An Introduction To C On The C166 Family

A Short Course In The Fundamentals Of C166 Microcontroller Family Programming, Application And Tools.

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1. Overview

1.1 Course Introduction

This course is intended as a basic introduction to C166 microcontroller programming. It will teach you the basic skills and techniques required to produce efficient C166 programs and give you some ideas how the powerful peripheral set can be employed. A learning-by-doing approach will be taken so that you will have a chance to try new language features straight away. A working C167CR-based microcomputer is provided, equipped with our ***HiTOP*** source level debugger with which programs can be tested. Many examples make use of the C167's powerful and innovative peripheral set so that you will gain an appreciation of how they can be applied in your own projects.

It is assumed that you are familiar with the fundamentals of the C language and have some experience of assembler programming, preferably on the C166 family. We make no apologies for showing some of the underlying assembler produced by the C166 compiler in those cases where misuse of compilation controls can cause program problems.

Each language feature is covered by a programming exercise. You have the choice of creating the program from the specification given or using the “shell” modules, which have the basic framework of the required program already mapped out. You will find complete working versions in the SOLUTION subdirectories from which you can take ideas, or use as is! The outlines of the examples can be found the WORK sub-directories for you to complete.

The content is based on the most common questions asked by C166 users and our own experience of what really counts in C166 programming. It is unlikely that you will remember everything once you start using C166 for real but what you will find is that you'll be able to refer back to the notes should anything difficult crop up. You will not end the course as a C166 expert but you will be in a position to start a major development, armed with the basic knowledge to ensure its success.

We will use the Keil **uVISION** Windows integrated development environment as the means of creating and compiling the exercises and ***HiTOP*** to debug them. The built-in uVision editor is an entirely main-stream Windows programming editor, with automatic error and syntax highlighting and should be familiar to anybody who has used a Windows word processor, Codewright or PFE. Hitex's ***HiTOP*** is a flexible source-level debugger for the C166 family, being used here in its monitor version.

1.2 Basic Objective In C166 Programming

To acheive the fastest possible execution by using only the C language, leading to...

=> Fastest system response to real time events
=> simpler, more maintainable code
=> cheaper EPROMs & RAMs
=> smaller bus width.
=> lowest system cost

1.3 Course Schedule

The course will run in approximately the following order:

Course introduction
Aims of course
Equipment and resources provided

An overview of the Siemens C166 microcontroller architecture
CPU design
Peripheral set
Memory map(s)

Setting up the compiler system
Basic concepts and procedures to be understood before using the tools

Creating a project
The **uVISION** “Project” manager
Basic terminology used in C166 programming
Fundamental compiler controls
Components of a C166 program

Using the *HiTOP* debugger
A quick driving lesson in Hitex’s ***HiTOP***

Exercise EX0: Construct a project from supplied software components, to run on EVA16C development board.

Exercise EX1: Practice using the controls and features of **uVISION** and ***HiTOP*** with an example program.

Adapting the ANSI C language to the C167 hardware
CPU-specific include files
Configuring the C167 bus interface in START167.A66

Exercise EX2: Modify START167.A66 to set up user stack, system stack and BUSCON1 to suit EVA167 hardware.

Global register optimization
The two C167 stacks
Redirecting formatted IO (printf() scanf()) etc.

Exercise EX3: Redirect redirect print() to LCD display to print a seconds counter to the LCD.

Constructing C166 programs
The “include file” method

Understanding the internal structure of the C166 core

Expediting data accesses via DPPs (Data-Page Pointers)

Exercise EX4: Working out physical addresses from DPP and EXTS examples

Special C keywords for different C167 memory areas

C166 Compiler memory models and memory management

Methods for putting specific code and data items at appropriate addresses
Linker controls and keywords
CLASSes and SECTIONs

Exercise EX5: Pitfalls when creating pointers to constant objects!

Customising memory models for efficiency
Coping with non-volatile RAM and memory-mapped IO devices

Exercise EX6: Using the NOINIT and SECTIONS control to address memory-mapped IO

Exercise EX7: Using the NOINIT and RENAMECLASS control to address memory-mapped IO

Typical memory maps for small, high performance systems

Exercise EX8: Constructing a linker control file for a typical C167 system

Exercise EX9: Relocating functions into idata for execution - checksumming ROMs

Non-ANSI code saving tricks and ideas

Squeezing extra performance from C by using assembly-programming tricks!

C pointers in C166

How C's pointer types are adapted to the C166 architecture
Accessing fixed addresses

Exercise EX12: Use the "HVAR" macro to access a memory-mapped DIL switch on chip select 4 and print value to LCD display.

Obscure embedded C problems - placing the pointer itself
Using variable address pointers for real programming tasks

Exercise EX14: Perform a memory test over the RAM from 0x50000 to 0x5FFFF and print results to LCD display.

Using C167 Peripherals In C

Using peripherals to perform tasks with near-zero software intervention

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Exercise EX15: Configure general purpose timer block 1 (GPT1) to measure speed and direction of quadrature-encoded input.

Interrupts in C166 - the 100ns context switch
Interrupt sources – the CAPture And COMpare (CAPCOM) unit

Exercise EX16: Make a 16-bit period & frequency measurement of square wave on P2.3 using the CAPCOM unit or optionally with the GPT1 timer2 on P3.7 (C165 users)

Exercise EX16A: Generating a periodic waveform with the CAPCOM unit on P2.15 or or optionally on P3.3 with the GPT1 timers 3 & 4 (C165 users)

Using the peripheral event controller (PEC) to reduce CPU loading with repetitive tasks.

Exercise EX17: Use the PEC to buffer continuous A/D readings into RAM buffers every 9.7us.

Exercise EX18: Receive a 4800 baud serial bit stream on P2.3 to reconstruct a message using the CAPCOM unit and timer 3/2.

Exercise EX19: Receive a 4800 baud serial bit stream on P2.3 to reconstruct a message using just the CAPCOM unit to reduce CPU overhead.

Using the C167 in Controller Area Networks (CAN) - *Optional Topic*

Basic CAN concepts
Calculating the bit timing parameters
Choosing the bit timing values

Exercise EX30: Calculate the bit timing register values for 100kbit/s and 75% sampling point.

Transmitting messages across CAN

Exercise EX31: Transmit the value on potentiometer zero on the 167IO board to the tutor's CAN monitoring program, using the supplied message ID..

Receiving messages across CAN

Exercise EX32: Receive the values of the pots. On three neighbouring stations and use them to control the bightness of three LEDs on the 167IO board.

Using the Remote Request Mode

Exercise EX33: Use the remote request mode to obtain any one of four short messages string from the tutor's node. This is a race!

Course Wrap-Up And Questions
Points arising from material covered.

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2. Setting Up The C166 Compiler System

There are a number of basic settings that must be made to allow the compiler to run correctly.

