_16	4 (2+2)	-32768, +32767.99998	0.000015259
fixed24_8	4 (3+1)	-8388608, +8388607.996	0.00390625
fixedU8_8	2 (1+1)	0, +255.996	0.00390625
fixedU8_16	3 (1+2)	0, +255.99998	0.000015259
fixedU8_24	4 (1+3)	0, +255.99999994	0.000000059605
fixedU16_8	3 (2+1)	0, +65535.996	0.00390625
fixedU16_16	4 (2+2)	0, +65535.99998	0.000015259
fixedU24_8	4 (3+1)	0, +16777215.996	0.00390625
(additional types with decimals only; no integer part)			
fixed_8	1 (0+1)	-0.5, +0.496	0.00390625
fixed_16	2 (0+2)	-0.5, +0.49998	0.000015259
fixed_24	3 (0+3)	-0.5, +0.49999994	0.000000059605


```

fixed_32    4 (0+4)    -0.5, +0.4999999998 0.0000000002328
fixedU_8    1 (0+1)    0, +0.996            0.00390625
fixedU_16   2 (0+2)    0, +0.99998          0.000015259
fixedU_24   3 (0+3)    0, +0.99999994      0.000000059605
fixedU_32   4 (0+4)    0, +0.9999999998    0.0000000002328

```

To sum up:

1. All types ending on _8 have 2 correct digits after decimal point
2. All types ending on _16 have 4 correct digits after decimal point
3. All types ending on _24 have 7 correct digits after decimal point
4. All types ending on _32 have 9 correct digits after decimal point

Fixed point constants

The 32 bit floating point format is used during compilation and calculation.

```

fixed8_8 a = 10.24;
fixed16_8 a = 8 * 1.23;
fixed8_16 x = 2.3e-3;
fixed8_16 x = 23.45e1;
fixed8_16 x = 23.45e-2;
fixed8_16 x = 0.;
fixed8_16 x = -1.23;

```

Constant rounding error example:

```

Constant: 0.036
Variable type: fixed16_8 (1 byte for decimals)

```

Error calculation: $0.036 * 256 = 9.216$. The byte values assigned to the variable are simply 0,0,9. The error is $(9/256 - 0.036) / 0.036 = -0.023$. The compiler prints this normalized error as a warning.

Type conversion

The fixed point types are handled as subtypes of float. Type casts are therefore infrequently required.

Fixed point interoperability

It is recommended to stick to one fixed point format in a program. The main problem when using mixed types is the enormous number of combinations which makes library support a challenge. However, many mixed operations are allowed when CC5X can map the types to the built in integer code generator:

```

fixed8_16 a, b;
fixed_16 c;
a = b + c; // OK, code is generated directly
a = b * 10.22; // OK: library function is supplied

a = b * c; // a new user library function is required!

// type cast can select an existing library function:
a = b * (fixed8_16)c;

```

Assigning variables to RAM addresses

All variables, including structures and arrays can be assigned to fixed address locations. This is useful for assigning names to port pins. It is also possible to assign overlapping variables (similar to union). The syntax is:

```

<type> <varName> @ <address>;
<type> <varName> @ <varName2>;
bit <bitName> @ <address>.<bit>;
bit <bitName> @ <varName>.<bit>;

```

Examples:

```

char th @ 0x25;
//bit th1 @ 0x25.1; // overlap warning
bit th1 @ th.1; // no warning

```

```

char tty;
bit b0;
char io @ tty;
bit bx0 @ b0;
bit bx2b @ tty.7;
//char tui @ b0; // size exceeded
//long r @ tty; // size exceeded

```

```

char tab[5];
long tr @ tab;
struct {
    long tiM;
    long uu;
} ham @ tab;

```

Pragma statements can also be used:

```

#pragma char port @ PORTC
#pragma char varX @ 0x23
#pragma bit IOpin @ PORTA.1
#pragma bit ready @ 0x20.2
#pragma bit ready @ PA2

```

If the compiler detects double assignments to the same RAM location, this will cause a warning to be printed. The warning can be avoided if the second assignment use the variable name from the first assignment instead of the address (*#pragma char var2 @ var1*).

An alternative is to use the #define statement:

```

#define PORTX PORTC
#define ready PA2

```

Priority when allocating variables:

1. Variables permanently assigned to a location
2. Local variables allocated by the compiler
3. Global variables allocated by the compiler

Supported type modifiers

```

static char a; /* a global variable; known in the current module
only, or having the same name scope as local variables when used in a
local block */

```

```

extern char a; // global variable (in another module)

```

```

auto char a; // local variable
// 'auto' is normally not used

```

```

register char a; // ignored type modifier

const char a; /* 'const' tells that compiler that the data is not
modified. This allows global data to be put in program memory. */

volatile char a; /* ignored type modifier. Note that CC5X use the
address to automatically decide that most of the special purpose
registers are volatile */

page0 void fx(void); // fx() resides in codepage 0
// page0,page1,page2,page3

bank0 char a; // variable 'a' resides in RAM bank 0
// bank0,bank1,bank2,bank3
// shrBank : unbanked locations, if available

size2 char *px; // pointer px is 16 bit wide
// size1,size2

```

Local Variables

Local variables are supported. The compiler performs a safe compression by checking the scope of the variables and reusing the locations when possible. The limited RAM space is therefore used efficiently. This feature is very useful, because deciding which variables can safely overlap is time consuming, especially during program redesign. Function parameters are located together with local variables.

Variables should be defined in the innermost block, because this allows best reuse of RAM locations. It is also possible to add inner blocks just to reduce the scope of the variables as shown in the following example:

```

void main(void)
{
    char i; /* no reuse is possible at the
            outermost level of 'main' */
    i = 9;
    { // an inner block is added
        char a;
        for (a = 0; a < 10; a++)
            i += fx(PORTB,0);
    }
    sub(i);
    { // local variables can be assigned immediate:
        char b = s + 1;
        int i1 = -1, i2 = 0;
        // more code
    }
}

```

Local variables may have the same name. However, the compiler adds an extension to produce an unique name in the assembly, list and COD files. When a function is not called (defined but not in use), then all parameters and local variables are truncated to the same (unused) location.

Temporary Variables

Operations like multiplication, division, modulo division and shifts often require temporary variables. However, the compiler needs NO PERMANENT SPACE for temporary variables.

The temporary variables are allocated the same way as local variables, but with a narrow scope. This means that the RAM locations can be reused in other parts of the program. This is an efficient strategy and often no extra space is required in application programs.

Arrays, structures and unions

One dimensional arrays is implemented. Note that indexed arithmetic is limited to 8 bit. Assignment is allowed for 8, 16, 24 and 32 bit.

```
char t[10], i, index, x, temp;
uns16 tx[3];

tx[i] = 10000;

t[1] = t[i] * 20; // ok
t[i] = t[x] * 20; // not allowed

temp = t[x] * 20;
t[i] = temp;
```

Normal C structures can be defined, also nested types. Unions are allowed.

```
struct hh {
    long a;
    char b;
} vx1;

union {
    struct {
        char a;
        int16 i;
    } pp;
    char x[4];
    uns32 l;
} uni;

// accessing structure elements
vx1.a = -10000;
uni.x[3] = vx1.b - 10;
```

The equivalent of a (small) multidimensional array can be constructed by using a structure. However, only one index can be a variable.

```
struct {
    char e[4];
    char i;
} multi[5];

multi[x].e[3] = 4;
multi[2].e[i+1] += temp;
```

Bitfields

Bitfields in structures are allowed. The size have to be 1, 8, 16, 24 or 32 bit.

```
struct bitfield {
    unsigned a : 1;
    bit      c;
```

```

    unsigned d : 32;
    char      aa;
} zz;

```

The CC5X compiler also allows the bitfield syntax to be used outside structures as a general way of defining variable size:

```
int x : 24; // a 24 bit signed variable
```

Typedef

Typedef allows defining new type identifiers consisting of structures or other data types:

```

typedef struct hh HH;
HH var1;
typedef unsigned ux : 16; // equal to uns16
ux r, a, b;

```

2.3 Using RAM Banks

Using more than one RAM bank is done by setting the active rambank:

```

/* variables proceeding the first rambank statement are placed in
mapped RAM or bank 0. This is also valid for local variables and
parameters */

#pragma rambank 1

char a,b,c; /* a,b and c are located in bank 1 */
/* parameters and local variables in functions placed here are also
located in bank 1 ! */

#pragma rambank 0

char d; /* located in bank 0 */

```

The compiler automatically finds the first free location in the selected bank.

NOTE: Local variables and function parameters also have to be located. It may be necessary to use `#pragma rambank` between some of the functions and even **INSIDE** a function. The recommended strategy is to locate local variables and function parameters in *mapped* RAM or bank 0. Mapped RAM is selected by:

```
#pragma rambank -
```

The bank type modifier

It is also possible to use the bank type modifier to select the RAM bank.

```

bank0..bank3, shrBank : can replace #pragma rambank
// shrBank is the unbanked locations, if available

bank1 char tx[3]; // tx[] is located in bank 1

```

The bank type modifier defines the RAM bank to locate the variable. It can locate global variables, function parameters and local variables. The bank type modifier applies to the variable itself, but not to the data accessed. This difference is important for pointers.

NOTE 1: The bank type modifier have higher priority than `#pragma rambank`.

NOTE 2: Using 'extern' makes it possible to state the variable definition several times. However, the first definition defines the rambank, and later definitions must use the same bank.

NOTE 3: When defining a function prototype, this will normally not locate the function parameters. However, when adding a bank type modifier to a function parameter in a prototype, this will define the bank to be used for this variable.

If variables are located in non-existing RAM banks for a device, these variables are mapped into existing RAM banks (bank 0). This applies to the bank type modifiers and the `#pragma rambank` statement.

Using RAM banks requires some planning. The optimal placement requires least code to update the bank selection bits. Some advise when locating variables:

1. Try to locate variables which are close related to each other in the same bank.
2. Try to locate all variables accessed in the same function in the same bank.
3. Switching between bank 0 and 3, or bank 1 and 2 require more instructions than the other combinations.
4. Use as few banks as possible. Fill bank 0 first, then bank 1, etc.
5. Remember that local variables and function parameters also may require updating of the bank selection bits.

RAM Bank Selection Bits

RAM and special purpose registers can be located in up to 4 banks. The 12 bit core uses bit 5 and 6 in FSR to select the right bank. In the 14 bit core, RP0 and RP1 in the STATUS register are used for this purpose.

The bank selection bits are automatically checked and updated by the compiler, and attempts to set or clear these bits in the source code are removed by the compiler. This feature can be switched off which means that correct updating has to be done in the source code.

The compiler uses global optimizing techniques to minimize the extra code needed to update the bank selection bits. Removing all unnecessary updating is difficult. However, there should be few redundant instructions.

The compiler inserts the following instructions:

```
BCF 04h,FSR_5    // 12 bit core (16C57,58,..)
BSF 04h,FSR_5    // 12 bit core (16C57,58,..)
BCF 04h,FSR_6    // 12 bit core (16C57,58,..)
BSF 04h,FSR_6    // 12 bit core (16C57,58,..)
CLRF FSR         // 12 bit core (16C57,58,..)

BCF 03h,RP0      // 14 bit core
BSF 03h,RP0      // 14 bit core
BCF 03h,RP1      // 14 bit core
BSF 03h,RP1      // 14 bit core
```

NOTE: The compiler REMOVES all bank updating done by the user. Actually all of the above stated instructions are removed. It is therefore possible to switch between manual and automatic updating by setting or removing the `-b` command line option.

Local user update regions

The automatic updating can be switched off locally. This is done by pragma statements:

```
#pragma update_FSR 0 /* OFF, 12 bit core */
#pragma update_FSR 1 /* ON, 12 bit core */

#pragma update_RP 0 /* OFF, 14 bit core */
#pragma update_RP 1 /* ON, 14 bit core */
```

These statements can be inserted anywhere, but they should surround a smallest possible region. Please check the generated assembly code to ensure that the desired results is achieved.

NOTE: The safest coding is to not assume any specific contents of the bank selection bits when a local update region is started. The compiler uses complex rules to update the bank selection bits outside the local regions. Also, all updating inside a local update region is traced to enable optimal updating when the local update region ends.

2.4 Pointers

Single level pointers is implemented. Note that pointer arithmetic is limited to 8 bit. Assignment is allowed for 8, 16, 24 and 32 bit.

```
char t[10], *p;

p = &t[1];
*p = 100;
p[2] ++;
```

Pointer models

Using 8 bit pointers when possible saves both code and RAM space. CC5X allows the size of all single pointers to be decided automatically. However, pointers in structures and arrays have to be decided in advance, by using the memory model command line options or a size type modifier. Note that the operator 'sizeof(pointer)' will fix the size according to the chosen default model. Using sizeof(pointer) is normally not required and should be avoided.

That default pointer sizes are used only when the pointer size is not chosen dynamically. The priority when deciding the pointer size is:

- 1) Pointer size type modifiers
- 2) Automatic chosen pointer size (single pointers)
- 3) Pointer size chosen according to the default model

Command line options:

- mc1 : default 'const' pointer size is 1 byte (8 bits)
- mc2 : default 'const' pointer size is 2 bytes (16 bits)
- mr1 : default RAM pointer size is 1 byte
- mr2 : default RAM pointer size is 2 bytes
- mm1 : default pointer size is 1 byte (all pointer types)
- mm2 : default pointer size is 2 bytes (all pointer types)

Pointer size type modifiers:

- size1: pointer size is 1 byte (8 bits)
- size2: pointer size is 2 bytes (16 bits)

```
bank1 size2 float *pf;
```

The supported pointer types are:

- a) 8 bit pointer to RAM. The compiler will automatically update the IRP bit if required (when RAM space exceeds 256 bytes).

- b) 16 bit pointer to RAM. This format is required only when the same pointer have to access locations in different 256 byte RAM segments.
- c) 8 bit pointer to program memory. This pointer can access up to 256 byte data.
- d) 16 bit pointer to program memory. This pointer can access more than 256 byte data.
- e) 8 bit pointer to RAM or program memory. This pointer can access up to 128 byte data and 128 byte RAM. Bit 7 is used to detect RAM or program memory access. The compiler will only chose this format if all RAM addresses loaded to the pointer is in the same bank (14 bit core).
- f) 16 bit pointer to RAM or program memory. Bit 15 is used to detect RAM or program memory access.

The 12 bit Core

Indirect RAM access on the 16C57/58/12C509 requires some care because the RAM bank selection bits resides in the FSR register (bit 5,6). The compiler can do most of the checking and generate error messages if required. Automatic bankbit updating can be switched off globally (*-b* command line option), or locally (`#pragma update_FSR 0`). Most of the checking described is performed only if the automatic bankbit updating is ON.

Reading and writing arrays is straight forward:

```
bank2 char a, e, t[3], s[3];

a = t[i];
s[i] = e;
s[i+3] = e;
```

The last three statements requires that variable *e* is located in mapped RAM (below 0x10) or in the same bank as array *s[]*. Otherwise an error message is printed to indicate that the compiler can not update the bank selection bits.

Pointers may need a `#pragma assume` statement:

```
#pragma rambank 3
char *px, r;
#define LTAB 5
char tab[LTAB];
#pragma assume *px in rambank 3

px = &tab[0];

*px = r;
if (++px == &tab[LTAB])
    px = &tab[0];
```

A pointer may access more than one bank. The `#pragma assume` statement should NOT be used in such cases. The only difference is that the compiler will know the contents of the FSR.5,6 when a variable in a specific bank is accessed. Therefore, a statement like:

```
*pointer_to_any_rambank = e;
```

requires that *e* in located in mapped RAM (address less than 0x10).

Note that the `#pragma assume` statement works for single pointers (and pointers in arrays), but not for pointers located in structures.

Arrays are often more efficient than pointers:


```

i = 0;
// ..
tab[i] = r;
if (++i == LTAB)
    i = 0;

```

Direct use of INDF and FSR is also possible:

```

FSR = px;
INDF = i;

```

Variable *i* have to reside in mapped RAM. The compiler performs the checking when INDF is accessed. The compiler does not try to trace the contents of FSR when it is loaded directly. Therefore, a statement like **px = r;* is normally preferred.

Using *#pragma assume *px in rambank 3* also makes loading of *px* more restrictive. An error message is printed if *px* is loaded with an address in another bank. The following cases are checked:

```

px = tab;           // same as &tab[0]
px = &tab[0];
px = &tab[i];
px = pxx;          // pxx is another pointer
px = &pxx[i];

```

A statement like *px = &tab[i];* may fool the compiler if the value of *i* is too large.

If the above syntax is too restrictive, then a local update region is the solution. All rambank updating then have to be done with C statements. Normally, local update regions requires inspection of the generated assembly file to avoid problems.

```

/* these statements clears the buffer */
i = LTAB;
#pragma update_FSR 0 /* OFF */
FSR = &tab[0];
do {
    INDF = 0;
    FSR ++;
} while (--i > 0);
#pragma update_FSR 1 /* ON */

```

Without a local update region:

```

i = LTAB;
do
    tab[i-1] = 0;
while (--i > 0);

```

In this example, the local update region only has a speed advantage. The same amount of instructions are generated. Note that although no rambank updating is required inside the above local region, the compiler does not know the contents of FSR.5,6 at the end of the region, and will therefore update these bits afterwards.

The 14 bit core: the IRP bit

For some 14 bit core chips, rambank 2 and 3 is in use. This means that register bit IRP have to be updated in user code when working with arrays and tables.

```
#pragma rambank 2
char array[50];
char x;

FSR = &array % 256 + x; // LSB of &array[x]
IRP = &array / 256;    // MSB
```

NOTE: IRP is not updated by the compiler if INDF is used directly in the user code. Using *array[x]* instead of INDF enables automatic updating of the IRP bit.

The compiler will trace all loading of pointers to decide how the IRP bit should be updated. This applies to both 8 and 16 bit pointers.

It is also possible to use *#pragma assume* to state the bank directly:

```
bank1 char t[3];
bank3 char i, *pi, *pit;
#pragma assume *pi in rambank 3 // or rambank 2
#pragma assume *pit in rambank 1 // or rambank 0
..
pi = &i;
pit = &t[2];
```

An error message is printed if a pointer is loaded with an address from the wrong RAM half. Note that rambank 0 and 1 are grouped together (the lower RAM half, 0 - 0xFF). Rambank 2 and 3 are the upper RAM half (0x100 - 0x1FF).

Updating of IRP can be switched off locally. The compiler does not remove superfluous updating of the IRP register. This means that IRP is updated for each pointer or table access.

An efficient strategy may be to locate (most of) the tables in upper or lower RAM (above or below address 0x100), and do all updating of IRP in the user code. Few updates are sometimes sufficient.

```
#pragma update_IRP 0 /* off */
..
IRP = 1; // updated by user code
..
#pragma update_IRP 1 /* on */
```

2.5 Const Data Support

CC5X supports constant data stored in program memory. The C keyword 'const' tells the compiler that these data do not change. Examples:

```
const char *ps = "Hello world!";
const float ftx[] = { 1.0, 33.34, 1.3e-10 };
..
t = *ps;
ps = "";
fx = ftx[i];
```

The implementation of constant data supports the following features:

- both 8 and 16 bit pointers to const data in the same application
- the size of single const pointers can be chosen automatically
- const pointers can access both RAM and program memory
- the compiler will not put all constant data in a single table, but rather make smaller tables if this saves code space

- some devices supports 14 bits data (PIC16F87X). The compiler will automatically chose this format if space can be saved. This allows very compact storage of 7 bit ASCII strings.
- duplicate strings and other data are automatically merged to save space

Recommendations:

It is recommended to use small data tables and structures. This allows the compiler to merge equal data items and build optimal blocks of constant data.