2.1 C166's Environment Variables

To help C166 find its include and library files, make sure that the \AUTOEXEC.BAT file on your PC contains the following:

```
PATH=C:\KEIL\C166\BIN;%PATH%

SET  C166INC=C:\KEIL\C166\INC
SET  C166LIB=C:\KEIL\C166\LIB
SET  TMP=C:\TEMP
```

Special Note On ***SET C166INC=***

(i) Any include file given thus:

```
#include <reg167.h>
```

will be searched for firstly in the current and directory and if not found, in the directories indicated by the SET C166INC= <PATHNAME>

2.2 Multiple Include File Search Paths

The SET:

```
SET C166INC=C:\KEIL\C166\INC;C:\166TRAIN\HEADERS
```

will cause C166 to search the \166TRAIN\HEADERS directory as well. Make sure that the AUTOEXEC.BAT contains this as well.

(i) In a C source file, if you enclose the include file name in quotes;

```
#include “reg167.h”
```

then only the current directory will be searched. If the include file cannot be found, C166 will report an error.

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3. Creating A New Project

uVISION operates on the basis of "Projects" where all the source files and compiler and linker options are stored in a ".UV2" file. This file is thus an important part of the software development process and must be archived with the source files and C166 compiler version used. The name of the project is left to the user but in the examples, the project name is based on the exercise name so that EXERCISE0 will use a project called EX0.UV2, EXERCISE1 will use a project called EX1.UV2 and so on.

To explain how the **uVISION** system is used and how a simple program can be constructed within it, the necessary steps will be run through in sequence, with enough detail to proceed to the next stage. This will form the basis of the first exercise, in \166TRAIN\EX0\SOLUTION.

3.1 Background Information On C166 Projects

3.1.1 Basic Data Types In C166

The data types available are:

```
bit             =    1-bit          0 - 1
char            =    8-bits         0 - +/- 127
unsigned char   =    8-bits         0 - 255
int             =    16-bits        0 - +/-32768
short           =    16-bits        0 - +/-32768
unsigned int    =    16-bits        0 - 65535
unsigned short  =    16-bits        0 - 65535
long            =    32-bits        0 - +/- 2.147483648x109
unsigned long   =    32-bits        0 - 4.29496795x109
float           =    32-bits        +/-1.176E-38 to +/-3.4E+38
double          =    64-bits        +/- 1.7E-308 to +/- 1.7E+308
pointer         =    16/32-bits Variable address
```

Notes:

- The 16-bit ANSI "short" type equates exactly to int. The latter takes the "natural" size of the CPU, here 16-bits.

- The machine size of the C166 is 16-bits hence int, short or unsigned int, unsigned short should be used when possible to produce the most compact and efficient code. The use of char and unsigned char will result in a lot of MOVBZ-type instructions which waste time.

- char and unsigned char: Unless you explicitly want a signed 8-bit number, always use unsigned char. Char is normally reserved for ASCII characters which have no sign.

Thus:

```
/*** Define an 8-bit number ***/

unsigned char byte_var ;

/*** Define a character string **/

char ASCII_string[] = { "Guten Tag" } ;
```

As the strcpy, strcat and other string functions all assume "char", you will get warnings if you try to manipulate "unsigned char" objects with them.

3.1.2 Basic Terms Used In C166 Programming

Unfortunately, some terms will have to be used to describe how to build the example program which as yet have not properly been defined. They will of course be fully explained later in the text. For now, here are some simplified definitions of terms used which will help you to understand roughly what is going on!

Compiler-Related Terms

```
IDATA           = On-chip RAM at 0xFA00 (C166) or 0xF600 (C167/5)
NEAR            = Area of off-chip RAM whose variables can be accessed in one instruction
                  (medium to fast speed access)
FAR             = Area of off-chip RAM whose variables require several instructions to
                  access (slow access)
Registers       = Bank of 16 general purpose word registers used for local (automatic)
                  variables,function parameters, intermediate calculation results.  (Fastest
                  access of all)
R1, R2 etc.     = Register within the current register bank
User Stack      = Artificial stack created by C166 to hold some local variables.  Formed
                  from MOV Rw, [R0+] type instructions. (Slow access)
System Stack    = C16x's own proper hardware stack in on-chip RAM with which PUSH and POP
                  instructions can be used and onto which return addresses are placed during
                  subroutine calls.
DPP0,1,2 & 3    = Registers which hold the base addresses of regions in multiples of 0x4000
                  (16k), each of which is 0x4000 bytes long.  For example, DPP3 always
                  equals 3, indicating a 16kb region from 3 * 0x4000, i.e. 0xC000 to 0xFFFF.
Memory Model    = How the compiler decides to place its variables, i.e. on-chip or off-chip,
                  fast or slow access
```

Linker-Related Terms

```
CLASSES         = Locates the named large date or code items at the stated address
SECTIONS        = Locates the code or data from a single source file (module) at the stated
                  address
VECTAB          = Sets the base address of interrupt vector table area.
REGBANK         = Locates the named registerbank at the stated address.
RESERVE         = Prevents any code or data object in the stated address range.
CINITAB         = Locates the variable initialisation tables in ROM
```

3.1.3 Memory Map Of EVA167 Board And Example Program

```
Monitor EPROMS:       0x00000 - 0x1FFFF    NOT AVAILABLE
On-chip XRAM RAM:     0x0E000 - 0x0E7FF
On-chip IDATA RAM:    0x0F600 - 0x0FDFF
Off-chip RAM:         0x40000 - 0x5FFFF
```

The off-chip RAM is notionally split into two ranges: 0x40000 - 0x4FFFF is treated as an EPROM area for code and constants and 0x50000 - 0x5FFFF is used as a RAM area.

```
Off chip RAM allocation:
Your interrupt vectors:   0x40000 - 0x403FF
Monitor's RAM:            0x40400 - 0x41FFF    NOT AVAILABLE
Your program starts at:   0x42000
Your program ends at:     0x4FFFF
Your off-chip RAM:        0x50000 - 0x5FFFF
```

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3.2 Setting Up The Directory Structure For The Example Project (Worked Solution)

3.2.1 Necessary Files To Build A Program

The basic files required to build a working C166 application are:

(i) Source files containing executable C statements

```
Extension: .C
```

(ii) Header files containing function prototypes and definitions

```
Extension: .H
```

(iii) An optional linker input file containing a list of object files and linker controls

```
Extension: .LIN
```

In exercise EX0 we will use **uVISION** to control the linker although in a real project a linker control file would be used.