Limitations:

- 1) The compiler will not initialize RAM variables on startup
- 2) Data items of 16 bit or more in structures with more than 256 byte data must be aligned

Storing 14 bit data

Some flash devices (PIC16F87X) supports 14 bits data stored in program memory. This allows compact storage of 7 bit ASCII strings and 14 bits data. The code sequence required for accessing these bits is longer than the code for a return table. This means that code is saved when the amount of data exceeds 40-50 bytes. The compiler will automatically chose the optimal storage format.

The 14 bit data format allows storing up to 16000 bytes of 7 bit ASCII text on a 8k device. The compiler will use the 14 bit format when a pragma statement is used. This is normally found in the header file for the device.

```
#pragma wideConstData
```

The device must also contain the following special purpose registers:

```
/*char*/ EEADRH,EEADR,EEDATH,EEDATA, /*bit*/ EEPGD,RD
```

When a constant table contains less than 256 byte of data, there will be a tradeoff between speed and size. Using a return table executes faster but requires more code when the table contains more than 40-50 bytes of data. If speed is required, the following pragma statement defines a new limit for size optimization.

```
#pragma wideConstData 200 // return table limit
```

Data of size 16 bit or more

The compiler allows access of 8,16,24 and 32 bits data, including fixed and floating point formats. When using arrays or structures with more than 256 byte data, single data items have to be aligned. Alignment means that there should not be any remainder when dividing the offset with the size of the data item. This is only a problem when defining structures containing data of different sizes.

```
const long t1[5] = { 10000, -10000, 0, 30000, -1 };
const uns24 th[] = { 1000000, 0xFFFFFFFF, 9000000 };
const int32 ti[] = { 1000000000, 0x7FFFFFFF,
                   -9000000000 };
const fixed8_8 tf[] = { -1.1, 200.25, -100.25 };
const float tp[] = { -1.1, 200.25, 23e20 };
const double td[] = { -1.1, 200.25, 23e-30};
const float16 ts[] = { -1.1, 200.25, 23e-30};
..
l = t1[i]; // reading a long integer
d = td[x]; // reading a double float constant
```

Code pages

When using devices with more than one codepage, the compiler will automatically calculate the optimal codepage for the data. The disadvantage is that the compiler will not know when a codepage is full, so the functions still have to be moved manually between codepages to find allowed and optimal combinations. Also, the data can be located on a specific codepage by using a page type modifier.

```
const page1 char tx[] = "Hello!";
```

Merging data

The compiler will automatically merge equal strings and sub-strings, and also other data items. Using small tables will increase the chance of finding data items that can be merged. Note that data containing initialized addresses (ROM and RAM) are not merged. Examples:

1. The string "world!" is identical to the last part of the string "Hello world!". It is therefore not required to use additional storage for the first string. The compiler handles the address calculations so that merged (or overlapping) strings are handled fully automatically. Note that the string termination '\0' also have to be equal, otherwise merging is not possible. For example, the string "world" can not be merged with the above strings.
2. Merging applies to all kinds of data. Data is compared byte by byte. This allows the first two of the following tables to be merged with the last one.

```
const char a1[] = { 10, 20, 30 };
const char a2[] = "ab";
const char a3[] = { 5, 10, 20, 30, 'a', 'b', 0 };
```

Examples

A table of pointers to strings:

```
const struct {
    const char *s;
} tb[] = {
    "Hello world",
    "Monday",
    "",
    "world" // automatically merged with first string
};

p = tb[i].s; // const char *p; char i;

t = *p++; // char t;
t = p[x]; // char x;
```

Note that 'const struct' is required to put the pointer array in program memory. Using 'const char *tx[];' means that the strings resides in program memory, but the table 'tx[]' resides in RAM.

String parameters:

```
myfunc("Hello"); // void myfunc(const char *str);
myfunc(&tab[i]); // char tab[20]; // string in RAM
myfunc(ctab); // const char ctab[] = "A string";
```

3 SYNTAX

3.1 Statements

C statements are separated by semicolons and surrounded by block delimiters:

```
{ <statement>; .. <statement>; }
```

The typical statements are:

```
// if, while, for, do, switch, break, continue,
// return, goto, <assignment>, <function call>
while (1) {
    k = 3;
X:
    if (PORTA == 0) {
        for (i = 0; i < 10; i++) {
            pin_1 = 0;
            do {
                a = sample();
                a = rr(a);
                s += a;
            }
            while (s < 200);
        }
        reg -= 1;
    }
    if (PORTA == 4)
        return 5;
    else if (count == 3)
        goto X;
    if (PORTB != 0)
        break;
}
```

if statement

```
if (<condition>)
    <statement>;
else if (<condition>)
    <statement>;
else
    <statement>;
```

The *else if* and *else* parts are optional.

while statement

```
while (<condition>)
    <statement>;

while (1) { .. } // infinite loop
```

for statement

```
for (<initialization>; <condition>; <increment>)
    <statement>;
```

initialization: all legal assignments or empty

condition: all legal conditions or empty
 increment: incrementing or decrementing a variable or empty

```
for (v = 0; v < 10; v++) { .. }
for (; v < 10; v++) { .. }
for (v = 0; ; v--) { .. }
```

do statement

```
do
    <statement>;
while (<condition>);
```

switch statement

```
switch (<variable>) {
    case <constant1>:
        <statement>; .. <statement>;
        break;
    case <constant2>:
        <statement>; .. <statement>;
        break;
    ..
    default:
        <statement>; .. <statement>;
        break;
}
```

<variable>: all 8 bit variables including W

break: optional

default: optional, can be put in the middle of the switch statement

```
switch (token) {
    case 2:
        i += 2;
        break;
    case 9:
    case 1:
    default:
        if (PORTA == 0x22)
            break;
    case 'P':
        pin1 = 0; i -= 2;
        break;
}
```

break statement

The 'break;' statement is used inside loop statements (for, while, do) to terminate the loop. It is also used in *switch* statements.

```
while (1) {
    ..
    if (var == 5)
        break;
    ..
}
```

continue statement

The 'continue;' statement is used inside loop statements (for, while, do) to force the next iteration of the loop to be executed, skipping any code in between. In *while* and *do-while* loops, the loop condition is executed next. In *for* loops, the increment is processed before the loop condition.

```
for (i = 0; i < 10; i++) {
    ..
    if (i == 7)
        continue;
    ..
}
```

return statement

```
return <expression>; /* exits the current function */

return; /* no return value */
return i+1; /* return value */
```

goto statement

```
goto <label>;
```

Jumps to a location, forward or backward.

```
goto XYZ;
..
XYZ:
..
```

3.2 Assignment and Conditions

```
<variable> = <value> <operation> <value>;
<variable> <operation> = <value>;
<variable> ++;
<variable> --;
```

```
variable:  of a supported type
operation: + - & | ^ * / % << >>
value:    <variable> or <constant>
constant: 34 0xFF 'A' 0b01101111
```

```
var1 = x + y;
W = W & 0x1F;
i = x - 100;
```

```
y ^= 'A'; // y = y ^ 'A';
W |= 3; // W = W | 3;
```

```
flag = 1; // bit variable
```

```
i++; // increment: i = i + 1;
i--; // decrement: i = i - 1;
```

Special syntax examples

```
#define mx !a
if (!mx) ..
```

```

W = W - 3; // ADDLW 256-3
b = fx() - 3;

// Post- and pre-incrementing of pointers
char *cp;
t = *--cp;
t |= *++cp;
*cp-- = t;
t = *cp++ + 10;

// extended pre-incrementing of variables
t = ++b | 3;
sum( --b, 10);
t = tab[ --b];

```

Conditions

```

[ ++ | -- ] <variable> <cond-oper> <value>
                                     [ && condition ]
                                     [ || condition ]

```

```

cond-oper : ==  !=  >  >=  <  <=

```

```

if (x == 7) ..
if (Carry == 1 && a1 < a2) ..
if (y > 44 || Carry || x != z) ..
if (--index > 0) ..
if (bx == 1 || ++i < max) ..
if (sub_1() != 0) ..

```

Bit variables

```

bit a, b, c, d;
char i, j, k;

```

```

bit bitfun(void) // bit return type (using Carry bit)
{
    return 0; // Clear Carry, return
    return 1; // Set Carry, return
    nop();
    return Carry; // return
    return b; // Carry=b; return
    return !i;
    return b & PORTA.3;
}
..
b = bitfun2(bitfun(), 1);
if (bitfun()) ..
if (!bitfun()) ..
if (bitfun() == 0) ..

b = !charfun();
b = charfun() > 0;
b = !bitfun();
Carry = bitfun();
b &= bitfun();

```



```

if (bitfun() == b) ..
if (bitfun() == PORTA.1) ..
i += b; // conditional increment
i -= b; // conditional decrement
i = k+Carry;
i = k-Carry;
b = !b; // Toggle bit (or b=b==0;)
b = !c; // assign inverted bit
PORTA.0 = !Carry;
a &= PORTA.0;
PORTA.1 |= a;
PORTA.2 &= a;

// assign condition using 8 bit char variables
b = !i;
b = !W;
b = j == 0;
b = k != 0;
b = i > 0;

// assign bit conditions
b = c&d; //also &&, |, ||, +, ^, ==, !=, <, >, >=, <=

// conditions using bit variables
if (b == c) .. // also !=, >, <, >=, <=

// initialized local bit variables
bit bx = cx == '+';
bit by = fx() != 0xFF;

```

Multiplication, division and modulo

```
multiplication : a16 = b16 * c16; // 16 * 16 bit
```

A general multiplication algorithm is implemented, allowing most combinations of variable sizes.

Including a math library allows library calls to be generated instead of inline code. The algorithm makes shortcuts when possible, for instance when multiplying by 2. This is treated as a left shift.

```

division      : a16 = b16 / c8; // 16 / 8 bit
modulo       : a32 = b32 % c16; // 32 % 16 bit

```

The division algorithm also allows most combinations of variable sizes. Shortcuts are made when dividing by 2 (or 2*2*..). These are treated as right shifts.

Precedence of C operators

```

Highest:      ( )
              ++ --
              * / %
              + -
              << >>
              < <= > >=
              == !=
              &
              ^
              |
              &&
              ||
Lowest:      = += -= *= /= etc.

```

Mixed variable sizes are allowed

```
a32 = (uns32) b24 * c8; // 24 * 8 bit, result 32 bit
a16 = a16 + b8;        // 16 + 8 bit, result 16 bit
```

Most combinations of variables are allowed, the compiler performs sign extension is required. Multiple operations in the same expression are allowed when using 8 bit variables.

```
a8 = b8 + c8 + d8 + 10;
```

3.3 Constants

```
x = 34;           /* decimal */
x = 0x22;        /* hexadecimal */
x = 'A';         /* ASCII */
x = 0b010101;   /* binary */

x = 0x1234 / 256; /* 0x12 : MSB */
x = 0x1234 % 256; /* 0x34 : LSB */
x = 33 % 4;      /* 1 */
x = 0xF & 0xF3;  /* 3 */
x = 0x2 | 0x8;   /* 10 */
x = 0x2 ^ 0xF;   /* 0b1101 */
x = 0b10 << 2;   /* 8 */
x = r1 + (3 * 8 - 2); /* 22 */
x = r1 + (3 + 99 + 67 - 2); /* 167 */
x = ((0xF & 0xF3) + 1) * 4; /* 16 */
```

Please note that parentheses are required in some cases.

Constant Expressions

The size of integers is by default 8 bits for this compiler (other C compilers use typically 16 or 32 bits depending on the CPU capabilities). An error is printed if the constant expression loses significant bits because of value range limitations.

```
char a;
a = (10 * 100) / 256; // an error is printed
a = (10L * 100) / 256; // no error
a = ((uns16) 10 * 100) / 256; // no error
a = (uns16) (10 * 100) / 256; // error again
a = (10 * 200) / 256; // no error, 200 is a long int
```

Adding a *L* means conversion to long (16 bit).

The command line option *-cu* force 32 bit evaluation of constants (upward compatibility) so that no significant bits are lost.

Some new built in types can also be used:

TYPE	SIZE	MIN	MAX
----	----	---	---
int8 : 8 bit signed	1	-128	127
int16: 16 bit signed	2	-32768	32767
int24: 24 bit signed	3	-8388608	8388607
int32: 32 bit signed	4	-2147483648	2147483647
uns8 : 8 bit unsigned	1	0	255
uns16: 16 bit unsigned	2	0	65535
uns24: 24 bit unsigned	3	0	16777215
uns32: 32 bit unsigned	4	0	4294967295

The constant type is by default the shortest signed integer. Adding an *U* behind a constant means that it is treated as unsigned. Note that constants above 0x7FFFFFFF are unsigned by default (with or without an *U* behind).

Enumeration

An enumeration is a set of named integer constants. It can often replace a number of *#define* statements. The numbering starts with 0, but this can be changed:

```
enum { A1, A2, A3, A4 };
enum { alfa = 8, beta, zeta = -4, eps };
```

3.4 Functions

Function definitions can look as follows:

```
void subroutine2(char p) { /* C statements */}
bit function1(void) { }
long function2(char W) { }
void main(void) { }
```

Function calls:

```
subroutine1();
subroutine2(24);
bitX = function1();
x = function2(W);
y = fx1(fx3(x));
```

The compiler need to know the definition of a function before it is called to enable type checking. A prototype is a function definition without statements. Prototypes are useful when the function is called before it is defined. The parameter name is optional in prototypes:

```
char function3(char);
void subroutine1(void);
```

Function return values

Functions can return values up to 4 bytes wide. Return values can be assigned to a variable or discarded. Handling and using return values is automated by the compiler.

The least significant byte is always placed in *W* when using 14 bit core devices. Signed variables and variables larger than 8 bits also use temporary variables on the computed stack. The 12 bit core use the *W* register when returning 8 bit constants. All other return values are placed in return variables on the computed stack.

A function can return any value type. The *W* register is used for 8 bit return value if possible. The Carry flag is used for bit return values. The compiler will automatically allocate a temporary variable for other return types. A function with no return value is of type *void*.

Parameters in function calls

There are no fixed limit on the number of parameters allowed in function calls. Space for parameters are allocated in the same way as local variables which allows efficient reuse. The bit type is also allowed.

Note that if *W* is used, this has to be the LAST parameter.

```
char func(char a, uns16 b, bit ob, char W);
```

Internal functions

The internal functions provides direct access to certain inline code:

```
btsc(Carry); // void btsc(char); - BTFSC f,b
btss(bit2); // void btss(char); - BTFSS f,b
```

```

clrwdt();      // void clrwdt(void); - CLRWDT
clearRAM();    // void clearRAM(void); clears all RAM
i = decsz(i);  // char decsz(char); - DECFSZ f,d
W = incsz(i);  // char incsz(char); - INCFSZ f,d
nop();         // void nop(void); - NOP
nop2();        // void nop2(void); - GOTO next address
retint();     // void retint(void); - RETFIE
W = rl(i);    // char rl(char); - RLF i,d
i = rr(i);    // char rr(char); - RRF i,d
sleep();      // void sleep(void); - SLEEP
skip(i);      // void skip(char); - computed goto
k = swap(k);  // char swap(char); - SWAPF k,d

```

The internal rotate functions are also available for the larger variable sizes:

```

a16 = rl(a16); // 16 bit left rotation
a32 = rr(a32); // 32 bit right rotation

```

The inline function `nop2()` is implemented by a GOTO to the next address. Thus, `nop2()` can replace two `nop()` to get more compact code. The main use of `nop()` and `nop2()` is to design exact delays in timing critical parts of the application.

3.5 Type Cast

Constants and variables of different types can be mixed in expressions. The compiler converts them automatically to the same type according to the stated rules. For example, the expression:

```
a = b + c;
```

consists of 2 separate operations. The first is the plus operation and the second is the assignment. The type conversion rules are first applied to $b+c$. The result of the plus operation and a are treated last.

The CC5X compiler use 8 bit int size and contains significantly many data types (integers, fixed and floating point). The type cast rules have been set up to provide best possible compatibility with standard C compilers (which typically use 16 or 32 bit int size).

The type conversion rules implemented are:

1. if one operand is double -> the other is converted to double
2. if one operand is float -> the other is converted to float
3. if one operand is 32 bit -> the other is converted to 32 bit
4. if one operand is 24 bit -> the other is converted to 24 bit
5. if one operand is long -> the other is converted to long
6. if one operand is unsigned -> the other is converted to unsigned

NOTES: The sign is extended before the operand is converted to unsigned. Assignment is also an operation. Constants are SIGNED, except if U is added. The bit type is converted to unsigned char. The fixed point types are handled as subtypes of float.

Type conversion in C is difficult. The compiler generates a warning if a typecast is required to make the intention clear:

```

uns16 a16;
char b8, c8;
a16 = b8 * c8;           // warning (8 bit result)
a16 = (uns16) (b8 * c8); // warning (8 bit result)
a16 = (uns16) b8 * c8;   // no warning (16 bit result)
a16 = (uns8) (b8 * c8);  // no warning (8 bit result)

```

3.6 Accessing Parts of a Variable

Each bit in a variable can be accessed directly:

```

uns32 a;
a.7 = 1;    // set bit 7 of variable a to 1
if (a.31 == 0) // test bit 31 of variable a
    t[i].4 = 0; // bit 4 of the i'th element

```

Bit 0: least significant bit
 Bit 7: most significant bit of a 8 bit variable
 Bit 15: most significant bit of a 16 bit variable
 Bit 23: most significant bit of a 24 bit variable
 Bit 31: most significant bit of a 32 bit variable

Also, parts of a variable can be accessed directly:

```

uns16 a;
uns32 b;
a.low8 = 100; // set the least significant 8 bits
a = b.high16; // load the most significant 16 bits

```

low8 : least significant byte
 high8 : most significant byte
 mid8 : second byte
 midL8 : second byte
 midH8 : third byte
 low16 : least significant 16 bit
 mid16 : middle 16 bit
 high16: most significant 16 bit
 low24 : least significant 24 bit
 high24: most significant 24 bit

The table shows which bits are accessed depending on the variable size in bytes (1,2,3,4) and the sub-index used. The * indicates normal use of the sub-index:

	1	2	3	4
low8	0-7	* 0-7	* 0-7	* 0-7
high8	0-7	* 8-15	* 16-23	* 24-31
mid8	0-7	8-15	* 8-15	8-15
midL8	0-7	8-15	8-15	* 8-15
midH8	0-7	8-15	16-23	* 16-23
low16	0-7	0-15	* 0-15	* 0-15
mid16	0-7	0-15	8-23	* 8-23
high16	0-7	0-15	* 8-23	* 16-31
low24	0-7	0-15	0-23	* 0-23
high24	0-7	0-15	0-23	* 8-31

3.7 C Extensions

CC5X adds some extensions to the standard C syntax:

1. The *bit* variable type
2. The *interrupt* function type

3. C++ style comments are allowed :

```
// a comment, valid to the end of the line
```

4. Local variables can be declared between statements as in C++. Standard C requires local variables to be defined in the beginning of a block.

5. Binary constants : 0bxxxxxx or bin(xxxxxx)

The individual bits can be separated by the ':'

```
0b0100
0b.0.000.1.01.00000
bin(0100)
bin(0001.0100)
```

6. Preprocessor statements can be put into macros. Such preprocessor statements are not extended to multiple lines. The inserted preprocessor statements are evaluated when the macro is expanded, and not when it is defined.

```
#define MAX      \
{                \
  a = 0;         \
  #if AAA == 0 && BBB == 0 \
    b = 0;       \
  #endif        \
}
```

7. Several of the type modifiers are not standard in C (page0..page3, bank0..bank3, shrBank, size1,size2)

More C extensions are allowed by the #pragma statement.