(iv) A project control file containing the list of source files in the project and the compiler controls etc.:

```
Extension: .UV2
```

C166 will emit the following files types:

```
.OBJ - Unlocated object file with no absolute addresses assigned.

.LST - A list file containing the original source lines but with any errors or warnings
       indicated

.SRC - An optional file containing the assembler code generated by the compilation process.
       This can be assembled with A166 to produce the .OBJ file as an alternative to going
       straight to a .OBJ file from the compiler.

.ERR - A summary of the errors and warnings that occurred during compilation
```

The L166 linker will emit the following files:

```
.<noextension> - Absolute object file in the Siemens extended OMF66 format, containing a
binary representation of the program plus optionally, debug symbol information.  It also
holds the necessary make information to allow uVISION to rebuild the program.

.M66 - A map file containing the address and length of all classes, sections and
registerbanks.

.REG - A special file which holds information on all the registermasks generated by every
function in the program.  By giving this file back to the compiler, it can be used to allow
global register usage optimisation.

.LNK - A linker control file automatically generated by uVISION which contains the user's own
.LIN linker control file with the object file list prepended to it.
```

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It is assumed that the various files that constitute the project will be arranged within and off a root directory of:

```
\166TRAIN\EX0\SOLUTION
```

In the following, this will be referred to as the project "**ROOT**" directory.

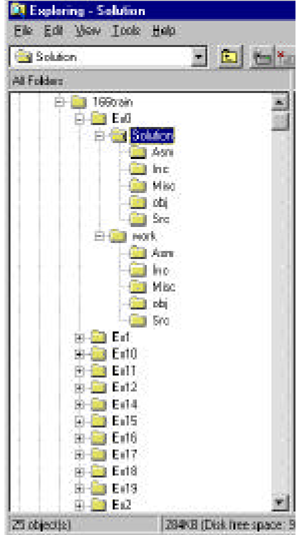
While all files could be placed in the root directory of the project and uVISION left to show only those files which are appropriate, it is neater to make sub-directories for the different types of file within the project:

```
ROOT Object files, EXEC.PRJ project file, EXEC.LIN linker file
ASM  Assembler source files
INC  Include files (.h)
MISC Control file for SP166KE symbol processor
SRC  C source files (.C)
```

In the completed example project, the following files can be found in each sub-directory:

```
ROOT EXEC.PRJ:  Project control file
     EXEC.REG:  Global register optimisation file
     EXEC.LIN:  Linker control file
     EXEC.LNK:  EXEC.LIN with object file list added automatically by uVISION
     EXEC.LER:  Linker error report file created by uVISION
     EXEC.M66:  MAP file showing location of every program object
     EXEC:      Absolute OMF66 executable file
     EXEC.HTX:  Code binary file for HITOP166/WIN
     EXEC.SYM:  Symbol database file for HITOP166/WIN
     START167.OBJ, MAIN.OBJ, PUTCHAR.OBJ, SOFTUART.OBJ object files

\ASM START167.A66 assembler source file

\INC SOFTUART.H, INTMAC.H header files

\MISC SFR_167.CTL C167 SFR definitions file for SP166KE.EXE symbol processor

\SRC MAIN.C, PUTCHAR.C, SOFTUART.C, MAIN.LST, PUTCHAR.LST,SOFTUART.LST
```

The project directory should contain the following sub-directory structure from \166TRAIN\EX0\SOLUTION:



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3.2.2 Laying Out A C166 Program Module (Source File)

Here is how we suggest you layout your C166 modules. You can find a ready made “empty” MAIN.C in \166TRAIN\USEFUL although there is a suitable one in the EX0 directory already.

```
Sample MAIN.C

#pragma SMALL    /* Compiler controls */
#pragma MOD167

/*** CPU Specific Includes ***/

#include <reg167.h>

/*** ANSI Library Includes ***/

#include <stdio.h>

/*** Module Specific Includes ***/

// not used yet!

/*** Global Data Declarations ***/


/*** Function Prototypes ***/

void main(void) ;


/*** Executable Functions ***/

void main(void) {   // Enter here from reset
   }
```

This is compiled with:

```
C166 MAIN.C DEBUG SMALL REGFILE(EXEC.REG) WL(2)
```

Or:

with the **uVISION** Project-Compile File command.

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3.2.3 L166 Linker Input Files

Although it is possible to drive L166 directly from the command line, this can get very tiresome on real programs. L166 is able to take its input from a text file which usually has the same file name stem as the executable but with the extension ".LIN". Here is a sample one:

EXEC.LIN:

```
VECTAB(0x40000)
CLASSES(NCODE(0x40400),NCONST(0x40400),NDATA(0x48000))
SECTIONS(?C_CLRMEMSECSTART(0x40400),?C_INITSEC)
REGFILE(exec.reg)
```

This is invoked with:

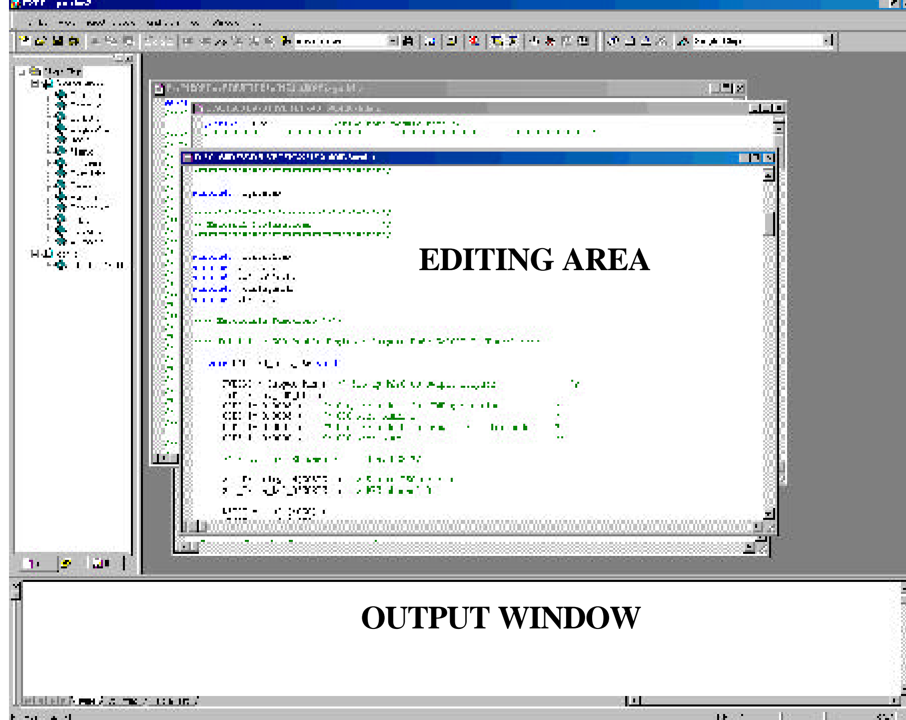
```
L166 @EXEC.LIN
```

Or: with the uVISION Project-Build command.

3.3 Creating A Project With The uVISION2 Workbench

3.3.1 uVISION2 Overview

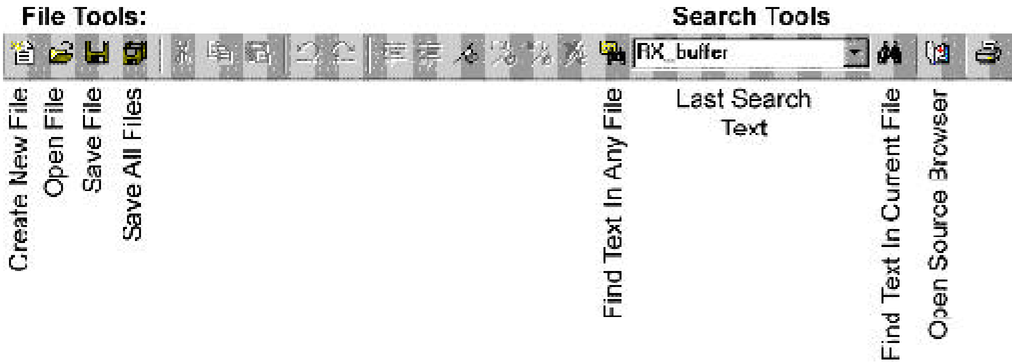
uVISION2 provides an industry-standard Windows interface to the Keil C166 compiler and linker tools. It is reasonably straightforward to configure and can support large program developments. Its user interface is split into special windows, as shown below:

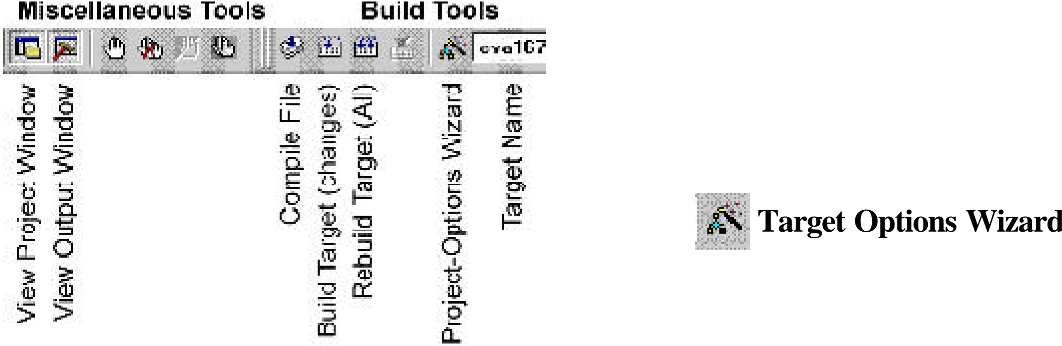


uVISION2 considers C166 programs as "PROJECTS" which can be built in different ways to suit different "TARGETS" - in a real development, you may have a set of source files that are compiled with different controls for different hardware platforms, that may also require different memory maps. For example, in the training exercises, we will be building programs for a "MONITOR" target that has the code offset by 0x40000, as required by the ***HiTOP*** debugger (in this guise). For such a program to run directly from EPROM on the board, a second target is used which differs only in that is has the code at zero.

3.3.2 Important uVISION2 Features

The Toolbar Functions

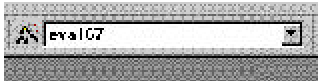




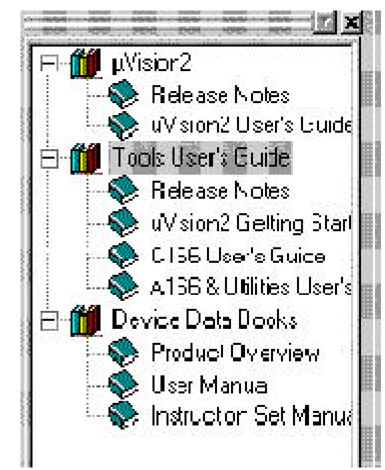
Target Options Wizard

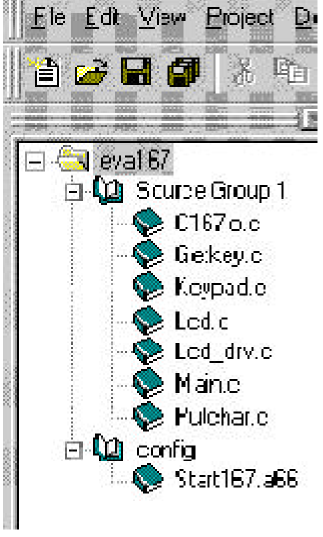
Compiler And CPU Documentation

Select The Target Type



Most **uVISION** functions can be accessed from the toolbar. We will use **uVISION2** to produce the all the example programs, as will be explained in the next few sections.





Project File Details

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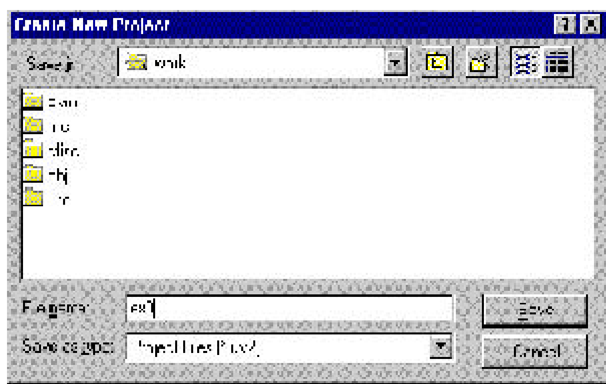
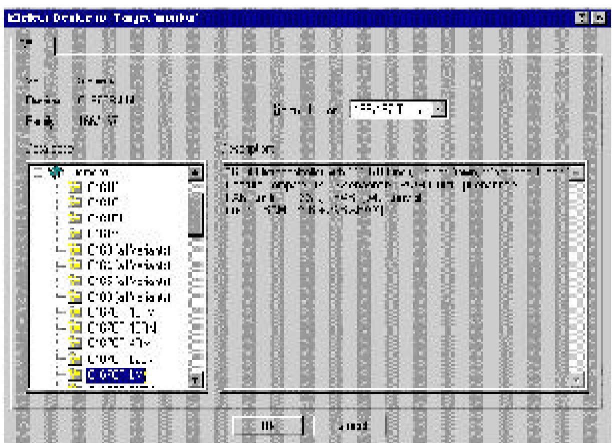
3.3.3 Setting Up The Basic Project Structure



With **uVISION** already running...