3.8 Predefined Symbols

The basic PICmicro registers are predefined (header files defines the rest):

```
W, INDF, PCL, STATUS, FSR, PORTA, Carry, etc.
```

The following names are defined as internal functions, and are translated into special instructions or instruction sequences.

```
btsc, btss, clearRAM, clrwdt, decfsz, incfsz, nop, nop2, retint, rl,
rr, sleep, skip, swap
```

Extensions to the standard C keywords:

```
bank0, bank1, bank2, bank3, bit, fixed8_8, .. fixed24_8, float16,
float24, float32, int8, int16, int24, int32, interrupt, page0, page1,
page2, page3, shrBank, size1, size2, uns8, uns16, uns24, uns32
```

Standard C keywords used:

```
auto, break, case, char, const, continue, default, double, enum,
extern, do, else, float, for, goto, if, int, long, return, short,
signed, sizeof, static, struct, switch, typedef, union, unsigned,
void, while,
define, elif, ifdef, ifndef, include, endif, error, pragma, undef
```

The remaining standard C keywords are detected and compiled. One is ignored (*register*), and the rest cause a warning to be printed (*volatile, line*).

Automatically defined macros and symbols

The following symbols are automatically defined when using the CC5X compiler, and can be used in preprocessor macros:

```

__CodePages__ := equal to 1..4, depending on the
                number of code pages on the actual chip

__CC5X__      := Integer version number: 3002 means 3.0B

__CoreSet__   := 1200: 12 bit core, 1400: 14 bit core

__IRP_SFR__   := 1 if IRP is active when accessing
                special function registers using INDF, 0
                otherwise. Note that '#pragma update_IRP 0'
                will set this macro to 0 until
                '#pragma update_IRP 1' is processed.

__IRP_RAM__   := 1 if IRP is active when accessing RAM
                registers using INDF, 0 otherwise. Using
                '#pragma update_IRP 0' will set this macro
                to 0 until '#pragma update_IRP 1'.

_16CXX        := always defined (12 and 14 bit cores)

_16C5X        := when the 12 bit core is selected

_16C54        := when the 16C54 is selected, similar for
                the other devices

```

3.9 Upward Compatibility

The aim is to provide best possible upward compatibility from version to version. Sometimes the generated code is improved. If the application programs contain timing critical parts (depends on an exact instruction count), then these parts should be verified again, for example by using the MSDOS program *fc* (file compare) on the generated assembly files.

Evaluation of constant expression is slightly changed from version 2.x in order to adapt to standard C. An error message is printed if significant bits are lost. The cure is to use type conversion.

```
a = (uns16) 10 * 100;
```

Alternatively will the command line option *-cu* force 32 bit evaluation of constant expressions. The option *-wS* changes the error message to a warning.

4 PREPROCESSOR DIRECTIVES

The preprocessor recognizes the following keywords:

```
#define, #undef, #include
#if, #ifdef, #ifndef, #elif, #else, #endif
#error, #pragma
```

A preprocessor line can be extended by putting a `\` at the end of the line. This requires that there are no space characters behind the `\`.

`#define`

```
#define counter    v1
#define MAX        145
#define echo(x)    v2 = x
#define mix()      echo(1) /* nested macro */
```

Note that all *#define*'s are global, even if they are put inside a function.

Preprocessor directives can be put into the *#define* statement.

`#include`

```
#include "test.h"
#include <test.h>
```

#include's can be nested. When using *#include "test.h"* the current directory is first searched. If the file is not found there, then the library directories are searched, in the same order as supplied in the command line option list (*-I<dir>*). The current directory is skipped when using *#include <test.h>*.

`#undef`

```
#define MAX        145
..
#undef MAX /* removes definition of MAX */
```

#undef does the opposite of *#define*. The *#undef* statement will not produce any error message if the symbol is not defined.

`#if`

```
#if defined ALFA && ALFA == 1
..
/* statements compiled if ALFA is equal to 1 */
/* conditional compilation may be nested */
#endif
```

An arbitrary complex constant expression can be supplied. The expression is evaluated the same way as a normal C conditional statement is processed. However, every constant is converted to a 32 bit signed constant first.

- 1) macro's are automatically expanded
- 2) *defined(SYMBOL)* and *defined SYMBOL* are replaced by 1 if the symbol is defined, otherwise 0.
- 3) legal constants : 1234 -1 'a' '\\'
- 4) legal operations : + - * / % >> <<
 - == != < <= > >= || &&
 - ! ~ ()

#ifdef

```
#ifdef SYMBOL
..
/* Statements compiled if SYMBOL is defined.
   Conditional compilation can be nested. SYMBOL
   should not be a variable or a function name. */
#endif
```

#ifndef

```
#ifndef SYMBOL
/* statements compiled if SYMBOL is
   not defined */
#endif
```

#elif

```
#ifdef AX
..
#elif defined BX || defined CX
/* statements compiled if AX is not
   defined, and BX or CX is defined */
#endif
```

#else

```
#ifdef SYMBOL
..
#else
..
#endif
```

#endif

```
#ifdef SYMBOL
..
#endif
```

#error

```
#error This is a custom defined error message
```

The compiler generates an error message using the text found behind #error.

#pragma

The pragma statement is used for processor specific implementations.

4.1 The pragma Statement

Available pragma statements:

```
#pragma asm2var 1
#pragma assert /e text passed to the debugger
#pragma assume *p in rambank 3
#pragma bit ready @ STATUS.7
#pragma cdata[1] = 0, 0x2000
#pragma char varX @ 7
#pragma chip PIC16C55
#pragma codepage 0
```

```

#pragma computedGoto 0
#pragma config WDTE=off, FOSC=HS
#pragma library 1 / on
#pragma location 2
#pragma optimize 0 /* ALL off */
#pragma origin 0x200
#pragma rambank 1
#pragma rambase 48 /* bank 1 */
#pragma ramdef 0x190 : 0x19F
#pragma resetVector 0 // at location 0
#pragma return[] = "Hello" 0 1 'H'
#pragma stackLevels 4 // max 64
#pragma update_FSR 1 /* ON */
#pragma update_IRP 0 /* OFF */
#pragma update_PAGE 0 /* OFF */
#pragma update_RP 0 /* OFF */
#pragma wideConstData 70

```

#pragma asm2var 1

Enable equ to variable transformation. Defined in file Section 6.6 *Inline Assembly*.

#pragma assert [/] <type> <text field>

Assert statements allows messages to be passed to the simulator, emulator, etc. Refer to Section 7.3 *Assert Statements* for details.

#pragma assume *<pointer> in rambank <n>

The *#pragma assume* statement tells the compiler that a pointer operates in a limited address range. Refer to Section 2.4 *Pointers* for details.

#pragma bit <name> @ <N.B or variable[B]>

Defines the global bit variable <name>. Useful for assigning a bit variable to a certain address. Only valid addresses are allowed:

```

#pragma bit bitxx @ 0x20.7
#pragma bit ready @ STATUS.7
#pragma bit ready @ PA2

```

NOTE: If the compiler detects double assignments to the same RAM location, this will cause a warning to be printed. The warning can be avoided if the second assignment use the variable name from the first assignment instead of the address (*#pragma bit var2 @ var1*).

#pragma cdata[ADDRESS] = <VXS>, .., <VXS>

The cdata statement can store 14 bit data in program memory at fixed addresses. It can also be used to store data in EEPROM memory. Refer to Section 6.9 *The cdata Statement* for details.

```

#pragma cdata[ADDRESS] = <VXS>, .., <VXS>
#pragma cdata[] = <VXS>, .., <VXS>
#pragma cdata.IDENTIFIER = <VXS>, .., <VXS>

```

```

ADDRESS: 0 .. 0x7FFE
VXS : < VALUE | EXPRESSION | STRING>
VALUE: 0 .. 0x3FFF
EXPRESSION: any valid C constant expression,
            i.e. 0x1000 | (3*1234)
STRING: "Valid C String\r\n\0\x24\x8\xe\xff\xff\\\"

```

#pragma char <name> @ <constant or variable>

Defines the global variable <name>. Useful for assigning a variable to a certain address. Only valid addresses are allowed:

```
#pragma char i @ 0x20
#pragma char PORTX @ PORTC
```

NOTE: If the compiler detects double assignments to the same RAM location, this will cause a warning to be printed. The warning can be avoided if the second assignment use the variable name from the first assignment instead of the address (*#pragma char var2 @ var1*).

#pragma chip [=] <device>

Defines the chip type. This allows the compiler to select the right boundaries for code and memory size, variable names, etc. Note that the chip type can also be defined as a command line option.

```
#pragma chip PIC16C55
```

This statement have to proceed any normal C statements, but some preprocessor statements, like #if and #define, can be compiled first.

The supported devices are either known internally (16C54,55,56,57,58, 61,64,65, 71,73,74, 84, 620,621,622) or defined in a PICmicro header file (i.e.16F877.h). It is also possible to make new header files. Refer to file 'chip.txt' for details.

#pragma codepage [=] <0,1,2,3>

```
    // 12 bit core      14 bit core
0   // 0x000 - 0x1FF   0x0000 - 0x07FF
1   // 0x200 - 0x3FF   0x0800 - 0x0FFF
2   // 0x400 - 0x5FF   0x1000 - 0x17FF
3   // 0x600 - 0x7FF   0x1800 - 0x1FFF
```

Defines the codepage to be used. Code is located at the start of the active codepage, or from the current active location on that page. The codepage can not be changed inside a function. Non-existing pages for a specific controller are mapped into existing ones.

```
#pragma codepage 3
/* following functions are located on codepage 3 */
```

#pragma computedGoto [=] <0,1,2>

This statement can be used when constructing complicated computed goto's. Refer to Section 9.2 *Computed Goto* for details.

```
#pragma computedGoto 1 // start region
#pragma computedGoto 0 // end of region
#pragma computedGoto 2 // start large region
```

#pragma config <id> = <state> [, <id> = <state>]

```
<id>      : PWRTE, WDTE, FOSC, BODEN, ID
<state>   : on, off, LP,HS,XT,RC, <number>, ~<number>
```

```
#pragma config WDTE=off, FOSC=HS
#pragma config WDTE=0, FOSC=2, PWRTE=1
```

```
#pragma config |= 0x100 // set bit 8
```

```
#pragma config &= 0xFFFC // clear bit 0 and 1
#pragma config &= ~3      // clear bit 0 and 1
```

Refer to Section 4.2 *PICmicro Configuration* for more details.

#pragma config_def [=] <value>

Defines the position and size of the supported config identifiers, and is normally found in PICmicro header files. Refer to file 'chip.txt' for details.

#pragma library <0/1>

CC5X will automatically delete unused (library) functions.

```
#pragma library 1
// functions that are deleted if unused
// applies to prototypes and function definitions
#pragma library 0
```

#pragma location [=] <0,1,2,3,->

This statement can be used to locate the functions on different codepages. Refer to Section 6.1 *Program Code Pages* for more details.

#pragma optimize [=] [N:] <0,1>

This statement enables optimization to be switched ON or OFF in a local region. A specific type of optimization can also be switched on or off. The default setting is on.

1. redirect goto to goto
2. remove superfluous gotos
3. replace goto by skip instructions
4. remove instructions that affects the zero-flag only.
5. replace INCF and DECF by INCFSZ and DECFSZ
6. remove superfluous updating of PA0 and PA1
7. remove other superfluous instructions
8. remove superfluous loading of W

Examples:

```
#pragma optimize 0    /* ALL off */
#pragma optimize 1    /* ALL on */
#pragma optimize 2:1 /* type 2 on */
#pragma optimize 1:0 /* type 1 off */
```

```
/* combinations are also possible */
#pragma optimize 3:0, 4:0, 5:1
#pragma optimize 1, 1:0, 2:0, 3:0
```

NOTE: The command line option *-u* will switch optimization off globally, which means that all settings in the source code is ignored.

#pragma origin [=] <n>

Valid address region : 0x0000 - 0x1FFF

Defines the address (and codepage) of the following code. The current active location on a codepage can not be moved backwards, even if there is no code in that area. Origin can not be changed inside a function.

Examples:

```
#pragma origin 4 // interrupt start address
#pragma origin 0x700
```

#pragma rambank [=] <0,1,2,3,->

14 bit core:

```
- => mapped space: (chip specific)
0 => bank 0: 0 (0x000) - 127 (0x07F)
1 => bank 1: 128 (0x080) - 255 (0x0FF)
2 => bank 2: 256 (0x100) - 383 (0x17F)
3 => bank 3: 384 (0x180) - 511 (0x1FF)
```

12 bit core:

```
- => mapped space: 8 - 15 (0x0F)
0 => bank 0: 16 (0x10) - 31 (0x1F)
1 => bank 1: 48 (0x30) - 63 (0x3F)
2 => bank 2: 80 (0x50) - 95 (0x5F)
3 => bank 3: 112 (0x70) - 127 (0x7F)
```

#pragma rambank defines the region(s) where the compiler will allocate variable space. The compiler gives an error message when all locations in the current bank are allocated.

RAM banks are only valid for some of the controllers. Non-existing banks for the other controllers are mapped into defined RAM space.

#pragma rambase [=] <n>

Defines the start address when declaring global variables. This statement is included for backward compatibility reasons only. The use of *rambank* and *rambase* are very similar. The address have to be within the RAM space of the chip used.

12 bit core note: The locations from address 0 to 31 are treated as a unit. Using start address 7 means that locations in the mapped register space and bank 0 are allocated. Using start address 32 implies that locations in the mapped register space are allocated.

NOTE: The start address is not valid for local variables, but *rambase* can be used to select a specific RAM-bank.

#pragma ramdef <ra> : <rb> [MAPPING]

This statement is normally used in PICmicro header files. Refer to file 'chip.txt' for details.

#pragma resetVector <n>

Some chips have an unusual startup vector location (like the PIC16C508/9). The reset-vector then have to be specified. This statement is normally NOT required, because the compiler normally use the default location, which is the first (14 bit core) or the last location (12 bit core).

```
#pragma resetVector 0x1FF // at last code location
#pragma resetVector 0 // at location 0
#pragma resetVector 10 // at location 10
#pragma resetVector - // NO reset-vector at all
```

#pragma return[<n>] = <strings or constants>

Allows multiple return statements to be inserted. This statement should be preceded by the *skip()* statement. The compiler may otherwise remove most returns. The constant <n> is optional, but it allows

the compiler to print a warning when the number of constants is not equal to <n>. Refer to Section 9.2 *Computed Goto* for more details. Note that 'const' data types should normally be used for constant data.

```

skip(W);
#define NoH 11
#pragma return[NoH] = "Hello world"
#pragma return[5] = 1, 4, 5, 6, 7
#pragma return[] = 0 1 2 3 44 'H' \
                  "Hello" 2 3 4 0x44
#pragma return[] = 'H' 'e' 'l' 'l' 'o'
#pragma return[3] = 0b0101110 \
                  0b111      0x10
#pragma return[9] = "a \" \r\n\0"
#pragma return[] = (10+10*2), (0x80+'E') "nd"
#pragma return[] = 10000 : 16 /* 16 bit constant */ \
                  0x123456 : 24 /* 24 bit constant */ \
                  (10000 * 10000) : 32 /* 32 bit constant */

```

#pragma stackLevels <n>

The number of call levels can be defined (normally not required). The 12 bit core use by default 2 levels. The 14 bit core use by default 8 levels.

```
#pragma stackLevels 4 // max 64
```

#pragma update_FSR [=] <0,1>

Allows the automatic updating of the bank selection bits FSR.5 and FSR.6 to be switched on and off locally. This can be useful in some cases when INDF is used directly in the user code. The statement works for core 12 devices with more than one RAM bank. It is ignored for the other devices.

```
#pragma update_FSR 0 /* OFF */
#pragma update_FSR 1 /* ON */
```

These statements can be inserted anywhere, but they should surround a region as small as possible.

#pragma update_IRP [=] <0,1>

Allows the automatic updating of the indirect bank selection bit IRP to be switched on and off locally. The statement is ignored when using the 12 bit core.

```
#pragma update_IRP 0 /* OFF */
#pragma update_IRP 1 /* ON */
```

These statements can be inserted anywhere.

#pragma update_PAGE [=] <0,1>

Allows the automatic updating of the page selection bits to be switched on and off locally. This is not recommended except in special cases. The page bits resides in the STATUS register for core 12 devices, and in PCLATH for core 14.

```
#pragma update_PAGE 0 /* OFF */
#pragma update_PAGE 1 /* ON */
```

#pragma update_RP [=] <0,1>

Allows the automatic updating of the bank selection bits RP0 and RP1 to be switched on and off locally. The statement is ignored when using the 12 bit core.

```
#pragma update_RP 0 /* OFF */
#pragma update_RP 1 /* ON */
```

These statements can be inserted anywhere, but they should surround a region as small as possible.

#pragma wideConstData [<N>]

Enable storing of 14 bit data for 14 bit core devices. Details is found in Section 2.5 *Const Data Support*.

4.2 PICmicro Configuration

PICmicro configuration information can be put in the generated hex and assembly file. ID locations can also be programmed. The configuration information is generated IF AND ONLY IF the *#pragma config* statement is included. Note that some PICmicro programming devices may reject this information, especially setting of the ID locations.

Syntax:

```
#pragma config <id> = <state> [, <id> = <state>]

<id>      : PWRTE, WDTE, FOSC, BODEN, ID
<state>   : on, off, LP,HS,XT,RC, <number>, ~<number>

#pragma config WDTE=off, FOSC=HS
#pragma config WDTE=0, FOSC=2, PWRTE=1
#pragma config |= 0x100 // set bit 8
#pragma config &= 0xFFFC // clear bit 0 and 1
#pragma config &= ~3 // clear bit 0 and 1
#pragma config |= 3 // set bit 0 and 1
```

More than one *#pragma config* statement is possible. The default setting of the attributes is 0.

The operators '|' and '&' can be used to achieve high-level readability:

```
#define CP_off |= 0x3F30 // 16C62X and similar
#pragma config CP_off, FOSC = LP
```

Programming of ID-locations:

```
#pragma config ID=0x1234 // all 4 locations, 4*4 bit
#pragma config ID[0] = 0xFFF // location 0
#pragma config ID[1] = 0x010 // location 1
#pragma config ID[2]=1, ID[3]=0x23
```

The config and ID information is added at the end of the generated assembly and hex file.

Configuration word address:

- 12 bit core: 0xFFF
- 14 bit core: 0x2007

ID words:

PICmicro	ADDRESS	
16C54/55	0x200-0x203	4 locations
16C56	0x400-0x403	4 locations
16C57/58	0x800-0x803	4 locations
14 bit core	0x2000-0x2003	4 locations

5 COMMAND LINE OPTIONS

The compiler needs a C source file name to start compiling. Other arguments can be added if required. The syntax is:

```
CC5X [options] <src>.c [options]
```

-a[<asmfile>]: produce assembly file.

The default file name is <src>.asm

-A[scHDpftmiJbeokgN+N+N] : assembly file options

s: symbolic arguments are replaced by numbers

c: no C source code is printed

H: hexadecimal numbers only

D: decimal numbers only

p: no '!' in front of decimal constants

f: no object format directive is printed

t: no tabulators, normal spaces only

m: single source line only

i: no source indentation, straight left margin

J: put source after instructions to achieve a compact assembly file.

b: do not add rambank info to variables in the assembly file

e: do not add ',l' to instructions when result is written back to the register

o: do not replace OPTION with OPTION_REG

k: do not convert all hexadecimal numbers (11h -> 0x11)

g: do not use PROCESSOR instead of the list directive

N+N+N: label, mnemonic and argument spacing. Default is 8+6+10.

-b: do not update bank selection bits

12 bit core: FSR.5 and 6

14 bit core: STATUS.RP0 and RP1

-bu: non-optimized updating of the bank selection bits

-CC[<file>] : produce COD file, C mode

-CA[<file>] : produce COD file, ASM mode

-dc: do not write compiler output file <src>.occ

-D<name>[=xxx] : define macro. Equivalent to #define name xxx

-e: single line error messages (no source lines are printed).

-ed : do not print error details

-ew : do not print warning details

-eL : list error and warning details at the end

-E<N> : stop after <N> errors (default is 4).

-f<hex-file-format> : i.e. INHX8M, INHX8S, INHX16, INHX32. Default is INHX8M. Note that INHX8S use output files: <file>.HXH and <file>.HXL

-F: produce error file <src>.err

-g: do not replace call by goto

-GW: dynamic selected skip() format, warning on long format (default)

- GD**: dynamic selected skip() format
- GS**: always short skip() format (error if boundary is crossed)
- GL**: always long skip() format

- I<directory>** : include files directory. Up to 5 library directories can be supplied by using separate -I<dir> options. When using #include "test.h" the current directory is first searched. If the file is not found there, then the library directories are searched, in the same order as supplied in the command line option list (-I<dir>). The current directory is skipped when using #include <test.h>.

- j**: do not update page selection bits
12 bit core: STATUS.PA0 and PA1
14 bit core: PCLATH.3 and 4

- L[<col>,<lin>]** : produce list file <src>.lst
The maximum number of columns per line <col> and lines per page <lin> can be changed. The default setting is -L80,60

- mc1**: default 'const' pointer size is 1 byte (8 bits)
- mc2**: default 'const' pointer size is 2 bytes (16 bits)
- mr1**: default RAM pointer size is 1 byte
- mr2**: default RAM pointer size is 2 bytes
- mm1**: default pointer size is 1 byte (all pointer types)
- mm2**: default pointer size is 2 bytes (all pointer types)

- o<name>** : write hex file to name

- O<directory>** : output files directory. Files generated by the compiler are put on this directory, except when a full path name is supplied.

- p<device>** : defines the chip type. The device have to be known internally: 16C54,55,56,57,58,61,64,65, 71,73,74, 84 or supported by a header file (i.e. 16F877.H). Default device is 16C54.

- q<N>** : assume disabled interrupt at the <N> deepest call levels. I.e. -q1 allows the main program to use all stack levels for function calls. If the interrupt routine makes function calls, then -q2 etc. can be used. Disabling interrupt at the deepest call level MUST be properly ensured in the user application program.

- r** : generate relocatable assembly (no hex file)
- r2[<filename.lkr>]** : use separate logical section for interrupt routine
- rp<N>** : name on codepage 0 is PROG<N>, default PROG1
- rb<N>** : name on RAM bank 0 is BANK<N>, default BANK0
- ro<N>** : add offset <N> when generating local variable block name

- Q**: write the call tree to <src>.fcs.

- S**: silent operation of the compiler

- u** : no optimizing

- V[**rnuD**]** : generate variable file, <src>.var, sorted by address as default.
r: only variables which are referenced in the code
n: sort by name
u: unsorted
D: decimal numbers

- we**: no warning when fixed point constants are rounded
- wB**: warning when function is called from another code page

-wI: warning on long inline code for multiplication and division
-wL: (12 bit core only) print warning on all GOTO links to functions residing on hidden half of a codepage.
-wO: warning on operator library calls
-wP: warning when code page bits are not correct
-wr: no warning on recursive calls
-wS: warning (no error) when constant expression loses significant bits
-wU: warning on uncalled functions

-cu: use 32 bit evaluation of constant expressions

-x<file> : assembler executable: -xC:\progra~1\mplab\mpasm.exe
-X<option> : assembler option: -X/q (all options must be separate)

-W: wait until key pressed after compilation

A path name can be written using '/' if this is supported by the file system, example:

```
c:/compiler/lib/file.h
```

Default compiler settings:

- hex file output on file <name>.hex
- processor = 16C54
- optimizing on
- extended call level is allowed
- update bank and page selection bits

Permanent assigned settings:

- nested comments is allowed
- char is unsigned

5.1 Options on a file

Options can be put on a file. The syntax is:

```
cc5x [...] +<filename> [...]
```

Many option files can be included, and up to 5 levels of nested include files are allowed. Options on a file allows an unlimited number of options to be stated. Linefeed, space and TAB separates each option. Comments can be added in the option file using the syntax:

```
// the rest of the line is a comment
```

Spaces can be added to each option if a space is added behind the '-' starting the option. This syntax disables using more than one option on each line. Examples:

```

- D MAC = 1 + OP
- p 16C54      // comment
-p 16C54      // this will not work
- p 15C64 -a  // not this either

```

Note that the file path if the file does not reside on the current directory.

6 PROGRAM CODE

6.1 Program Code Pages

Many of the PICmicro devices have more than one code page. A code page contains 512 words on the 12 bit core and 2048 words on the 14 bit core. Using more than one code page requires `#pragma` statements. All functions following a `#pragma codepage` statement are put on the page specified. Codepage 0 is used as default.

```
/* functions proceeding the first codepage statement are placed on
codepage 0 */

#pragma codepage 2

char fx(void) { .. }
/* this function is placed on codepage 2 */

#pragma codepage 1

/* following functions are placed on codepage 1 */
```

When switching between codepages, the compiler will keep track on the next free location on each codepage. Use of codepages is just a matter of optimization, as long as the compiler accepts the selection. The optimal combination requires least code (or has a speed advantage). The optimizer removes unnecessary setting and clearing of the page selection bits.

Some of the PICmicro devices have 4 code pages. Note that calls which requires switching between page 0 and 3, or page 1 and 2 requires more instructions than the other combinations.

The compiler produces an error message when page limits are exceeded. Invalid code pages are mapped to valid ones.

Another way of locating functions

The statement `#pragma location` is capable of locating prototypes on codepages as well as function definitions. The statement is useful when locating functions defined in library files, or when locating functions in large programs. Its normal use is in limited regions in header files. The rules when using `#pragma location` are:

1. A function prototype will locate the function on the desired codepage, even if the current active codepage is different when the function definition is compiled.
2. `#pragma location` have higher priority than `#pragma codepage`.
3. `#pragma location -` restores the active codepage defined by the last `#pragma codepage` (or `#pragma origin`).

```
#pragma location 1 // codepage 1
void f1(void);    // assigned to codepage 1
void f2(void);
void f3(void);

#pragma location 3 // codepage 3
void f4(void);

#pragma location - // return to the active codepage
void f5(void);    // this prototype is not located
```

Notes:

1. The location statements have to be compiled before the function definition
2. Functions not located are placed on the current active codepage
3. A warning is printed in case of conflicts

The *#pragma location* statement should only be used if required. An example is when functions inside a module (file) have to be placed on different codepages, or if much tuning is required to find the optimal combination. The *#pragma codepage* statement is normally sufficient.

The page type modifier

The page type modifiers `page0..page3` can replace `#pragma location/codepage`.

```
page2 void fx(void) { .. } // in codepage 2
page1 char f2(char a); // in codepage 1
```

The page type modifier defines the codepage to locate the function in, both for function prototypes and function definitions.

NOTE 1: The page type modifier have higher priority than both `#pragma codepage` and `#pragma location`

NOTE 2: When the codepage have been defined using the page type modifier or `#pragma location`, then the location is fixed and can not be changed in the function definition or by using a second prototype.

Invalid code pages are mapped to valid ones.

Page selection bits

The page selection bits PA0 and PA1 are automatically updated by the compiler, and attempts to set or clear these bits in the source code are removed by the optimizer. This can be switched off by the `-j` command line option.

Core 12 note: assigning a value to the status register (f3) may cause the automatic updating to fail.

6.2 Subroutine Call Level Checking

Subroutine calls are limited to 2 levels for the 12 bit core and 8 levels for the 14 bit core. The compiler **automatically** checks that this limit is not exceeded.

The compiler can replace `CALL` by `GOTO` to seemingly achieve deeper call levels.

1. When a function is called once only, the call can be replaced by a goto. All corresponding returns are replaced by gotos. Call is NOT replaced by goto when:
 - a) The program counter (PCL) is manipulated in the user code (computed goto) in a function of type *char*.
 - b) The number of return literal exceeds 10
 - c) The function is called from another codepage and the number of returns exceeds 10
2. Call followed by return is replaced by a single goto.

When subroutines are located in the second half of a codepage, it can not be called directly when using 12 bit core devices. The compiler automatically inserts links to such "hidden" subroutines.

Stack level checking when using interrupt

CC5X will normally assume that an interrupt can occur anywhere in the main program, also at the deepest call level. An error message is printed if stack overflow may occur. This is not always true,

because the interrupt enable bits controls when interrupts are allowed. Sometimes the main program need all 8 stack levels for making calls.

The `-q<N>` option force CC5X to assume that interrupt will NOT occur at the `<N>` deepest call levels of the main program.

The application writer must then ensure that interrupt will not occur when executing functions at the deepest `<N>` call levels, normally by using the global interrupt enable bit. CC5X will generate a warning for the critical functions. (The normal error message is always generated when the application contains more than 8 call levels.)

For example, the `-q1` option generates a warning for functions calls that will put the return address at stack level 8 (no free stack entry for interrupt). Using `-q2` means an additional warning at stack level 7 if the interrupt routine requires 2 levels, i.e. contains function calls.

It is NOT recommended to use the `-q<N>` as a default option.

Recursive functions

Recursive functions are possible. Please note that the termination condition have to be defined in the application code, and therefore the call level checking can not be done by the compiler. Also note that the compiler does not allow any local variables in recursive functions. Function parameters and local variables can be handled by writing code that emulates a stack.

A warning is printed when the compiler detects a function which call itself directly or through another function. This warning can be switched off with the `-wr` command line option.

6.3 Interrupts

The 14 bit core allows interrupts:

- external interrupt on RB0/INT pin
- external interrupt on port pins change, RB4:7
- internal interrupt on TMR0 overflow
- .. and other controller specific interrupts

The structure of the interrupt service routine is as follows:

```
#include "int16CXX.h"
#pragma origin 4

interrupt serverX(void)
{
    // W and STATUS are saved by the next macro.
    // PCLATH is also saved if necessary.
    // The code produced is strongly CPU-dependent.

    int_save_registers    // W, STATUS (and PCLATH)
    //char sv_FSR; sv_FSR = FSR; // if required

    // handle the interrupt

    //FSR = sv_FSR;          // if required
    int_restore_registers // W, STATUS (and PCLATH)
}
```

The keyword *interrupt* allows the routine to be terminated by a RETFIE instruction. It is possible to call a function from the interrupt routine (it have to be defined by a prototype function definition first).

The interrupt routine requires at least one free stack location because the return address is pushed on the stack. This is automatically checked by the compiler, even function calls from the interrupt routine. However, if the program contains recursive functions, then the call level can not be checked by the compiler.

The interrupt vector is permanently set to address 4. The interrupt service routine can only be located at this address if it is the first function defined in the program. The `#pragma origin` statement have to be used in order to skip unused program locations.

Vital registers such as STATUS and W should be saved and restored by the interrupt routine. However, registers that are not modified by the interrupt routine do not have to be saved. Saving and restoring registers is device dependent. The file `int16CXX.H` contains recommended program sequences for saving and restoring registers. FSR must be saved manually if the interrupt service routine use it for accessing RAM arrays. For instance to access data buffers used for serial communication. The interrupt routine can also contain local variables. Space is allocated separately because interrupts can occur anytime.

It is possible to design SPECIAL service routines if the use of interrupts is limited to certain program regions, for instance in wait loops or after SLEEP instructions. In such cases registers do not have to be saved. Be careful with PCLATH and RP0/RP1 anyway.

NOTE: clearing GIE requires special attention on some PICmicro devices. The recommended procedure is: `do GIE = 0; while (GIE == 1);`

Note that this applies only to some of the devices (the first designed ones). Refer to the documentation from Microchip for more details.

INTERRUPTS CAN BE VERY DIFFICULT. THE PITFALLS ARE MANY.

6.4 Startup and Termination Code

The startup code consists of a jump to `main()` which has to be located on page zero. No variables are initiated. All initialization has to be done by user code. This simplifies design when using the watchdog timer or MCLR pin for wakeup purposes.

The SLEEP instruction is executed when the processor exit `main()`. This stops program execution and the chip enters the low power mode. Program execution may be restarted by a watchdog timer timeout or a low state on the MCLR pin.

The 14 bit core also allows restart by interrupt. An extra GOTO is therefore inserted if main is allowed to terminate (SLEEP). This ensures repeated execution of the main program. However, no extra GOTO is added when a `sleep()` command is inserted anywhere else in the application program.

Clearing ALL RAM locations

The internal function `clearRAM()` will set all RAM locations to zero. The generated code use the FSR register. The recommended usage is:

```
void main(void)
{
    if (TO == 1 && PD == 1 /* power up */) {
        WARM_RESET:
            clearRAM(); // set all RAM to 0
    }
    ..
    if (condition)
        goto WARM_RESET;
}
```

The code size and timing depends on the actual chip. The following table describes the basic types. Chip devices not found here maps to one of the described types.

INS	ICYC	TOTCYC	4MHz	RAM	START	LAST	BANKS	PICmicro
8	6	145	0.15ms	25	7	0x1F	-	16C54
9	4	202	0.20ms	41	7	0x3F	2	16C509
13	4	290	0.29ms	72	8	0x7F	4	16C57
8	7	254	0.25ms	36	12	0x2F	-	16C84
6	5	482	0.48ms	96	32	0x7F	1	16C620A
12	5	644	0.64ms	128	32	0xBF	2	12C671
9	4	770	0.77ms	176	32	0xFF	2	16C642
9	4	770	0.77ms	192	32	0xFF	2	16C74
10	4	771	0.77ms	192	32	0xFF	4	16C923
19	5	1110	1.11ms	224	32	0x14F	4	16C627
12	4	1058	1.06ms	256	32	0x17F	4	16C773
15	4	1807	1.81ms	368	32	0x1FF	4	16C77

INS: number of assembly instructions required
 ICYC: cycles (4*clock) for each RAM location cleared
 TOTCYC: total number of cycles (4*clock) required
 4MHz: approx. time in milliseconds required at 4 MHz
 RAM: total number of RAM locations
 START: first RAM address
 LAST: last RAM address
 BANKS: number of RAM banks
 PICmicro: chip type described

6.5 Library Support

The library support includes **standard math** and support for **user defined libraries**. The library files should be included in the beginning of the application, but after the interrupt routine for all libraries located on codepage 0.

```
// ..interrupt routine
#include "math16.h" // 16 bit integer math
#include "math24f.h" // 24 bit floating point
#include "math24lb.h" // 24 bit math functions
```

CC5X will automatically delete unused library functions. This feature can also be used to delete unused application functions:

```
#pragma library 1
// library functions that are deleted if unused
#pragma library 0
```

Math libraries

Integer: 8, 16, 24 and 32 bit, signed and unsigned
 Fixed point: 20 formats, signed and unsigned
 Floating point: 16, 24 and 32 bit

All libraries are optimized to get compact code. All variables (except for the floating point flags) are allocated on the generated stack to enable efficient RAM reuse with other local variables. A new concept of transparent sharing of parameters in a library is introduced to save code.

Note that fixed point requires manual worst case analysis to get correct results. This must include calculation of accumulated error and avoiding truncation and loss of significant bits. It is often straight forward to get correct results when using floating point. However, floating point functions requires significantly more code. In general, floating point and fixed point are both slow to execute. Floating point is FASTER than fixed point on multiplication and division, but slower on most other operations.

Operations not found in the libraries are handled by the built in code generator. Also, the compiler will use inline code for operations that are most efficient handled inline.

The following command line options are available:

- we: no warning when fixed point constants are rounded
- wO: warning on operator library calls
- wI: warning on long inline code for multiplication and division

Integer libraries

The math integer libraries allows selection between different optimizations, speed or size. The libraries contains operations for multiplication, division and division remainder.

```
math16.h : basic library, up to 16 bit
math24.h : basic library, up to 24 bit
math32.h : basic library, up to 32 bit
```

```
math16m.h: speed, size, 8*8, 16*16
math24m.h: speed, size, 8*8, 16*16, and 24*8 multiply
math32m.h: speed, size, 8*8, 16*16, and 32*8 multiply
```

The math??m.h libraries can be used when execution speed is critical.

NOTE 1: they must be included first (before math??h)

NOTE 2: math??h contains similar functions (which are deleted)

The min and max timing cycles are approximate only.

Sign: -: unsigned, S: signed

Sign	Res=arg1	op	arg2	Program	Approx. CYCLES
A:math32.h					
B:math24.h					
C:math16.h					
ABC	-	16	= 8 * 8	13	83 83 83
ABC	S/-	16	= 16 * 16	18	197 222 277
AB.	-	24	= 16 * 8	15	198 198 198
..C	-	16	= 16 * 8	16	179 179 179
.B.	-	24	= 24 * 8	16	247 247 247
A..	-	32	= 32 * 8	17	356 356 356
.B.	-	24	= 24 * 16	26	217 263 361
A..	-	32	= 32 * 16	31	239 310 447
.B.	-	24	= 24 * 24	25	337 410 553
A..	S/-	32	= 32 * 32	31	513 654 929
ABC	-	16	= 16 / 8	18	235 235 235
AB.	-	24	= 24 / 8	19	368 368 368
A..	-	32	= 32 / 8	20	517 517 517
ABC	-	16	= 16 / 16	25	287 291 335
.B.	-	24	= 24 / 16	31	481 512 633
A..	-	32	= 32 / 16	32	665 718 873

.B.	-	24 = 24 / 24	36	564	576	732
A..	-	32 = 32 / 32	47	943	966	1295
ABC	S	16 = 16 / 8	33	196	201	211
AB.	S	24 = 24 / 8	37	305	310	326
A..	S	32 = 32 / 8	41	430	436	457
ABC	S	16 = 16 / 16	49	296	309	361
.B.	S	24 = 24 / 16	53	450	473	543
A..	S	32 = 32 / 16	57	626	660	747
.B.	S	24 = 24 / 24	66	573	597	762
A..	S	32 = 32 / 32	83	952	990	1329
ABC	-	8 = 16 % 8	18	226	226	226
.B.	-	8 = 24 % 8	19	354	354	354
A..	-	8 = 32 % 8	20	502	502	502
ABC	-	16 = 16 % 16	23	280	283	312
.B.	-	16 = 24 % 16	29	463	497	599
A..	-	16 = 32 % 16	30	636	698	828
.B.	-	24 = 24 % 24	34	556	567	700
A..	-	32 = 32 % 32	45	934	955	1254
ABC	S	8 = 16 % 8	30	189	190	195
ABC	S	16 = 16 % 16	46	290	297	332
.B.	S	16 = 24 % 16	50	442	455	501
A..	S	16 = 32 % 16	54	614	634	692
.B.	S	24 = 24 % 24	66	567	584	725
A..	S	32 = 32 % 32	86	944	974	1284

A:math32m.h

B:math24m.h

			Code	min	aver	max
ABC	-	16 = 8 * 8	37	50	50	50
ABC	S/-	16 = 16 * 16	23+37	74	147	158
.B.	-	24 = 24 * 8	32+37	124	162	166
A..	-	32 = 32 * 8	43+37	178	212	222

Fixed point libraries

math16x.h : 16 bit fixed point, 8_8, signed and unsigned

math24x.h : 24 bit fixed point 8_16, 16_8, signed and unsigned

math32x.h : 32 bit fixed point 8_24, 16_16, 24_8, signed and unsigned

The libraries can be used separately or combined.