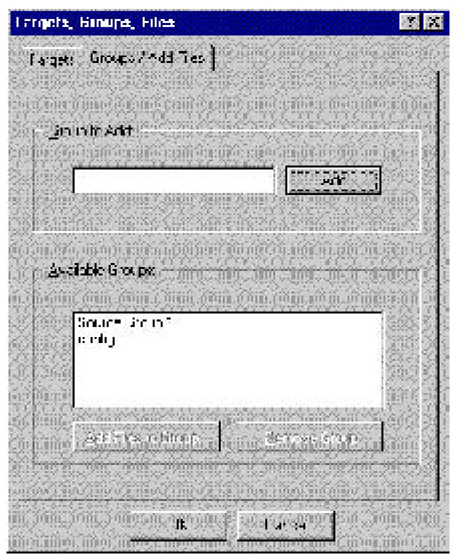
- Select Project-New and navigate to \166TRAIN\EX0\WORK. Enter the project name "EX0" in the dialog box.

- Enter the main project sub-directory and type in the project name, here “EX0.UV2”. The UV2 file is equivalent to the MAKEFILE in a conventional system. It contains all the make, assembler, compiler and linker options entered from uVISION’s Options menu. It therefore has a major influence on how the program is constructed and **must** be archived along with all the source files. Click "OK" to exit.



Next **uVISION** needs to be told which CPU the program will be built for - the "Select Device For Target 1" dialog box will appear automatically. Select the Infineon (formerly Siemens) C167CR-LM device from the CPU list.

uVISION allows a number of TARGETs to be defined. The C167 hardware platform to be used here will running a monitor debugger so a TARGET called "monitor" will be created. Select the "Targets, Groups, Files" item on the Project menu. Add the target name "monitor" in the top dialog box and click "Add". Click on the existing target TARGET1 and click "Remove Target" as this target is no longer required- "monitor " will now become the current target. Exit the menu with "OK".



uVISION allows files of similar types to be collected togther in "Groups". In the project, all the C source files will be in the existing "Source Group1" group whilst the START167.A66 assembler-coded start-up file will be in a new group "Config". From the Project menu, select the Groups/Add Files tab and enter "config" in the dialog box. You should end up with two groups , "Source Group 1"and "config" to which we will later add program source files.

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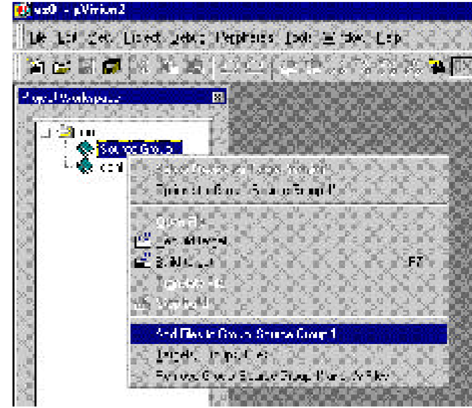
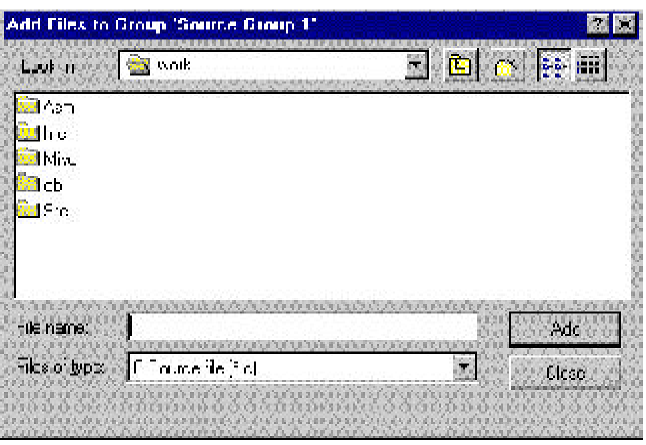
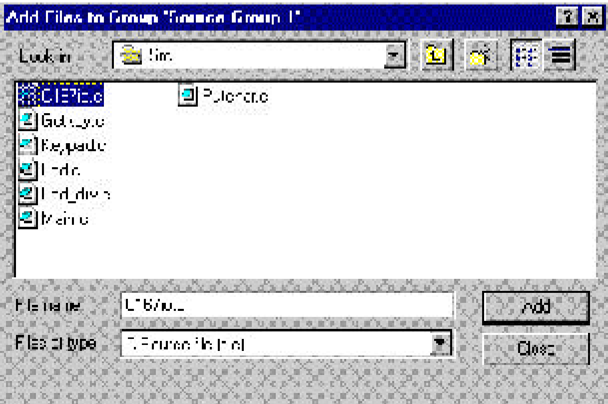
The source files that constitute the project are added by selecting first Source Group 1 and right-clicking and then choosing "Add Files To Group "Source Group 1".



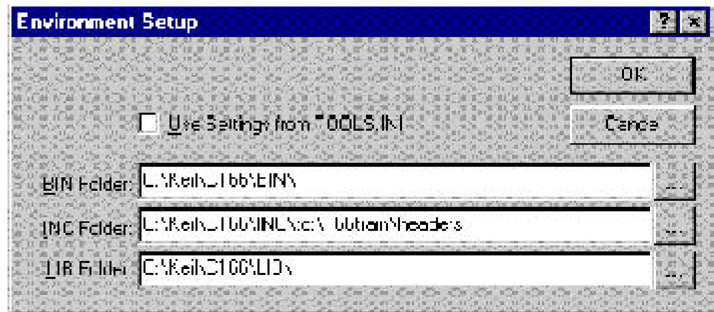


The C source files for Source Group 1 are added by entering the directory "SRC" and double clicking on the required source files. In the example, all source files are needed. Use "Close" to end the task.



A similar process is required to add the single .A66assembler file to the "config" group. Right click the config group and select add files to group 'config'. Double click START167.A66 and then "Close".

To enable **uVISION** to find the compiler executable plus header files and libraries, the Project-Environment Setup menu must be completed. This is similar to a MS-DOS set up that might be entered in AUTOEXE.BAT if the compiler was to be used from a MAKE utility or batch files.



The example uses a header file (INTMAC.H) located in C:\166TRAIN\HEADERS so this path must be added after a semicolon delimiter in the "INC Folder" box.

Hint: If you get a warning along the lines of "Error during parsing Line: #pragma..." then suspect that this menu has not been properly configured.

Note that you must have previously created a C:\TEMP directory - failure to do so could result in "Out of Workspace " warnings when compiling.

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3.3.4 Setting The Tool Options

The compiler, assembler and linker options are set through the "OPTIONS" wizard, located at the top right of the screen. . The Options for target menu is split into eight sections that are selectable from the tabs at the top of the panel. Each target specified in the project has its own target options.

The Target Tab Explained

- Enter the **Clock speed** as 20MHz. The actual oscillator frequency is 5MHz but the C167CR has an internal PLL that multiplies this by 4.

- The **Memory Model** is" HLarge", the preferred model for the majority of C167 programs. The **Memory model** determines how the compiler will allocate program to different data areas. The choice of memory model is explained in chapter 9.