The timing stated is measured in instruction cycles (4*clock) and includes parameter transfer, call, return and assignment of the return value. The timing values are found by executing a large number of iterations using selected argument values.

Sign: -: unsigned, S: signed

Sign	Res=arg1	op	arg2	Program	Approx.	CYCLES	
math16x.h:							
S	8_8	=	8_8 * 8_8	47	226	263	339
-	8_8	=	8_8 * 8_8	23	214	252	326
S	8_8	=	8_8 / 8_8	51	497	518	584
-	8_8	=	8_8 / 8_8	35	528	558	680

math24x.h:		Code	min	aver	max
S	16_8 = 16_8 * 16_8	60	376	450	577
-	16_8 = 16_8 * 16_8	27	364	437	580
S	16_8 = 16_8 / 16_8	68	850	893	1093
-	16_8 = 16_8 / 16_8	46	894	944	1222
S	8_16 = 8_16 * 8_16	60	354	428	555
-	8_16 = 8_16 * 8_16	28	342	415	558
S	8_16 = 8_16 / 8_16	68	1050	1116	1349
-	8_16 = 8_16 / 8_16	46	1104	1188	1520
math32x.h:		Code	min	aver	max
S	24_8 = 24_8 * 24_8	77	558	722	983
-	24_8 = 24_8 * 24_8	35	546	709	1026
S	24_8 = 24_8 / 24_8	85	1298	1366	1761
-	24_8 = 24_8 / 24_8	57	1361	1432	1929
S	16_16= 16_16*16_16	78	561	704	930
-	16_16= 16_16*16_16	36	549	690	965
S	16_16= 16_16/16_16	85	1546	1650	2097
-	16_16= 16_16/16_16	57	1617	1733	2305
S	8_24 = 8_24 * 8_24	77	529	672	896
-	8_24 = 8_24 * 8_24	35	517	658	933
S	8_24 = 8_24 / 8_24	85	1794	1936	2433
-	8_24 = 8_24 / 8_24	57	1872	2033	2680

Floating point libraries

math16f.h : 16 bit floating point basic math

math24f.h : 24 bit floating point basic math
 math24lb.h : 24 bit floating point library

math32f.h : 32 bit floating point basic math
 math32lb.h : 32 bit floating point library

NOTE: The timing values includes parameter transfer, call and return and also assignment of the return value.

Basic 32 bit math:		*** Timing ****			
	Size	min	aver	max	
a * b:	multiplication	91	380	468	553
a / b:	division	125	523	610	742
a + b:	addition	182	39	135	225
a - b:	subtraction	add+5	46	142	232
int32 -> float32		79	44	77	114
float32 -> int32		89	35	90	142

Basic 24 bit math:		*** Timing ****			
	Size	min	aver	max	
a * b:	multiplication	77	226	261	294
a / b:	division	102	323	359	427
a + b:	addition	152	33	114	173
a - b:	subtraction	add+5			

```
int24 -> float24
float24 -> int24
```

```
Basic 16 bit math:          *** Timing ****
                             Size  min  aver  max
a * b: multiplication      62    104   107   114
a / b: division             82    137   154   171
a + b: addition             118     27    86   130
a - b: subtraction      add+5
int16 -> float16
float16 -> int16
```

The following operations are handled by inline code: assignment, comparing with constants, multiplication and division by a multiple of 2 (i.e. $a*0.5$, $b * 1024.0$, $c/4.0$)

Floating point library functions

```
float24 sqrt(float24); // square root
  Input range: positive number including zero
  Accuracy: ME:1-2, relative error: <  $3*10^{*-5}$  (*)
  Timing: min aver max 1366 1561 1758 (**)
  Size: 153 words + basic 24 bit math library
  Minimum complete program example: 396 words

float32 sqrt(float32); // square root
  Input range: positive number including zero
  Accuracy: ME:1-2, relative error: <  $1.2*10^{*-7}$  (*)
  Timing: min aver max 3447 3932 4450 (**)
  Size: 168 words + basic 32 bit math library
  Minimum complete program example: 588 words

float24 log(float24); // natural log function
  Input range: positive number above zero
  Accuracy: ME:1, relative error: <  $1.5*10^{*-5}$  (*)
  Timing: min aver max 2179 3075 3299 (**)
  Size: 214 words + basic 24 bit math library
  Minimum complete program example: 623 words

float32 log(float32); // natural log function
  Input range: positive number above zero
  Accuracy: ME:1, relative error: <  $6*10^{*-8}$  (*)
  Timing: min aver max 3493 4766 5145 (**)
  Size: 265 words + basic 32 bit math library
  Minimum complete program example: 762 words

float24 log10(float24); // log10 function
  Input range: positive number above zero
  Accuracy: ME:1-2, relative error: <  $3*10^{*-5}$  (*)
  Timing: min aver max 2435 3333 3569 (**)
  Size: 15 words + size of log()
  Minimum complete program example: 638 words

float32 log10(float32); // log10 function
  Input range: positive number above zero
  Accuracy: ME:1-2, relative error: <  $1.2*10^{*-7}$  (*)
  Timing: min aver max 3935 5229 5586 (**)
```

```

Size: 17 words + size of log()
Minimum complete program example: 779 words

float24 exp(float24); // exponential (e**x) function
Input range: -87.3365447506, +88.7228391117
Accuracy: ME:1, relative error: < 1.5*10**-5 (*)
Timing: min aver max 1969 3026 3264 (**)
Size: 251 words + 102(floor24) + basic 24 bit math
Minimum complete program example: 673 words

float32 exp(float32); // exponential (e**x) function
Input range: -87.3365447506, +88.7228391117
Accuracy: ME:1, relative error: < 6*10**-8 (*)
Timing: min aver max 4465 4741 5134 (**)
Size: 322 words + 145(floor32) + basic 32 bit math
Minimum complete program example: 847 words

float24 exp10(float24); // 10**x function
Input range: -37.9297794537, +38.531839445
Accuracy: ME:1, relative error: < 1.5*10**-5 (*)
Timing: min aver max 1987 3005 3194 (**)
Size: 256 words + 102(floor24) + basic 24 bit math
Minimum complete program example: 678 words

float32 exp10(float32); // 10**x function
Input range: -37.9297794537, +38.531839445
Accuracy: ME:1, relative error: < 6*10**-8 (*)
Timing: min aver max 3605 4716 5045 (**)
Size: 326 words + 145(floor32) + basic 32 bit math
Minimum complete program example: 851 words

float24 sin(float24); // sine, input in radians
float24 cos(float24); // cosine, input in radians
Input range: -512.0, +512.0
Accuracy: error: < 3*10**-5 (*)
The relative error can be larger when the output is
near 0 (for example near sin(2*PI)), but the
absolute error is lower than the stated value.
Timing: min aver max 396 2492 2746 (**)
Size: 215 words + basic 24 bit math library
Minimum complete program example: 595 words

float32 sin(float32); // sine, input in radians
float32 cos(float32); // cosine, input in radians
Input range: -512.0, +512.0 : Can be used over a
much wider range if lower accuracy is accepted
(degrades gradually to 1 significant decimal digit
at input value 10**6)
Accuracy: error: < 1.2*10**-7 (*)
The relative error can be larger when the output is
near 0 (for example near sin(2*PI)), but the
absolute error is lower than the stated value.
Timing: min aver max 543 5220 5855 (**)
Size: 357 words + basic 32 bit math library
Minimum complete program example: 818 words

```

(*) The accuracy of the math functions have been checked using many thousands of calculations. ME=1 means that the mantissa value can be wrong by +/- 1 (i.e. 1 bit). The relative error is then $1.5 \cdot 10^{-5}$ for 24 bit floating point, and $6 \cdot 10^{-8}$ for 32 bit floating point. Only a small fraction of the calculations may have the stated error.

(**) The min and max timing stated have been found by simulating many thousands calculations. The min and max limits are approximate only. All timing is measured in instruction cycles. When using a 4 MHz oscillator, one instruction cycle is 1 microsecond.

Fast and compact inline operations

The compiler will use inline code for efficiency at some important operations:

Integer:

- converting to left and right shifts: $a*8$, $a/2$
- selecting high/low bytes/words: $a/256$, $a\%256$, $b\%0x10000$
- replacing remainder by AND operation: $a\%64$, $a\%0x80$

Fixed Point:

- converting to left and right shifts: $a*8$, $a/2$
- all operations except multiplication and division are implemented inline

Floating point:

- add/sub (incr/decr) of exponent: $a*128.0$, $a/2$
- operations == and != : $a==b$, $a!=0.0$
- comparing with constants: $a>0$, $a<=10.0$
- inverting the sign bit: $a=-a$, $b=-a$

Using prototypes and multiple code pages

Using floating point on the 12 bit core where each codepage is 512 words will be challenging. It is normally not required to define prototypes, even when using many code pages. If you want to place the library functions to a certain codepage, this is easiest done by:

```
#pragma codepage 1
#include "math24f.h"
#pragma codepage 0
```

Prototypes can be used when functions are called before they are defined. Note that operator functions need a function name to be defined as prototypes.

Also note that the compiler use a linear search from the beginning of the operator table until a match for the current operation is found. The operator definition/prototype sequence may therefore influence the operator selected.

It is not recommended to modify the libraries by adding 'pragma codepage' between the functions. Instead, prototypes and 'pragma location' or the page type modifier makes function placement easier to set up and tune. For example, placing the division function on codepage 1 and the other on the default codepage can be done by:

```
..
#include "my_math.h"
..
#include "math24f.h"
..
```

```
//----- beginning-of-file my_math.h -----
float24 operator* _fmul24(sharedM float24 arg1, sharedM float24
arg2);
page1 float24 operator/_fdiv24(sharedM float24 arg1,sharedM float24
arg2);
float24 operator+ _fadd24(sharedM float24 arg1, sharedM float24
arg2);
// .. etc.
//----- end-of-file my_math.h -----
```

Fixed point example

```
#include "16C73.h"
#include "math24x.h"
uns16 data;
fixed16_8 tx, av, mg, a, vx, prev, kp;

void main(void)
{
    vx = 3.127;
    tx += data;           // automatic type cast
    data = kp;           // assign integer part
    if ( tx < 0 )
        tx = -tx;       // make positive
    av = tx/20.0;
    mg = av * 1.25;
    a = mg * 0.98;       // 0.980469, error: 0.000478
    prev = vx;
    vx = a/5.0 + prev;
    kp = vx * 0.036;     // 0.03515626, error: 0.024
    kp = vx / (1.0/0.036); // 27.7773437
}
```

CODE: 274 instructions including library (130)

Floating point example

CODE: 635 instructions including library (470). The code is identical to the above fixed point example to enable code size comparison.

```
#include "16C73.h"
#include "math24f.h"
uns16 data;
float tx, av, mg, a, vx, prev, kp;

void main(void)
{
    InitFpFlags();      // enable rounding as default
    vx = 3.127;
    tx += data;         // automatic type cast
    data = kp;         // assign integer part
    if ( tx < 0 )
        tx = -tx;     // make positive
    av = tx/20.0;
    mg = av * 1.25;
    a = mg * 0.98;
    prev = vx;
```

```

    vx = a/5.0 + prev;
    kp = vx * 0.036;
    kp = vx / (1.0/0.036);
}

```

How to save code

Choices that influence code size:

1. What libraries to include (24/32 bit float or fixed point)
2. Rounding can be disabled permanently. Note that this will reduce the accuracy of the math functions slightly.

```

#define DISABLE_ROUNDING
#include "math32f.h"

```

3. Optimization, currently available on division only. Note that speed is default. Also note that the saving is only 5 - 7 instructions. Timing difference is up to 15-20 percent.

```

#define FP_OPTIM_SIZE // optimize for SIZE
#define FP_OPTIM_SPEED // optimize for SPEED: default

```

The recommended strategy is to select a main library for the demanding math operations. Different floating and fixed point operations should only be mixed if there is a good reason for it.

Mixing different data types is possible to save code and RAM space. For example using a small type in an array and a larger type for the math operations.

So, first decide what math library to include. For floating point the main decision is between the 24 bit or the 32 bit library. If you use 32 bit operations, this can be combined with 24 (and 16) bit floating point types to save RAM.

Automatic type conversion:

```

integer <-> float/double
integer <-> fixed point
float <-> double
fixed point <-> float/double : requires additional functions

```

In general, using the smallest possible data type will save code and RAM space. This must be balanced against the extra work to analyze the program to prevent overflow and too large accumulated errors. If there is plenty of code space in the controller, and timing is no problem, then large types can be used. Otherwise analysis is required to get optimal selections.

It is recommended to keep the number of called library functions as low as possible. Although function selection is done automatically by the compiler, it is possible to use type casts or even make a custom library by copying the required functions from existing libraries. All libraries are written in C. CC5X can print a warning for each operator function that is called (option -wO).

6.6 Inline Assembly

The CC5X compiler supports inline assembly located inside a C function. There are some restrictions compared to general assembly. First, it is only possible to CALL other functions. Second, GOTO is restricted to labels inside the function. If these restrictions makes program design too difficult, consider using the linker support and link C and assembly modules using MPLINK.

```

#asm
.. assembly instructions
#endasm

```

Features:

- many assembly formats
- equ statements can be converted to variable definitions
- macro and conditional assembly capabilities
- call C functions and access C variables
- C style comments is possible
- optional optimization
- optional automatic bank and page updating

Note that the file *inline.h* is for emulating inline assembly, and should NOT be included when using real inline assembly. The compiler does not optimize inline assembly or update the bank or page bits unless it is instructed to do so.

Inline assembly is NOT C statements, but are executed in between the C statements. It is not recommended to write the code like this:

```
if (a==b)
    #asm
        nop // this is not a C statement (by definition)
    #endasm
a = 0; // THIS is the conditional statement!!!
```

Inline assembly supports DW. This can be used to insert data or special instructions. CC5X will assume that the data inserted are instructions, but will not interpret or know the action performed. Bank selection bits are assumed to be undefined when finishing executing DW instructions. PCLATH bit 3 (and 4) must remain unchanged or restored to correct value if more than one code page is available on the device. Example use is found in startup.txt.

```
#asm
    DW 0x3FFF    ; any data or instruction
    DW /*CALL*/ 0x2000 + ADDRESS
#endasm
```

Assembly instructions are not case sensitive. However, variables and symbols requires the right lower or upper case on each letter.

```
clrw
Nop
NOP
```

Constant formats:

```
MOVLW 10                ; decimal radix is default
MOVLW 0xFF              ; hexadecimal
MOVLW 0b010001         ; binary      (C style)
MOVLW 'A'              ; a character (C style)
MOVLW .31              ; decimal constant
MOVLW .31 + 20 - 1     ; plus and minus are allowed
MOVLW H'FF'           ; hexadecimal (radix 16)
MOVLW h'0FF'          ; hexadecimal (radix 16)
MOVLW B'011001'       ; binary (radix 2)
MOVLW b'1110.1101'    ; binary (radix 2)
MOVLW D'200'          ; decimal (radix 10)
MOVLW d'222'          ; decimal (radix 10)
MOVLW MAXNUM24EXP     ; defined by EQU or #define
;MOVLW 22h            ; NOT allowed
```


Formats when loading then result into the W register:

```

decf ax,0
iorwf ax,w
iorwf ax,W

```

Formats when writing the result back to the RAM register:

```

decf ax
decf ax,1
iorwf ax,f
iorwf ax,F

```

Bit variables are accessed by the following formats:

```

bcf Carry
bsf Zero_
bcf ax,B2      ; B2 defined by EQU or #define
bcf ax,1
bcf STATUS,Carry ; Carry is a bit variable

```

Arrays, structures and variables larger than 1 byte can be accessed by using an offset.

```

clrf a32      ; uns32 a32; // 4 bytes
clrf a32+0
clrf a32+3
clrf tab+9    ; char tab[10];
; clrf tab-1 ; not allowed

```

Labels can start anywhere on the line:

```

goto LABEL4
LABEL1
:LABEL2
LABEL3:
LABEL4 nop
nop
goto LABEL2

```

Functions are called directly. All single 8 bit parameter are transferred using the W register.

```

movlw 10
call f1      ; equivalent to f1( 10);

```

The ONLY way to transfer multiple parameters (and parameters different from 8 bit) is to end assembly mode, use C syntax and restart assembly mode again.

```

#endasm
func( a, 10, e);
#asm

```

Some instructions are disabled, depending on core type:

```

option      ; 12 bits core only
tris PORTA  ; 12 bits core only
movwf OPTION ; 14 bits core only
movwf TRISA ; 14 bits core only

```

The EQU statement can be used for defining constants. Assembly blocks containing EQU's only can be put outside the functions. Note that Equ constants can only be accessed in assembly mode. Constants defined by #define can be used both in C and assembly mode.

```
#asm
B0          equ    0
B7          equ    7
MAXNUM24EXP equ    0xFF
#endasm
```

Equ can also be used to define variable addresses. However, the compiler do not know the know the difference between an Equ address and an Equ constant until it is used by an instruction. When an Equ symbol is used as a variable, that location is disabled for use by other variables. The symbol then changes from an Equ symbol to a variable symbol and is made available in C mode also. There is a slight danger in this logic. DO NOT USE a series of Equ's to define an array. If one of the locations are not read or written directly, the compiler will not know that it is a part of an array and may use it for other purposes. Reading and writing through FSR and INDF is not used to transform equ definitions. Therefore, define arrays by using C syntax (or #pragma char).

```
// enable equ to variable transformation
#pragma asm2var 1
..
A1          equ    0x20
..
CLRF A1
;A1 is changed from an equ constant to a char variable
```

Comments types allowed in assembly mode:

```
NOP      ; a comment
NOP      // C style comments are also valid
/*
CLRW     ;
NOP      /* nested C style comments are also valid */
*/
```

Conditional assembly is allowed. However, the C style syntax have to be used.

```
#ifdef SYMBOLA
nop
#else
clrw
#endif
```

C style macros can contain assembly instructions, and also conditional statements. Note that the compiler does not check the contents of a macro when it is defined.

```
#define UUA(a,b)\
clrw\
movlw a \
#if a == 10 \
nop      \
#endif   \
clrf b

UUA(10,ax)
UUA(9,PORTA)
```

Most preprocessor statements can be used in assembly mode:

```
#pragma return[] = "Hello"
```

The compiler can optimize and perform bank and page updating in assembly mode. This does not happen automatically, but has to be switched on in the source code. It is normally safe to switch on optimization and bank/page updating. Instructions updating the bank and page register are removed before the compiler insert new instructions. If the assembly contains critical timing, then the settings should be left off, at least in local regions.

```
// default local assembly settings are b- o- p-
#pragma asm default b+ o+ // change default settings

#asm // using default local settings
#endasm

#asm b- o- p+ // define local settings
#pragma asm o+ // change setting in assembly mode
#endasm // end current local settings
```

Interpretation:

o+ : current optimization is performed in assembly mode
 o- : no optimization in assembly mode
 b+ : current bank bit updating is performed in assembly mode
 b- : no bank bit update in assembly mode
 p+ : current page bit updating is performed in assembly mode
 p- : no page bit update in assembly mode

Note that *b+ o+ p+* means that updating is performed if the current setting in C mode is on. Updating is NOT performed if it is switched off in the C code when assembly mode starts. The command line options *-b, -u, -j* will switch updating off globally. The corresponding source code settings are then ignored.