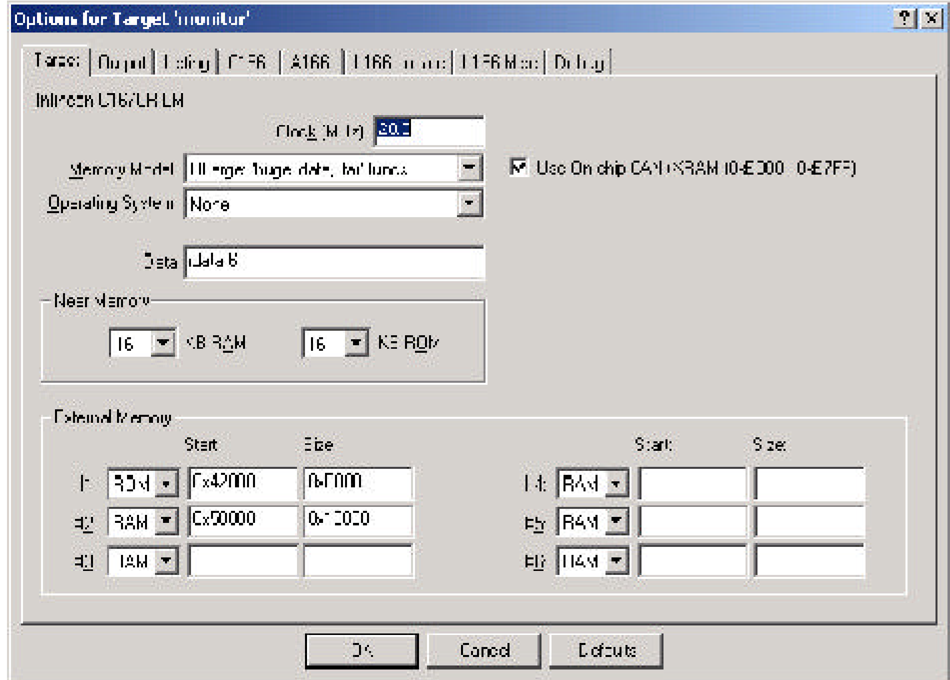
- **Operating System** is" none" in this example

- Although not strictly necessary, the XRAM at 0xE000 and the C167CR CAN module are enabled by ticking the "Use On-chip CAN+XRAM" box.

- **Data** should be set to "idata 6" so that the compiler will place all data objects of up to 6 bytes in length will be placed into the on-chip idata area at 0xF600. This is a way of making sure that large objects such as arrays and structures do not eat up valuable fast on-chip RAM.

- The **Near Memory** boxes are an advanced feature and should be left at 16KB RAM and 16KB ROM. Their real purpose will be explained later!

- The **External Memory** boxes allow you to specify where the ROM and RAM areas are in the hardware. For the EVA16C board used in the example, the user's CODE area starts at 0x42000 and is of length 0xE000 bytes. Use the down arrow on the "#1" box ans selct ROM. The user's RAM area is from 0x50000 of size 0x10000 and these addresses should be entered in the #2 box.



3.3.4.1 The Listing Tab Explained

Here the most useful option is the Generate .LST File after compilation. This will contain the original source file with any errors or warnings indicated where they occured. The “Include Symbols” option is useful as it will list all the function and variable names, along with their type information at the base of list file.

3.3.4.2 The Output Tab Explained

This menu specifies the output file names and allows the ***HiTOP*** symbol processor to be included in the build process and a HEXfile to be emitted for FLASH programming.

- In the example,the **Name of executable** is EX0 and it will be placed into the ..\OBJ directory through the **Select Folder fo Objects...** button.

- The ***HiTOP*** debugger requires **Debug** information

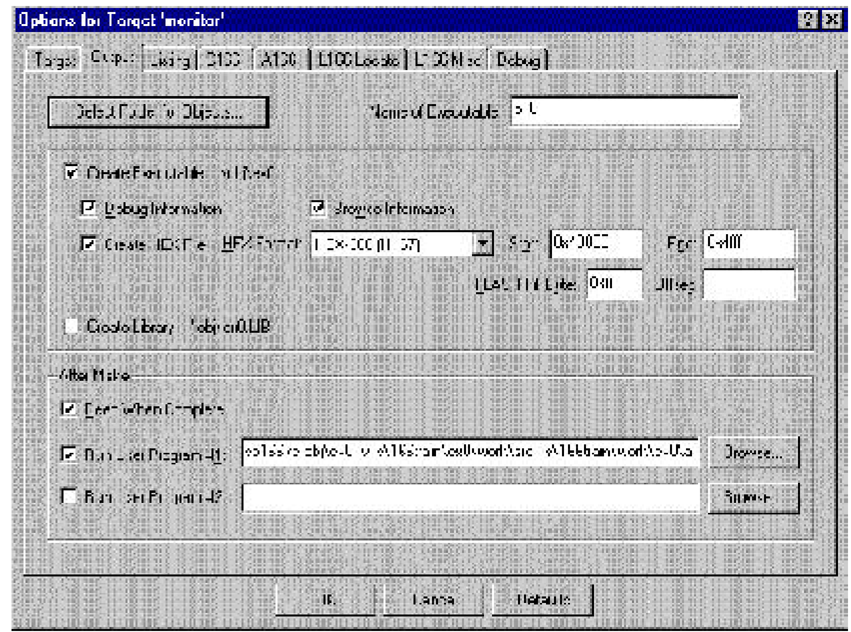
- uVISION includes a browser function which is enabled via **Browse Information**

- After the make process has completed, a **Beep When Complete** can be specified

- The ***HiTOP*** debugger requires a special symbol utility to be run which converts the EX0 output file in the OMF66 format into the .HTX format. This requires **Run User Program #1** to be ticked and the line:

```
sp166ke obj\ex0 -v -s\166train\ex0\work\src -s\166train\ex0\work\asm
```

to be added in the dialog box. The -s option allows the full pathname of the source files to be passed to the utility so that ***HiTOP*** can give source level debugging.



3.3.4.3 The C166 Tab Explained

There are three ways of controlling how the C166 compiler and A166 assembler translate a particular source file:

(i) Via the command line:

```
C166 MAIN.C DEBUG MOD167 HLARGE
```

(ii) Via the #pragma keyword:

```
#pragma MOD167
#pragma HLARGE
#pragma DEBUG
```

(iii) Via **uVISION**'s Options-C166 Compiler... menu item, covered in detail later.

In anything but the smallest of projects, method (i) is not suitable. In practice, it is sometimes used just to quickly compile something from the MS-DOS command line with an unusual control such as "SRC", which produces a valid assembler/C mixed file. This ".SRC" file can be useful for assessing code quality or for interfacing to assembler-coded functions.