Generating Single Instructions

The file *INLINE.H* describes how to emulate inline assembly using C code. This allows single instructions to be generated. Intended usage is mainly for code with critical timing.

The compiler will normally generate single instructions if the C statements are simple. Remember to inspect the generated assembly file if the application algorithm depends upon a precisely defined instruction sequence. The following example show how to generate single instructions from C code.

```
nop(); // NOP
f = W; // MOVWF f
W = 0; // CLRW
f = 0; // CLRF f
W = f - W; // SUBWF f,W
f = f - W; // SUBWF f
W = f - 1; // DECF f,W
f = f - 1; // DECF f
W = f | W; // IORWF f,W
f = f | W; // IORWF f
W = f & W; // ANDWF f,W
f = f & W; // ANDWF f
W = f ^ W; // XORWF f,W
f = f ^ W; // XORWF f
W = f + W; // ADDWF f,W
f = f + W; // ADDWF f
W = f; // MOVF f,W
W = f ^ 255; // COMF f,W
```

```

f = f ^ 255;    // COMF f
W = f + 1;     // INCF f,W
f = f + 1;     // INCF f
W = decsz(i);  // DECFSZ f,W
f = decsz(i);  // DECFSZ f
W = rr(f);     // RRF f,W
f = rr(f);     // RRF f
W = rl(f);     // RLF f,W
f = rl(f);     // RLF f
W = swap(f);   // SWAPF f,W
f = swap(f);   // SWAPF f
W = incsz(i);  // INCFSZ f,W
f = incsz(i);  // INCFSZ f
b = 0;         // BCF f,b
b = 1;         // BSF f,b
btsc(b);       // BTFSC f,b
btss(b);       // BTFSS f,b
OPTION = W;    // OPTION (MOVWF on core 14)
sleep();       // SLEEP
clrwdt();      // CLRWDT
TRISA = W;     // TRIS f (MOVWF on core 14)
return 5;      // RETLW 5
s1();          // CALL s1
goto X;        // GOTO X
nop2();        // GOTO next address (delay 2 cycles)
W = 45;        // MOVLW 45
W = W | 23;    // IORLW 23
W = W & 53;    // ANDLW 53
W = W ^ 12;    // XORLW 12

```

Addition for the 14 bit core:

```

W = 33 + W;    // ADDLW 33
W = 33 - W;    // SUBLW 33
return;        // RETURN
retint();      // RETFIE

```

6.7 Optimizing the Code

The CC5X compiler contains an advanced code generator which is designed to generate compact code. For example when comparing a 32 bit unsigned variable with a 32 bit constant, this normally requires 16 (or 15) instructions. When comparing a 32 bit variable with 0, this count is reduced to 6 (or 5). The code generator detects and take advantage of similar situations to enable compact code.

Most of the code is generated inline, even multiplication and division. However, if many similar and demanding math operations have to be performed, then it is recommended to include a math library.

Optimized Syntax

Bit toggle now use the W register to get compact code:

```

bit b;
b = !b;    // MOVLW K, XORWF var

```

Testing multiple bits of 16 bit variables or greater:

```

uns16 x;
if (x & 0xF0)

```

```

if (!(x & 0x3C))
if ((x & 0xF00) == 0x300)
if ((x & 0x7F00) < 0x4000)

```

Testing single bits using the '&' operator:

```

if (a & 0x10)           // BTFSC/BTFSS a,4
if (!(a & 0x80))       // BTFSS/BTFSC a,7
if ((a16 & 0x200) == 0) // BTFSS/BTFSC a16+1,1

```

Peephole optimization

Peephole optimizing is done in a separate compiler pass which removes superfluous instructions or rewrite the code by using other instructions. This optimization can be switched off by the `-u` command line option. The optimization steps are:

- 1) redirect goto to goto
- 2) remove superfluous gotos
- 3) replace goto by skip instructions
- 4) replace INCF and DECF by INCFSZ and DECFSZ
- 5) remove instructions that affects the zero- flag only.
- 6) remove superfluous updating of PA0 and PA1
- 7) remove other superfluous instructions
- 8) remove superfluous loading of the W register

NOTE: Optimization can also be switched on or off in a local region. Please refer to the `#pragma optimize` statement for more details.

```

; while (1) {
;     if (Carry == 0) {
m001   BTFSC status,Carry
        GOTO m004 ; REDIRECTED TO m001 (1)
        ; i++;
        INCF i ; REPLACED BY INCFSZ (4)
        ; if (i != 0)
        MOVF i ; REMOVED (5)
        BTFSS status,Zero_ ; REMOVED (4)
        GOTO m002 ; REMOVED (3)
        ; var++;
        INCF var ;
        ; test += 2;
m002   MOVLW .2
        ADDWF test
        ; if (test == 0)
        MOVF test ; REMOVED (5)
        BTFSS status,Zero_ ; REPLACED BY BTFSC (3)
        GOTO m003 ; REMOVED (3)
        ; break;
        GOTO m005
        ; W = var;
m003   MOVF var,W
        ; if (W == 0)
        XORLW .0 ; REMOVED (5)
        BTFSS status,Zero_
        GOTO m004 ; REDIRECTED TO m001 (1)
        ; break;
        GOTO m005 ; REMOVED (7)

```

```

m004    GOTO m001      ; REMOVED (2)
                ;      sub1();
m005    BSF status,PA0
        CALL sub1
        BCF status,PA0 ; REMOVED (6)
                ;      sub2();
        BSF status,PA0 ; REMOVED (6)
        BSF status,PA1
        CALL sub2
        BCF status,PA0
        BCF status,PA1

```

6.8 Linker Support

CC5X supports the relocatable assembly format defined by Microchip. This means that MPLINK can be used to link code modules generated by CC5X, also including assembly modules. There are many details to be aware of. It is therefore recommended to read this file carefully. The important issues are related to:

- external functions and variables
- ram bank updating
- page bit updating
- call level checking
- MPLINK script files
- MPLAB integration

The command line option '-r' makes CC5X generate relocatable assembly. This file is then assembled by MPASM and linked together with other C and assembly modules by MPLINK. This can be automated by using 'make' to build the whole application in several stages.

NOTE that if you need the application program to be as compact as possible, then it is recommended to use only ONE C module. Source code modularity is obtained by using many C files and include these in the main C module by using #include.

Command line options:

```

-r : generate relocatable assembly (no hex file)
-r2[<file.lkr>]: use separate section for interrupt

```

External assembler options:

```

-x<file> : assembler: -xC:\progra~1\mplab\mpasm.exe
-X<option>: assembler option: -X/q (all options must be separate)

```

Assembly file options (normally not used):

```

-rp<N> : name on codepage 0 is PROG<N>, default PROG1
-rb<N> : name on RAM bank 0 is BANK<N>, default BANK0
-ro<N> : add offset <N> on local variable block name

```

Variables

Variables defined in other module can be accessed. CC5X needs to know the type, and this is done by adding 'extern' in front of a variable definition.

```
extern char a;
```

All global variables that are not 'static' are made available for other modules automatically. CC5X inserts 'GLOBAL' statements in the generated assembly file.

CC5X will generate a 'MOVLW LOW (var_name+<offset>)' when using the address operators '&var_name'.

Global bit variables is a challenge. It is recommended to first define a char variable and then use 'bit bx @ ch.0;'. Otherwise CC5X will defines a global char variable with random name. This name have the format '_Gbit<X><X>' where <X> is a (more or less) random selected letter. This variable is reserved by a RES statement and used in the assembly file when generating relocatable assembly.

```
bit b1;
b1 = 0;    // BCF _GbitQB+0,0
```

The variable file (*.var) is slightly modified when generating relocatable assembly. Note that most addresses stated in the variable file are reallocated by MPLINK.

Local variables

CC5X uses a different naming strategy on local variables when generating relocatable assembly. CC5X reserves a continuous block in each ram bank (or shared bank) and use this name when accessing local variables.

IMPORTANT RESTRICTION: The main() routine, interrupt service routines and all extern functions are defined as independent call trees or paths. A function called from two independent call paths can not contain local variables or parameters because address sharing can not be computed in advance. CC5X detects this and generates an error message.

The name of the local RAM blocks are _LcRA, _LcRB, etc. The last letter is related to the RAM bank and the second last to the module name. Adding option -ro1 will for example change name _LcAA to _LcBA. This can be used if there is a collision between local variable block defined in separate C modules. MPLINK detects such collisions.

```
-ro<N> : add offset <N> on local variable block name
```

Local variables for external available functions are allocated separately. One block for each extern function. This often means inefficiently use of RAM. It is therefore recommended to use 'extern' only on those functions that have to be extern, and use few local variables in the extern functions. Also consider using global variables.

Header files

It is recommended to make common header files that contains global definitions that are included in all C modules. Such files can contain definitions (#define), IO variable names, etc.

Using RAM banks

RAM bank definitions only applies to devices with RAM located in more than one bank.

Note that the RAM bank of ALL variables have to be known (defined) during compilation. Otherwise the bank bit updating will not be correct. The bank is defined by using '#pragma rambank' between the variable definition statements, also for 'extern' variables. An alternative is to use the bank type modifier (bank0..bank3, shrBank).

```
#pragma rambank 0
char a,b;
#pragma rambank 1
extern char array1[10];
#pragma rambank -
extern char ex;    // shared/common RAM
```

Bank bit updating

CC5X use an advanced algorithm to update the bank selection bits. However, it is not possible to trace calls to external functions. Therefore, calling an external function or allowing incoming calls makes CC5X assume that the bank bits are undefined. This often means that more code compared to the optimal bank bit update strategy.

It is therefore recommended to only use 'extern' on those functions that have to be extern, and keep the number of calls between modules to a minimum.

Functions

Functions residing in other modules can be called. Functions defined can be called from other modules (also from assembly modules).

NOTE that ALL functions that are called from another module needs an 'extern' first. This is an extra requirement that is optional in C. The reason is that the compiler needs to decide the strategy on bank bit updating and local variables allocation. It is most efficient to use FEW extern functions.

```
extern void func1(void); // defined in another module

extern void fc2(void) { } // available to all modules
```

NOTE that extern functions can only have a single 8 bit parameter which is transferred in W. This is because local storage information is not shared between modules. The return value can not be larger than 8 bit for the same reason (bit values are returned in Carry).

CC5X inserts a 'GLOBAL <function>' in the generated assembly code for all external available functions. 'EXTERN <function>' is inserted for functions defined in other modules.

If the C module contains main(), then a 'goto main' is inserted in the STARTUP section.

Using code pages

Page bit updating only applies to functions with more than one code page.

The code page of all function calls have to be known (defined) during compilation. Otherwise the page bit updating will not be correct. The page is defined by using '#pragma location' or the page type modifier for functions defined in another module. For functions defined in the current module, '#pragma codepage' can also be used.

It is recommended to define the function heading (prototypes) for all extern functions in a header file including page information. This file should be included in all C modules.

Interrupts

CC5X requires that the interrupt function is located at address 4. Writing the interrupt service routine in C using MPLINK will require some care. The main issue is to set up the linker script file as described later in this file. Two options are possible:

ALTERNATIVE 1: Use the linking sequence to locate the interrupt service routine. This is done by listing the module with the interrupt service routine FIRST in the module list used by MPLINK. This is the important point which makes MPLINK put the interrupt service routine in the beginning of the PROG/PROG1 logical code section (address 4). When using MPLAB, the C module containing the interrupt function must be listed first in the project file list. The list file generated by MPLINK should be inspected to ensure that the interrupt routine starts at address 4. Another important point is to remove the

#pragma origin 4 when using MPLINK. This is the only difference in the C source compared to using the built in CC5X linker (single C module).

ALTERNATIVE 2: Set up a SEPARATE logical section in the linker script file for the interrupt service routine. This is a more robust solution. CC5X will generate a partial script file to avoid manual address calculation. The partial script file must be included in the main script file. The setup is described in Section *The MPLINK script file*.

It is also possible to design an assembly module containing the interrupt service routine. Information on how to do this should be found in the MPASM/MPLINK documentation.

Call level checking

CC5X will normally check that the call level is not exceeded. This is only partially possible when using MPLINK. CC5X can ONLY check the current module, NOT the whole linked application.

When calling an external function from the C code, CC5X will assume that the external call is one level deep. This checking is sometimes enough, especially if all C code is put in one module, and the assembly code modules are called from well known stack levels. Calling C function from assembly will require manual analysis.

Therefore, careful verification of the call structure is required to avoid program crash when overwriting a return value on the hardware stack (which is 2 or 8 levels deep). The compiler generated *.fcs files can provide information for this checking.

Calls to external functions is written in the *.fcs file. External function calls are marked [EXTERN].

Computed goto

14 bit core: CC5X will always use the long format when generating code for skip(). It is not possible to use the -GS option. The long format is 3 instructions longer than the short format.

12 bits core: All destination addresses must be located in the first 256 word half of the codepage. Unfortunately CC5X can not check the layout done by MPLINK. It is therefore strongly recommended to apply some manual design rules that will prevent destination addresses to be moved into the invisible (high) code page half. This can be done by ensuring a linking sequence that will put all modules containing computed goto at the beginning (offset 0) of the codepage. Inspection of the generated list file is recommended.

Recommendations when using MPLINK

1. Use as few C modules as possible because of:
 - a) inefficient bank bit updating between modules
 - b) local variable space can not be reused between modules
 - c) only single 8 bit parameter in calls between modules
 - d) only 8 or 1 bit return values between modules
2. Use definition header files that are shared between modules. Include the shared definition in all C modules to enable consistency checking.
 - a) function headings (prototypes). Add page information when using more than one code page:


```
// module1.c
extern page0 void sub(char ax);
// module2.c
extern page1 void mpy(void);
```

```
// Do not add extern to functions that are not called
// from other modules.
char localFunctionA(void); // local function
// Note that it is required to use extern in the
// function definition when an extern prototype
// is not defined.
```

b) variables: add bank information

```
// module1.c
extern shrBank char b;
#define ARRAY_SIZE 10
extern bank0 char array[ARRAY_SIZE];
// module3.asm
extern bank1 char mulcnd, mulplr, H_byte, L_byte;
```

c) constants, definitions, enumerations and type information

```
#define MyGlobalDef 1
enum { S1 = 10, S2, S3, S4 S5 };
// names assigned to port pins
#pragma bit in @ PORTB.0
#pragma bit out @ PORTB.1
```

3. define bit variables to overlap with a char variable

```
/* extern */ char myBits;
bit b1 @ myBits.0;
bit b2 @ myBits.1;
// use 'extern char myBits;' for global bits and
// put the definitions in a shared header file.
// Move definition 'char myBits;' to one of the
// modules.
```

4. Make a linker script file according to the description stated later. Follow the guidelines when using interrupts.

5. Set up a 'makefile' to enable automatic (re)compilation and linking. Follow the guidelines when using MPLAB. Edit and use the option '+reloc.inc' when compiling C modules.

6. Do the final call level checking manually

7. Update conventions in assembly functions called from C modules:

- a) The bank selection bits should be updated in the beginning of assembly functions that are called from C.
- b) The page selection bits must be correct (set to the current module page) when returning.

MPLAB and MPASM support

Please refer to 'linker.txt' for details on how to set up a project with several modules in MPLAB.

The linker script file must be made (or adapted) according to the description stated.

Note that MPASM will generate its own warnings and messages. These should normally be ignored. MPASM do not know about the automatic bank bit updating and will display messages about this. MPASM have generated the message if the asm file extension is used in the message.

Program execution tracing will always use the assembly file as source when using the -r option and MPASM/ MPLINK. MPASM can generate object code from assembly modules. There are some restrictions and additions when using relocatable modules compared to using a single assembly module.

CC5X does not support the object code directly, but generates relocatable assembly that MPASM use to generate the object file. MPASM is started from within the CC5X so that no extra command is required (only the right command line options).

Case Sensitivity option in MPASM is by default On, and should remain On because C use case dependent identifiers.

Options to start MPASM and generate relocatable object code:

```
-xC:\progra~1\mplab\mpasm.exe -X/o -X/q
```

Options when assembling and linking a single file:

```
-xC:\progra~1\mplab\mpasm.exe -X/q
```

If the CC5X error file option (-F) is missing, CC5X will read the error file generated by MPASM and write the error and warnings found there to the screen and the output file (*.occ). The error file is then deleted.

If the CC5X error file option (-F) is present, CC5X will write error and warnings to the error file (*.err) and append the error and warnings generated by MPASM at the end of this file.

Note that MPLAB will automatically show the contents of the error file if it is non-empty. Otherwise the screen output is displayed in 'Build Results' window.

The MPLINK script file

MICROCHIP supplies sample linker script files for each device with the file extension '.lkr' (look in the MPLAB directory). When making a linker script file for a specific project, this file can be copied and edited to suit the needs of CC5X. The changes are general and valid for several projects.

The sample MPLINK script files must be changed slightly if the interrupt function is written in C. The reason is that the interrupt function must start at address 4 when using CC5X. It could be possible to use a vector at address 4, but this slows down interrupt response. Anyway, using a goto vector directly is not possible when the device contains more than 2048 words of code. This is because PCLATH needs to be saved before it can be updated.