Usually, a combination of (ii) and (iii) is used. However, the user must decide which controls should be supplied by **uVISION** and which should be embedded in the source by the #pragma keyword. Where the default compiler setting is acceptable, it is not really necessary to explicitly state the control. As a general rule, anything which can alter the generated code must be given by a #pragma: although **uVISION** is unlikely to lose or alter a control over the duration of a project, bitter experience has shown that just prior to release, something will go astray and some vital control will disappear, resulting in a subtle change to the code. This will invalidate any proving work which has been done and may well result in unexpected program behaviour. Therefore you should not rely on an external tool (i.e. **uVISION**) to set the really important controls!

If you are using a conventional command-line approach with an external MAKE utility, then the same rules apply in that your makefile should ideally not supply the "hard controls". In all cases, it is acceptable to place the really critical controls in a header file, usually named "PRAGMAS.H" which contain them.

Even if you do not intend to use **uVISION**, it does provide a quick way of putting togther the control key-words you require as it displays the final command line in the "Compiler Control String" box. The resulting string can then be used to construct the individual #pragma control lines in your source files - in effect, **uVISION** acts like an interactive user manual!

Here are some tips as to where to put the controls in a real project:

(i) Compiler Hardwired "HARD CONTROLS"

Generally anything which can influence the code generator or optimizer - here are a few of the most common:

```
MOD167          -     Enable C167 family code generator
SMALL           -     Set the memory model
NODPPSAVE       -     Do not stack DPP3 on entry to interrupt routines (C167 only)
OPTIMIZE(x)     -     Bias the code generator towards optimum program SIZE or SPEED
```

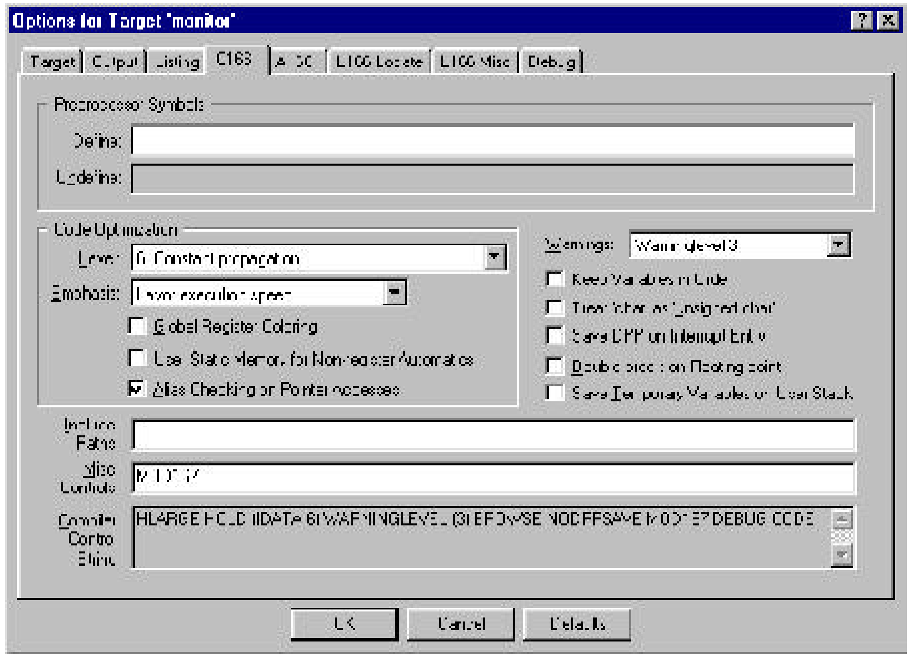
WARNINGLEVEL(x)	**-**	**Check for C language use and abuse**
STATIC	-	Put locals which overflow the available registers into statically allocated memory segments rather than using the user stack.
ORDER	-	Place variables in RAM and constants in EPROM in the order in which they appear in the source file
FLOAT64	-	Enable the "double" 64 bit float type and use double precision floating point for all trigonometric and transcendental mathematics library functions.

Note: *Other controls exist which can influence the final code such as RENAMECLASS and NOINIT but as these require a detailed understanding of the structure of a C166 system to use, they will not be covered until later in the course.*

(ii) uVISION Compiler "SOFT CONTROLS"

DEBUG	-	Enable symbol information for debuggers
SRC	-	Produce an assemblable equivalent of C source file
LISTINCLUDE	-	Expand include files out within .LST file
SYMBOLS	-	Place listing of module's symbols in the listing file

Here, the options appropriate for the training examples will be given. However these will probably be suitable for your own projects as well. The settings given in the following will be needed in exercise EX0 to illustrate the compilation and linking of the example program in \166TRAIN\EX0\WORK. Whilst most of the controls are best given via #pragma, you can still state them in the **uVISION** C166 compiler options menu. If the controls supplied via the two routes do not match, you will get a "CONFLICTING CONTROL" warning.



- Save DPP on interrupt s optimises interrupt service routines: on the C167, DPP3 is always set to 3 to indicate the base of the SYSTEM area at 0xC000 and DPP0 is never changed from its power-up value, unless the user alters it himself. Therefore, C166 need not stack these two registers on entry to an interrupt routine, thereby saving two PUSHes and POPs (0.4us @20MHz).

Alias checking on pointer access is an advanced option which can acheive a small code saving on pointer operations. The NOALIAS control can cause unexpected results in when global or static objects are modified by pointers. In most cases source code that could be upset by this control does not conform to the MISRA-C guidelines and should therefore not be present anyway. It is recommended that this control is not used.

Example

Without NOALIAS

```
struct { int i1; inti2; } *p_struct ;
int val ;

void func1(int *p_val) {
   p_struct->i1 = val ;    // Read val
   *p_val = 0 ;            // Zero val via pointer
   p_struct->i2 = val ;    // Read val again.  Now it is zero
   }


void func2(void) {
   func1(&val) ;
   }
```

With NOALIAS

```
struct { int i1; inti2; } *p_struct ;
int val ;

void func1(int *p_val) {
   p_struct->i1 = val ;    // Read val
   *p_val = 0 ;            // Zero val via pointer
   p_struct->i2 = val ;    // Read val again.  Value from first read carried forward
   }                       // so zeroing by pointer in previous line is not seen


void func2(void) {
   func1(&val) ;
   }
```

Use static memory for non-register automatics influences how the compiler treats local variables (automatics). Normally C166 will try to put as many local variables into registers (R1-R15) as possible as the MOV Rw,Rw register-to-register instructions execute in 100ns (@20MHz). All the normal ADD, SUB, CMP type instructions are available in the register-to-register variety so that any such operation will take just 100ns. Variables that overflow the available local registers are placed on the “User Stack”, as in a PC-type compiler and are addressed via MOV R1,[R0 + #displacement] type instructions. As a RISC CPU, there are few “stack-relative” instructions so that operating on user stack variables usually takes several instructions.