CHANGE 1: Interrupt routine in C WITH a separate logical section. CC5X generates a partial script file when using the -r2 (or -r2[<file.lkr>]) command line option. This file is written if (and only if) CC5X compiles a module with an interrupt service routine. It may look like:

```
CODEPAGE NAME=intserv START=0x4 END=0x1C
CODEPAGE NAME=page0 START=0x1D END=0x7FF
```

Example change in the main script file:

```
//CODEPAGE NAME=page0 START=0x4 END=0x7FF
INCLUDE module1.lkr // or other script file name
SECTION NAME=ISERVER ROM=intserv // Interrupt
```

CHANGE 2: Interrupt routine in C WITHOUT a separate logical section. Example change:

```
// OLD VALUE 0x4
CODEPAGE NAME=vectors START=0x0 END=0x3 PROTECTED

// OLD VALUE 0x5
CODEPAGE NAME=page0 START=0x4 END=0x7FF
```

CHANGE 3: If INTERRUPTS are not used, then the first code page can start at address 1. Example change:

```
// OLD VALUE                                0x4
CODEPAGE NAME=vectors START=0x0 END=0x0 PROTECTED

// OLD VALUE                                0x5
CODEPAGE NAME=page0 START=0x1 END=0x7FF
```

CHANGE 4: The 12 bit core devices need a logic section for the startup vector. Example change for the 16C57:

```
// OLD VALUE                                0x7FF
CODEPAGE NAME=page3 START=0x600 END=0x7FE

CODEPAGE NAME=vectors START=0x7FF END=0x7FF // NEW
SECTION NAME=STARTUP ROM=vectors // NEW
```

CHANGE 5: Certain devices requires a special interrupt save sequence that needs to use certain RAM locations (0x20 and 0xA0). These addresses must be made unavailable for allocation in the linker script file. This applies to 14000, 16C63, 16C63A, 16C65, 16C65A, 16C65B, 16C73, 16C73A, 16C73B, 16C74, 16C74A, 16C74B, 16F873, 16F874 and similar devices. CC5X generates a warning when variables are assigned to fixed addresses. Example change:

```
// OLD VALUE                                0x20
DATABANK NAME=gpr0 START=0x21 END=0x7F

// OLD VALUE                                0xA0
DATABANK NAME=gpr1 START=0xA1 END=0xFF
```

CHANGE 6: LOGICAL RAM sections must be added, one for each DATABANK that contain RAM locations (not special function registers). Note that if a logical RAM section is missing, then the variables that belongs to this section will be put in the "default" section. MPLINK gives no error on missing logical sections in the script file and the program will fail.

```
SECTION NAME=BANK0 RAM=gpr0 // RAM bank 0
SECTION NAME=BANK1 RAM=gpr1 // RAM bank 1
SECTION NAME=BANK2 RAM=gpr2 // RAM bank 2
SECTION NAME=BANK3 RAM=gpr3 // RAM bank 3
SECTION NAME=SHRAM RAM=gprnobnk // shared RAM
SECTION NAME=GPRAM RAM=gprs // no RAM banks
```

Logical code blocks:

```
STARTUP startvector
ISERVER optional section for interrupt routine
PROG for devices with one codepage only
PROG1 first codepage
PROG2
PROG3
PROG4
CONFIG config word
IDLOCS id-locations
```

Logical RAM blocks:

```
GPRAM devices without RAM banks
BANK0 bank 0
```

```

BANK1    bank 1
BANK2    bank 2
BANK3    bank 3
SHRAM    shared/common RAM (if available on device)

```

Command line options:

Page naming:

```

-rp0     : PROG0 is the name of the first codepage
-rp1     : PROG1 is the name of the first codepage

```

Bank naming:

```

-rb0     : BANK0 is the name of the first RAM bank
-rb1     : BANK1 is the name of the first RAM bank

```

Separate interrupt logical section (named ISERVER):

```

-r2      : use name of current module (.lkr)
-r2<file.lkr> : use defined file name

```

Example with 3 modules

This example demonstrates the syntax only.

```

//*****
// MODULE1.C
#pragma chip PIC16C63
#include "globdef1.h"
#include "int16CXX.H"

#pragma origin 4

interrupt int_server(void)
{
    int_save_registers    // W, STATUS (and PCLATH)
    if (RTIF) {
        /* TMR0 overflow interrupt */
        TMR0 = -45;
        RTIF = 0; /* reset flag */
    }
    if (INTF) {
        /* INT interrupt */
        INTF = 0; /* reset flag */
    }
    if (RBIF) {
        /* RB port change interrupt */
        W = PORTB; /* clear mismatch */
        RBIF = 0; /* reset flag */
    }
    int_restore_registers // W, STATUS (and PCLATH)
}

char a;
bit b1, b2;

void main(void)
{
    PORTA = 0b0010;

```

```

    TRISA = 0b0001;

    if (TO == 1 && PD == 1 /* power up */) {
        clearRAM(); // set all RAM to 0
        a = 5;
        b1 = 1;
    }
    mulcnd = 10;
    mulplr = 20;
    mpy(); // assembly routine (demo)

    b2 = !b1;
    do {
        if (in == 1)
            break;
        sub(a&3);
    } while (a < 200);
}

//*****
// MODULE2.C
#pragma chip PIC16C63
#include "globdef1.h"

void sub(bank1 char ax)
{
    bank1 char i;      /* a local variable */

    /* generate pulses */
    for (i = 0; i <= ax+1; i++) {
        out = 1;
        nop2();
        out = 0;
        a++; // increment global variable
    }
}

;*****
; GLOBDEF1.H
// names assigned to port pins
#pragma bit in @ PORTA.0
#pragma bit out @ PORTA.1

// module1.c
extern bank0 char a;

// module3.asm
extern bank1 char mulcnd, mulplr, H_byte, L_byte;

// module2.c
extern page0 void sub(char ax);

// module3.asm
extern page0 void mpy(void);

```

```

; *****
; MODULE3.ASM
    #INCLUDE "P16C63.INC"
BANK1  UDATA
mulcnd RES 1 ; 8 bit multiplicand
mulplr RES 1 ; 8 bit multiplier
H_byte RES 1 ; High byte of the 16 bit result
L_byte RES 1 ; Low byte of the 16 bit result
count  RES 1 ; loop counter

    GLOBAL mulcnd, mulplr, H_byte, L_byte

PROG1  CODE    ; page0
mpy
    GLOBAL mpy
    bsf STATUS, RP0 ; access bank 1
    clrf H_byte
    movlw 8
    movwf count
    movf mulcnd, W
loop   rrf mulplr, F
      btfsc STATUS, C
      addwf H_byte, F
      rrf H_byte, F
      rrf L_byte, F
      decfsz count, F
      goto loop
      retlw 0

    END

//*****
// File: 16c63.lkr
LIBPATH .

CODEPAGE  NAME=vectors  START=0x0      END=0x3      PROTECTED
//CODEPAGE  NAME=page0   START=0x4      END=0x7FF
INCLUDE  module1.lkr
CODEPAGE  NAME=page1    START=0x800    END=0xFFFF
CODEPAGE  NAME=.idlocs  START=0x2000  END=0x2003  PROTECTED
CODEPAGE  NAME=.config  START=0x2007  END=0x2007  PROTECTED

DATABANK  NAME=sfr0     START=0x0     END=0x1F     PROTECTED
DATABANK  NAME=sfr1     START=0x80    END=0x9F     PROTECTED

DATABANK  NAME=gpr0     START=0x21    END=0x7F
DATABANK  NAME=gpr1     START=0xA1    END=0xFF

SECTION   NAME=STARTUP  ROM=vectors  // Reset vector
SECTION   NAME=ISERVER  ROM=intserv  // Interrupt
SECTION   NAME=PROG1    ROM=page0    // ROM code page0
SECTION   NAME=PROG2    ROM=page1    // ROM code page1
SECTION   NAME=IDLOCS   ROM=.idlocs  // ID locations
SECTION   NAME=CONFIG   ROM=.config  // Configuration

SECTION   NAME=BANK0    RAM=gpr0     // RAM bank 0
SECTION   NAME=BANK1    RAM=gpr1     // RAM bank 1

```

```
//*****
// File: module1.lkr : generated by CC5X when using
// the -r2 option

CODEPAGE NAME=intserv START=0x4 END=0x1C
CODEPAGE NAME=page0 START=0x1D END=0x7FF
```

6.9 The *cdata* Statement

The *cdata* statement stores 14 bit data in program memory.

NOTE 1: *cdata*[] can currently **not** be used with relocatable assembly. When using MPLINK, such data statements can be put in an assembly module.

NOTE 2: Constant data should normally be stored using the 'const' type modifier. However, *cdata*[] is useful for storing EEPROM data, or data and instructions at fixed addresses.

NOTE 3: There is no check on validity of the inserted data or address. However, it is NOT possible to overwrite program code and other *cdata* sections. The data is added at the end of the assembly and hex file in the same order as it is defined.

SYNTAX:

```
#pragma cdata[ADDRESS] = <VXS>, .., <VXS>
#pragma cdata[] = <VXS>, .., <VXS>
#pragma cdata.IDENTIFIER = <VXS>, .., <VXS>
```

ADDRESS: 0 .. 0x7FFE

VXS : < VALUE | EXPRESSION | STRING>

VALUE: 0 .. 0x3FFF

EXPRESSION: C constant expr. (i.e. 0x1000+(3*1234))

STRING: "Valid C String\r\n\0\x24\x8\xe\xff\xff\\\""

String translation: \xHH or \xH : hexadecimal number

\0 => 0	\1 => 1	\2 => 2	\3 => 3	\4 => 4
\5 => 5	\6 => 6	\7 => 7	\a => 7	\b => 8
\t => 9	\n => 10	\f => 12	\v => 11	\r => 13

Strings are stored as 7 bit ASCII characters (14 bit core devices). The least significant 7 bits of each code word are filled first. Strings are aligned on word addresses for each <VXS>. However, alignment does not occur when writing "abc" "def".

IDENTIFIER: any undefined identifier. It is converted to a macro identifier and set to the current *cdata* word address. The purpose is to provide an automatic way to find the address of stored items.

Empty *cdata* statements can be used to set or read the current *cdata* address.

```
#pragma cdata[ADDRESS] // set current cdata address
#pragma cdata.IDENTIFIER // "get" current cdata address
```

Only *cdata* within the valid code space is counted when calculating the total number of code words.

Storing EEPROM data

Note that EEPROM data must be put in an assembly module when using MPLINK.


```

#define CDATA_START 0x2100
#pragma cdata[CDATA_START] // start of cdata block
#pragma cdata[] = 0x3F, 10, 20, 'a'
#pragma cdata[] = "a\b\c\0"
// '\0' is added in strings due to 14 bit compression
#pragma cdata[] = 'a', 'b', 'c'

```

Using the cdata statement

1. Defining special startup sequences:

```

#define _NOP 0x0000
#pragma cdata[0] = _NOP
#pragma resetVector 1 // goto main at address 1

```

2. Restoring calibration values:

```

#define ResetAddress 0x3FF // 16C509(A)
#define _MOVLW 0x3000
#pragma cdata[ResetAddress]= _MOVLW + CalValue

```

3. Storing packed strings and other data in flash devices (16F87X)

The cdata definitions should be put in a separate file and included in the beginning of the program. This enables identifiers to be used in the program and checking to be performed.

```

#define CDATA_START 0x80
#pragma cdata[CDATA_START] // start of cdata block
#pragma cdata[] = 0x3FFF, 0x2000, 0x1000
#pragma cdata[] = 0x100, (10<<4) + 3456,\
                    10, 456, 10000

#define D7(l,h) l + h*128
#define D28(x) x%0x4000, x/0x4000
#pragma cdata[] = D7(10,20), D28(10234543)

#pragma cdata.ID0 = 0x10, 200+3000
#pragma cdata.ID1 = "Hello world\0"
#pragma cdata.ID2 = "Another string\r\n" "merged"

#pragma cdata.ID_TABLE = ID0, ID1, ID2 // store addresses

#pragma cdata.CDATA_END // end of cdata block
..
#pragma origin CDATA_END // program code follow here

void write(uns16 strID);
..

write(ID1);
write(ID2);

```

The cdata statements should normally be stored after the program code. All cdata start addresses have to be decided manually. The setup could be as follows:

```

.. cdata definitions
.. C functions at addresses lower than CDATA_START

```

```
#pragma origin CDATA_START
#pragma origin CDATA_END
.. C functions at addresses higher than CDATA_END
```

If the address defined by `CDATA_START` overlaps with function code, then an error will occur when `#pragma origin CDATA_START` is used. Statement `#pragma origin CDATA_END` checks that no invalid program code addresses is used. It is recommended to specify the address only at the beginning of a continuous cdata block (as shown).

Preprocessor statements can be used for checking size during compilation:

```
#if CDATA_END - CDATA_START > 20
#error This is too much
#endif
```

7 DEBUGGING

Removing compilation errors is a simple task. The real challenge is to reveal the many application bugs. ALWAYS remember to check the assembly file if the application program does not behave as expected. Using a compiler does not remove the need for understanding assembly code.

Debugging methods

There are several ways of debugging the program:

1. Test (parts of) the program on a *simulator*. This allows full control of the input signals and thus exact repetition of program execution. It is also possible to speed up testing to inspect long term behavior and check out rare situations. How to do this is application dependent.
2. Use a hardware *emulator*. An emulator allows inspection and tracing of the internal program state during execution in the normal application environment, including digital and analog electronics.
3. Insert application specific *test-code* and run the program on a prototype board. Then gradually remove the extra code from the verified program parts. The key is to take small steps and restore the program to a working state before doing the next change. The extra test code can consist of:
 - 1) Code that produces patterns (square waves) on the output pins. This can be checked by an oscilloscope.
 - 2) Repetition of output sequences.
 - 3) Extra delays or extra code to handle special situations.

The different debugging methods have their advantages and disadvantages. It can be efficient to switch between several methods.

Compiler bugs

Compiler bugs are hard to detect, because they are not checked out until most other tests have failed. (Silicon bugs can be even harder). Compiler bugs can often be removed by rewriting the code slightly, or, depending on the type of bug, try:

- 1) `#pragma optimize`
- 2) `#pragma update_FSR`
- 3) `#pragma update_RP`
- 4) command line option: `-u`
- 5) command line option: `-bu`
- 6) command line option: `-b`

ALWAYS remember to report instances of compiler bugs to B Knudsen Data.

7.1 Compilation Errors

The compiler prints error messages when errors are detected. The error message is preceded by 2 lines of source code and a marker line indicating where the compiler has located the error. The printing of source and marker lines can be switched off by the `-e` command line option. The maximum number of errors printed can also be altered. Setting the maximum to 12 lines is done by the command line option `-E12`.

The format of the error messages is:

```
Error <filename> <line number>: <error message>
```

Some errors are fatal, and cause the compiler to stop immediately. Otherwise the compiling process continues, but no output files are produced.

NOTE: When an error is detected, the compiler deletes existing hex and assembly files produced by the last successful compilation of the same source file.

Error and warning details

The compiler prints a short description of the error message to the output screen and to the *.occ file, but not to the *.err file. Note that the description will not be visible when enabling the error file in MPLAB. The *.occ file can then be opened and inspected.

```
-ed : do not print error details (disable)
-ew : do not print warning details (disable)
-eL : list error and warning details at the end
```

Some common compilation problems

- not enough variable space

Solution: Some redesign is required. The scope of local variables can be made more narrow. A better overlapping strategy for global variables can be tried.

- the compiler is unable to generate code

Solution: Some of the C statements have to be rewritten, possibly using simpler statements.

- too much code generated

Solution: rewrite parts of the code. By checking the assembly file it may be possible to detect inefficient code fragments. Rewriting by using the W register directly may sometimes reduce the code size. Experience has shown that around 10% of the hex code can be removed by hand-optimizing the C code. Optimal usage of the code pages and RAM banks is important. Note that the code reduction estimate is compared to the initial code written.

- codepage limits are exceeded

Solution: move functions to another codepage by using the pragma codepage or location statements. It is sometimes necessary to split a function into two separate functions.

- too deep call level

Solution: rewrite the code. Remember that the compiler handles most cases where functions are called once only. If there is a return array at the deepest call level, this code can be moved to the calling function:

```
void sel(char i) {
    Carry = 0;
    W = rl(i); /* multiply by 2 */
    skip(W);
    #pragma computedGoto 1
    W = '0'; goto ENDS;
    W = '1'; goto ENDS;
    W = '4';
    #pragma computedGoto 0
ENDS:
    /* processing continues here */
}
```

7.2 MPLAB Debugging Support

The CC5X compiler can be used inside the MPLAB environment. More details is found in 'debug.txt'. The COD file format for debugging purposes is supported. Two modes of source file debugging is available:

- Using the C source file(s).
- Using the generated assembly file as the source file. The format of the assembly file in order to suit the debugging tool. Take a look at the assembly file options. Some suggestions:

```
-A1+6+10 -AmiJ      : simulator I
-A1+6+6   -AmiJs     : simulator II
-A6+8+12Jt      : compact I
-Am6+8+12Jt     : compact II
```

Enabling the COD-file is done by a command line option:

`-CC<filename>`: generate debug file using C source file(s). `<filename>` is optional. The asm file option is also switched on.

`-CA<filename>`: generate debug file using generated assembly file as source. `<filename>` is optional. The asm file option is also switched on.

Arrays:

Arrays and structures represent a slight challenge, because all variables passed in the COD file are currently either char or bit types.

This is solved by adding new variables which appears during debugging:

```
char table[3];      -->  table,      /* offset 0 */
                       table_e1,   /* offset 1 */
                       table_e2    /* offset 2 */

struct {
    char a;
    char b;
} st;               -->  st,        /* offset 0 (element 'a') */
                       st_e1     /* offset 1 (element 'b') */
```

This means that the name of a structure element is not visible when inspecting variables in a debugger.

ICD debugging

Including ICD debugging support is simple, just use:

```
#define ICD_DEBUG
#include "16F877.H"
```

7.3 Assert Statements

Assert statements allows messages to be passed to the simulator, emulator, etc.

```
Syntax:  #pragma assert [/] <type> <text field>
```

`[/]` : optional character

```
<type> : a = user defined assert
        e = user defined emulator command
        f = user defined printf
        l = user defined log command
```

`<text field>`: undefined syntax, valid to the end of the line. The line can be extended by a `'\'` character like other preprocessor statements.

```
#pragma assert /e text passed to the debugger
#pragma assert e text passed to the debugger
```

```
#pragma assert ; this assert command is ignored
```

NOTE 1: comments in the <text field> will not be removed, but passed to the debugger.

NOTE 2: Only ASCII characters are allowed in the assert text field. However, a backslash allows some translation:

```
\0 => 0, \1 => 1, \2 => 2, \3 => 3, \4 => 4
\5 => 5, \6 => 6, \7 => 7, \a => 7, \b => 8
\t => 9, \n => 10, \v => 11, \f => 12, \r => 13
```

USE OF MACRO'S: Macro's can be used inside assert statements with some limitations. The macro should cover the whole text field AND the <type> identifier (or none of them). Macro's limited to a part of the text field are not translated. Macro's can be used to switch on and off a group of assert statements or to define similar assert statements.

```
#define COMMON_ASSERT a text field
#define AA /
. .
#pragma assert COMMON_ASSERT
#pragma assert AA a text field
```

Macro AA can also disable a group of assert statements if writing:

```
#define AA ;

#define XX /a /* this will NOT work */
#pragma assert XX causes an error message
```

7.4 Debugging in Another Environment

Testing a program larger than 500-1000 instructions can be difficult. It is possible to debug parts of the program in the MSDOS environment. Another C compiler have to be used for this purpose. Using another environment has many advantages, like faster debugging, additional test code, use of printf(), use of powerful debuggers, etc. The disadvantage is that some program rewriting is required.

All low level activity, like IO read and write, have to be handled different. Conditional compilation is recommended. This also allows additional test code to be easily included.

```
#ifndef SIM
// simulated sequence
// or test code (printf statements, etc.)
#else
// low-level PICmicro code
#endif
```

The following can be compiled and debugged without modifications:

1. General purpose RAM access
2. Bit operations (overlapping variables requires care)
3. Use of FSR and INDF (with some precautions)
4. Use of rl(), rr(), swap(), nop() and nop2(). Carry can be used together with rl() and rr(). Direct use of Zero_ should be avoided.
5. Use of the W register

The recommended sequence is to:

1. Write the program for the actual PICmicro device.
2. Continue working until it can be compiled successfully.
3. Debug low-level modules separately by writing small test programs (i.e. for keyboard handling, displays, IIC-bus IO, RT-clocks).

4. Add the necessary SIM code and definitions to the code. Debug (parts of) the program in another environment. Writing alternative code for the low-level modules is possible.
5. Return to the PICmicro environment and compile with SIM switched off and continue debugging using the actual chip.

File 'debug.txt' contains definitions that are useful when running a PICmicro application program in another environment using a standard C compiler.

8 FILES PRODUCED

The compiler produces a compiler output file and a hex file that may be used for programming the PICmicro chips directly. The hex file is produced only there are no errors during compilation. The compiler may also produce other files by setting some command line options:

- assembly, variable, list, function outline, COD and error files

8.1 Hex File

The default hex file format is INHX8M. The format is changed by the *-f* command line option. The INHX8M, INHX8S and INHX32 formats are:

```
:BBaaaaTT112233...CC
BB    - number of data words of 8 bits, max 16
aaaa  - hexadecimal address
TT    - type :
        00 : normal objects
        01 : end-of-file   (:00000001FF)
11    - 8 bits data word
CC    - checksum - the sum of all bytes is zero.
```

The 16 bit format used by INHX16 is defined by:

```
:BBaaaaTT111122223333...CC
BB    - number of data words of 16 bits, max 8
aaaa  - hexadecimal address
TT    - type :
        00 : normal objects
        01 : end-of-file   (:00000001FF)
1111  - 16 bits data word
CC    - checksum - the sum of all bytes is zero.
```

8.2 Assembly Output File

The compiler produces a complete assembly file. This file can be used as input to an assembler. Text from the source file is merged into the assembly file. This improves readability. Variable names are used throughout. A hex format directive is put into the assembly file. This can be switched off if needed. Local variables may have the same name. The compiler will add an extension to ensure that all variable names are unique.

There are many command line options which change the assembly file produced. Please note the difference between the *-a* and the *-A* options. The *-a* option is needed to produce an assembly file, while the *-A* option changes the contents of the assembly and list files.

The general format is *-A[scHDpftmiJbeokgN+N+N]*.

s: symbolic arguments are replaced by numbers

c: no C source code is printed

H: hexadecimal numbers only

D: decimal numbers only

p: no '.' in front of decimal constants

f: no object format directive is printed

t: no tabulators, normal spaces only

m: single source line only

i: no source indentation, straight left margin

J: put source after instructions to achieve a compact assembly file.

b: do not add rambank info to variables in the assembly file

e: do not add ',l' to instructions when result is written back to the register

o: do not replace OPTION with OPTION_REG

k: do not convert all hexadecimal numbers (11h -> 0x11)
 g: do not use PROCESSOR instead of the list directive
 N+N+N: label, mnemonic and argument spacing. Default is 8+6+10.

Note that the options are CASE sensitive.

Some examples:

```

Default :                               ;    x++;
      m001    INCF  x
-AsDJ :      m001    INCF  10           ;    x++;
-Ac :        m001    INCF  x
-AJ6+8+11 : m001  INCF  x              ;    x++;
-AiJ1+6+10 : m001
      INCF  x              ;x++;
-AiJs1+6+6 : m001
      INCF  0Ah           ;x++;
  
```

8.3 Variable File

The variable list file contains information on the variables declared. Variables are sorted by address by default, but this can be changed. The compiler needs the command line option `-V` to produce this file. The file name is `<src>.var`.

The general format is `-V[rnuD]`. The additional letters allows the file contents to be adjusted:

r: only variables which are referenced in the code
 n: sort variables by name
 u: keep the variables unsorted
 D: use decimal numbers

Variable file contents:

```

X [b] ADR :REF: name
  X -> L   : local variable
      G   : global variable
      P   : assigned to certain address
      R   : overlapping, directly assigned
      E   : unused external variable (not allocated)

  b -> -   : mapped RAM (available in all banks)
      0   : bank 0
      1   : bank 1
      etc.

  REF -> 12: number of instructions using the variable

  ADR -> 0Ah   : file address
      0Ch,0   : bit address (file + bit number)
  
```

Examples:

```

R [-] 0x006.0 : 1: in
R [-] 0x00B   : 10: alfa
P [-] 0x00B   : 12: fixc
L [-] 0x00D   : 1: lok
L [0] 0x012.0 : 6: b1
G [0] 0x012.1 : 16: bx
G [0] 0x015   : 23: b
  
```

When a function is not called (unused), all its parameters and local variables are truncated to the same location. Example:

```
L [-] 0x00F : 16<> pm_2_
```

8.4 List File

The compiler can also produce a list file. The command line option is `-L`. The general format is `-L[<col>,<lin>]`. The maximum number of columns per line `<col>` and lines per page `<lin>` can be altered. The default setting is `-L120,60`. The contents of the list file can be changed by using the `-A` option.

8.5 Function Call Structure

The function call structure can be written to file `<src>.fcs`. This is useful for codepage optimization and function restructuring in case of call level problems. Note that two different formats are produced; the first is a list of functions, the second is a recursive expansion of the function call structure. The command line option is `-Q` for both formats.

Format sample:

```
F: function1          : #1  : p0 <- p1
   func2              : #5  : p0 -> p3 **
   delay              : #2  : p0 -> p2 *
   func3              : #3  : p0 -> p0
```

The meaning of the symbols is:

1. `func2`, `delay` and `func3` are called from `function1`
2. `#1` : `function1` is called once
3. `#3` : `func3` is called 3 times (once from `function1`)
4. `p0 <- p1` : `function1` resides on page 0
5. `p0 <- p1` : `function1` is called from page 1
6. `p0 -> p3` : call to `func2` (resides on page 3)
7. `*` : one pagebit have to be updated before call
8. `**` : both pagebits have to be updated

The call structure is also expanded recursively:

```
L0  main
L1  function1
L2  func2
L2  delay
L2  func3
L1  function1 ..
```

Explanation of symbols used:

- `L1` : stack level 1 (max 2 or 8 levels). This is the REAL stack level, compensated when `CALL`'s have been replaced by `GOTO`.
- `..` : only the first call is fully expanded if more that one call to the same function occur inside the same function body.
- `[CALL->GOTO]` : `CALL` replaced by `GOTO` in order to get more call levels
- `[T-GOTO]` : `CALL+RETURN` is replaced by `GOTO` to save a call level.
- `[RECURSIVE]` : recursive function call

9 APPLICATION NOTES

9.1 Delays

Delays are frequently used. There are various methods of generating them:

1. Instruction cycle counting
2. Use of the TMR0 timer
3. Watchdog timeout for low power consumption
4. Use of variables achieves longer intervals

```
void delay(char millisec)
/* delays a multiple of 1 millisecond at 4 MHz */
{
    OPTION = 2; /* prescaler divide by 8 */
    do {
        TMR0 = 0;
        clrwdt(); /* only if necessary */
        while (TMR0 < 125) /* 125 * 8 = 1000 */
            ;
    } while (-- millisec > 0);
}
```

```
void delay10(char n)
/*Delays a multiple of 10 millisec.
Clock : 4 MHz => period T = 0.25 microsec.
DEFINITION: 1 is = 1 instruction cycle
error: 0.16 percent
*/
{
    char i;

    OPTION = 7;
    do {
        clrwdt(); /* only if necessary */
        i = TMR0 + 39; /* 256 us * 39 = 10 ms */
        while (i != TMR0)
            ;
    } while (--n > 0);
}
```

```
void _delay10(char x)
/*
Delays a multiple of 10 millisec.
Clock : 32768 Hz => period T = 30.518 microsec.
DEFINITION: 1 is = 1 instruction cycle
              = 4 * T = 122 microsec
10 ms = 82 is (81.92) => error: 0.1 percent
*/
{
    char i;
```

```

do {
    i = 26;          /* 2 is */
    do
        i = i - 1;
        while (i > 0); /* 26 * 3 - 1 = 77 is */
    } while (--x > 0); /* 3 is */
}

char counter;

void main(void)
{
    if (TO == 1) {
        /* power up or MCLR */
        PORTA = 0; /* write output latch first */
        TRISA = 0; /* all outputs */
        TRISB = 0xFF; /* all inputs */
    }
    else {
        /* watchdog wakeup */
        counter -= 1;
        if (counter > 0) {
            OPTION = 0x0B; /* WDT divide by 16 */
            sleep(); /* waiting 16 * 18 ms =
                    288 ms = 0.288 seconds */
        }
    }

    /* .. */

    delay(100); /* 100 millisec */

    /* .. */

    delay10(100); /* 1 second */

    /* .. */

    counter = 7; /* 7*0.288ms = 2000 ms */
    OPTION = 0x0B; /* 0 1011 : WDT divide by 16 */
    /* sleep(); waiting 16*18 ms = 0.288 seconds */
} /* total of 2 seconds, low power consumption */

```

9.2 Computed Goto

Computed goto is a compact and elegant way of implementing a multiselection. It can also be used for storing a table of constants. However, the 'const' type modifier is normally the best way to store constant data in program memory.

WARNING: Designing computed goto's of types not described in this section may fail. The generated assembly file will then have to be studied carefully because optimization and updating of the bank selection bits can be wrong.

The 12 bit core requires that all destinations of the computed goto are within the first half code page. The 14 bit core requires that PCLATH is correctly updated before loading PCL. The compiler can do ALL updating and checking automatically. Study the following code samples.

```

char sub0(char i)
{
    skip(i);    // jumps 'i' instructions forward
    #pragma return[] = "Hello world"
    #pragma return[] = 10 "more text" 0 1 2 3 0xFF

    /* This is a safe and position-independent method
       of coding return arrays or lookup constant
       tables. It works for all PICmicro devices. The
       compiler handles all checking and code
       generation issues. It is possible to use return
       arrays like above or any C statements. */

    return 110;
    return 0x2F;
}

char sub01(char W)
{
    skip(W);    // using W saves one instruction
    #pragma return[] = "Simple, isn't it" 0
    /* skip(W) is allowed on the 12 bit core and for
       the first 256 addresses of the 14 bit core */
}

```

Built in skip() function for computed goto

The skip() function also allow 16 bit parameter. When using an 8 bit parameter, carry is automatically generated (3 code words extra) if the table cross a 256 word address boundary. Carry is always inserted when generating relocatable assembly. Options available:

- GW: dynamic selected skip() format, warning on long format (default)
- GD: dynamic selected skip() format
- GS: always short skip() format (error if boundary is crossed)
- GL: always long skip() format

When using the -GS option, CC5X will generate an error if the table cross a 256 word code address boundary. The short format enables most compact code, but requires manually moving the table in the source code if the error is produced.

Computed Goto Regions

The compiler enters a goto region when skip() is detected. In this region optimization is slightly changed, and some address checks are made. The goto region normally ends where the function ends.

A goto region can also be started by a pragma statement:

```

#pragma computedGoto 1    // start c-goto region
// useful if PCL is written directly

```

A goto region can also be stopped by a pragma statement:

```

#pragma computedGoto 0    // end of c-goto region
/* recommended if the function contains code
   below the goto region, for instance when the
   table consists of an array of goto
   statements (examples follow later). */

```

Computed Goto Regions affects:

1. Optimization
2. Register bank bit updating (RP0/1, FSR5/6)
3. 256 word page checks

```

char sub01(char W)
{
    /* The computed goto region can be constructed
       just as in assembly language. However, '#pragma
       computedGoto' should be inserted around such a
       region. Otherwise unexpected results may
       occur. */

    #pragma computedGoto 1
    PCLATH = 0; // 14 bit core only
    PCL += W;

    /* 14 bit core: REMEMBER to make sure that the
       function is located within the first 256
       addresses. (There is no warning on this when
       'skip(W)' is NOT used) */

    return 'H';
    return 'e';
    return 'l';
    return 'l';
    return 'o';
    #pragma computedGoto 0
}

/* A VERY LARGE TABLE (with more than 256 byte)
   can also be constructed (14 bit core): */
char L_dst, H_dst;

char sub02(void)
{
    /* H_dst,L_dst : index to the desired element,
       starting from 0 */
    #define CGSTART 0x100
    PCLATH = CGSTART/256 + H_dst; // MSB offset
    PCL = L_dst; // GLOBAL JUMP AT THIS POINT
    return W; // dummy return, never executed

    /* IMPORTANT : THIS FUNCTION AND THE DESTINATION
       ADDRESSES HAVE TO BE LOCATED IN THE SAME 2048
       WORD CODEPAGE. OTHERWISE PCLATH WILL NOT BE
       CORRECT ON RETURN */
}

#pragma origin CGSTART // the starting point
/* The origin statement is the best way to
   set the starting point of the large return
   table. The address should be defined by a
   '#define' statement, because it then can
   be safely changed without multiple updating. */

```

```
char sub02r(void)
{
    #pragma computedGoto 2    // start of large table
    #pragma return[] = "ALFA"
    #pragma return[] = 0x10 0x11
    ..
}
#pragma origin 0x0320
/* using an origin statement after a large return
table is useful to check the number of return
instructions generated. In this case, there
should be 0x320-0x100=0x250=544 instructions.
If not, any differences will be reported by
the compiler, either as an error, or as a
message. */

void sub3(char s)
{
    /* the next statements could also be written as
a switch statement, but this solution is
fastest and most compact. */

    if (s >= 3)
        goto Default;
    skip(s);

    goto Case0;
    goto Case1;
    goto LastCase;
#pragma computedGoto 0    // end of c-goto region

Case0:
    /* user statements */
    return;

Case1:
LastCase:
    /* user statements */
    return;

Default:
    /* user statements */
    return;
}

void sub4(char s)
{
    /* this solution can be used if very fast
execution is important and a fixed number of
statements (2/4/8/..) is executed at each
selection. Please note that extra statements
have to be inserted to fill up empty space
between each case. */

    if (s >= 10)
        goto END;
    Carry = 0;
}
```

```

    s = rl(s); /* multiply by 2 */
    s = rl(s); /* multiply by 2 */
    skip(s);

    // execute 4 instructions at each selection
Case0: nop(); nop(); nop(); return;
Case1: nop(); nop(); nop(); return;
Case2: nop(); nop(); nop(); return;
Case3: nop(); nop(); nop(); return;
Case4: nop(); nop(); nop(); return;
Case5: nop(); nop(); nop(); goto END;
Case6: nop(); nop(); nop(); goto END;
Case7: nop(); nop(); nop(); goto END;
Case8: nop(); nop(); nop(); goto END;
Case9: nop(); nop(); nop(); goto END;
#pragma computedGoto 0 /* end of region */
END:

/*
  NOTE: "goto END" is necessary for ALL cases if
  the function is called from another codepage.
  NOTE: '#pragma optimize ..' can be
  useful in this situation.
  If the call level is too deep, note that the
  compiler can only replace CALL by GOTO if
  there are few 'return constant' inside the
  function.
*/
}

```

9.3 The switch statement

```

char select(char W)
{
    switch(W) {
        case 1: /* XORLW 1 */
            /* .. */
            break;
        case 2: /* XORLW 3 */
            break;
        case 3: /* XORLW 1 */
        case 4: /* XORLW 7 */
            return 4;
        case 5: /* XORLW 1 */
            return 5;
    }
    return 0; /* default */
}

```

The compiler performs a sequence of *XORLW <const>*. These constants are NOT the same as the constants written in the C code. However, the produced code is correct! If more compact code is required, then consider rewriting the switch statement as a computed goto. This is very efficient if the cases are close to each other (i.e. 2, 3, 4, 5, ..).

APPENDIX

A1 Using Interrupts

```
#pragma bit pin1 @ PORTA.1
#pragma bit pin2 @ PORTA.2

#include "int16CXX.H"

#pragma origin 4

interrupt int_server(void)
{
    int_save_registers    // W, STATUS (and PCLATH)

    if (RTIF) {
        /* TMR0 overflow interrupt */
        TMR0 = -45;
        if (pin1 == 1)
            pin1 = 0;
        else
            pin1 = 1;
        RTIF = 0; /* reset flag */
    }

    if (INTF) {
        /* INT interrupt */
        INTF = 0; /* reset flag */
    }

    if (RBIF) {
        /* RB port change interrupt */
        W = PORTB; /* clear mismatch */
        RBIF = 0; /* reset flag */
    }

    int_restore_registers // W, STATUS (and PCLATH)
}

void main(void)
{
    #ifdef _16C71
        ADCON1 = bin(11); /* port A = digital */
    #endif
    PORTA = 0; /* 76543210 */
    TRISA = bin(11111001);

    OPTION = 0; /* prescaler divide by 2 */
    TMR0 = -45; /* 45 * 2 = 90 periods */
    RTIE = 1; /* enable TMR0 interrupt */
    GIE = 1; /* interrupts allowed */
}
```

```

while (1) { /* infinite loop */
    pin2 = 0;
    nop2(); // 2 Instruction cycles
    nop(); // 1 Instruction cycle
    pin2 = 1;
}
}

```

A2 Predefined Register Names

Core 12:

```

char W;
char INDF, TMR0, PCL, STATUS, FSR, PORTA, PORTB;
char INDF0, RTCC, PC; // optional
char OPTION, TRISA, TRISB;
char PORTC, TRISC;
bit Carry, DC, Zero_, PD, TO, PA0, PA1, PA2;
bit FSR_5, FSR_6;

```

Core 14:

```

char W;
char INDF, TMR0, PCL, STATUS, FSR, PORTA, PORTB;
char INDF0, RTCC, PC; // optional
char OPTION, TRISA, TRISB;
char PCLATH, INTCON;
bit PS0, PS1, PS2, PSA, T0SE, T0CS, INTEDG, RBPU_;
bit RTE, RTS; // optional
bit Carry, DC, Zero_, PD, TO, RP0, RP1, IRP;
bit RBIF, INTF, T0IF, RBIE, INTE, T0IE, GIE;
bit RTIF, RTIE; // optional
bit PA0, PA1; // PCLATH

```

A3 Assembly Instructions

Assembly:	Status:	Function:
NOP	-	No operation
MOVWF f	-	f = W; Move W to f
CLRW	Z	W = 0; Clear W
CLRF f	Z	f = 0; Clear f
SUBWF f,d	C,DC,Z	d = f - W; Subtract W from f
DECF f,d	Z	d = f - 1; Decrement f
IORWF f,d	Z	d = f W; Inclusive OR W and f
ANDWF f,d	Z	d = f & W; AND W and f
XORWF f,d	Z	d = f ^ W; Exclusive OR W and f
ADDWF f,d	C,DC,Z	d = f + W; Add W and f
MOVF f,d	Z	d = f; Move f
COMF f,d	Z	d = f ^ 255; Complement f
INCF f,d	Z	d = f + 1; Increment f
DECFSZ f,d	-	Decrement f, skip if zero
RRF f,d	C	Rotate right f through carry bit
RLF f,d	C	Rotate left f through carry bit
SWAPF f,d	-	Swap halves f
INCFSZ f,d	-	Increment f, skip if zero
BCF f,b	-	f.b = 0; Bit clear f
BSF f,b	-	f.b = 1; Bit set f

BTFSC	f,b	-	Bit test f, skip if clear
BTFSS	f,b	-	Bit test f, skip if set
OPTION	-	-	OPTION = W; Load OPTION register
SLEEP	-	TO,PD	Go into standby mode, WDT = 0
CLRWDT	-	TO,PD	WDT = 0; Clear watchdog timer
TRIS	f	-	Tristate port f (f5,f6,f7)
RETLW	k	-	Return, put literal in W
CALL	k	-	Call subroutine
GOTO	k	-	Go to address
MOVLW	k	-	W = k; Move literal to W
IORLW	k	Z	W = W k; Incl. OR literal and W
ANDLW	k	Z	W = W & k; AND literal and W
XORLW	k	Z	W = W ^ k; Excl. OR literal and W

Addition for the 14 bit core

ADDLW	k	C,DC,Z	W = k + W; Add literal to W
SUBLW	k	C,DC,Z	W = k - W; Subtract W from literal
RETURN	-	-	Return from subroutine
RETFIE	-	-	Return from interrupt

Note:

d = 1	:	destination f:	DECF	f	:	f = f - 1
d = 0	:	destination W:	DECF	f,W	:	W = f - 1
f	:	file register	0 - 31			
Z	:	Zero bit	:	Z = 1 if result is 0		
C	:	Carry bit	:			
		ADDWF	:	C = 1 indicates overflow		
		SUBWF	:	C = 0 indicates overflow		
		RRF	:	C = bit 0 of file register f		
		RLF	:	C = bit 7 of file register f		
DC	:	Digit Carry bit	:			
		ADDWF	:	DC = 1 indicates digit overflow		
		SUBWF	:	DC = 0 indicates digit overflow		
TO	:	Timeout bit				
PD	:	Power down bit				

Instruction execution time

Most instructions execute in 4 clock cycles. The exceptions are instructions that modify the program counter. These execute in 8 clock cycles:

- GOTO and CALL
- skip instructions when next instruction is skipped
- instructions that modify the program counter, i.e: ADDWF PCL