A significant performance advantage for interrupt functions or those with a large number of local variables can therefore be had by forcing the compiler to put locals that cannot fit into registers (R1-R15) into (near) static RAM segments to create a “compiled” stack, as in the C51 compiler. The common ADD, SUB and CMP instructions all can operate directly on RAM so that there is little performance loss when compared to reegister variables.

Note that any functions within modules compiled with this control will no longer be reentrant, thus if enabled here in the C166 Options menu, no reentrancy will be possible across the entire program which may not be

acceptable. This control is therefore better used as a #pragma STATIC with only those modules which contain functions which can be used non-reentrantly, such as interrupt routines.

Whilst not essential, the compiler can be forced to make sure that variables are placed in memory in the order in which they appear in the C source file via the **Keep variables in order** option. This can sometimes result in wasted RAM as words (short and int types) cannot be placed on odd addresses by the L166 linker, resulting in odd bytes being left unused. In most situations, this control (a.k.a. #pragma ORDER) is best used within a source file whose data must be at a defined address - see section 9.12 for more details.

The Code Optimisation level is best left at maximum, the default which also means that C166 will try to generate the fastest possible code, even if it means increasing code size somewhat. Examples of where the **Emphasis** option has some effect is in switch() statements where the compiler will produce either a fast but bulky jump table to the case statements, or use a compact but slower "target address calculation" approach.

Double Precision Floating point may be required if you are using floating point numbers, the double keyword is actually treated as float by default, i.e. single precision (7 significant figures). To make the double type into a true double precision (13 significant figures) quantity, select this option. Float will remain as single precision but sin(), cos() log() etc. library functions will all become double precision.

Application Note:

Typical Execution Times (20MHz CPU clock)

(i) Single Precision Floating Point

```
divide = 9-11us approx
sin(x) function = 184-280us
```

(ii) Double Precision Floating Point

```
divide = 13-16us approx
sin(x) function = 220-340us
```

Treat char as unsigned will force the compiler to do as its name implies. By default, C166 treats the "char" type as a signed 8-bit quantity. Source code which originated from another compiler may assume that char is unsigned.

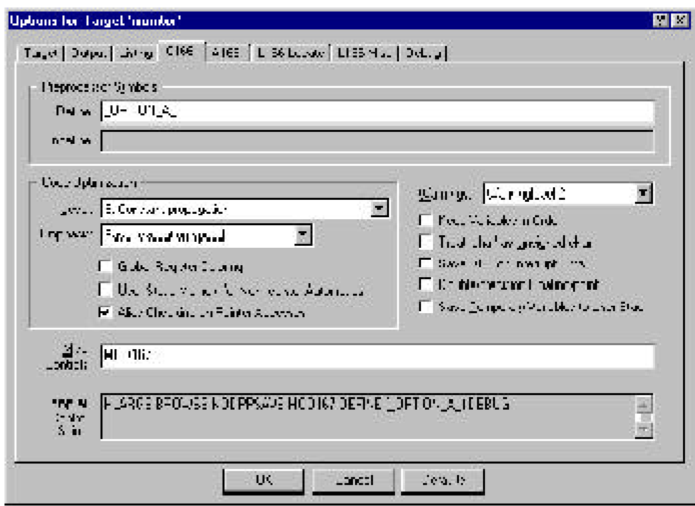
- **Global Register Coloring** is an optimisation that allows the Linker to recompile any source files which could have their register usage optimised using a different "register mask". This is an iterative process whereby the linker makes up to nine compile-link-optimize-compile attempts to make the best allocation of general purpose registers (R1 - R15) between nested functions. For the purposes of the exercises, leave the **Global Register Coloring** item disabled. As this feature extends the compile-link time considerably and is only really useful on larger programs, it is best left in the off state for the example program.

The **Warnings level** is set to "Level 2: detailed" by default so that an almost PC-lint type capability is enabled within C166. Do not be tempted to turn the warning level down as it will be possible to produce unsafe code which is however legal C, especially where pointer use (and misuse) is concerned You have been warned!

Tip: *If you want to discard any changes you have made, click the Default button to restore the original settings.*

- **Define** box allows any #defines to be passed to the compiler from the command line.

Example Of External #define:



```
#ifdef  _OPTION_A_
   clock_speed  = 16 ;  // This is set from outside source file by uVISION
#else
   clock_speed  = 20 ;
#endif
```

None are required in the example program!

Misc Controls box can be used to hold any special controls that will not be used in the main program development such as the SRC option. This is usually only used to quickly see what assembler code the compiler has produced during development of critical code sections. It must usually be removed before the next full build is performed.

Advanced note: By right clicking on individual source files, the compiler options for a single file can be set.

3.3.4.4 The A166 Tab

The A166 assembler is set up in much the same way as the compiler. However there are no special controls required for almost all C166 programs. However, in programs built without uVISION it is important that the assembler knows which memory model the compiler is using and that a C167 CPU is the target . The "HLARGE" in the A166 command line SET() control does this. Whilst the START167 source file contains a $SEGMENTED control, it is sensible to enable it here with the SEGMENTED control. If this control is not present, the assembler will only be able to produce programs which can run in the non-segmented CPU mode which means a memory space limit of just 64K.The complete A166 command line would be: MOD167 SET (HLARGE) DEBUG.

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3.3.4.5 The L166 Locate Tab

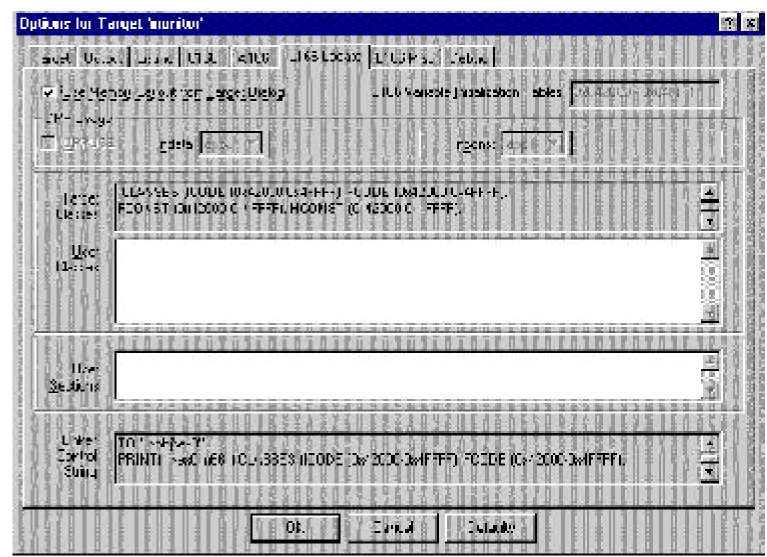
The L166 linker is set up in much the same way as the compiler. However, experience has shown that the nature of the controls necessary for the linker in a real project are best placed in a conventional ASCII text file, here named EX0.LIN. This contains only the controls necessary to locate the program at the correct addresses, i.e. the CODE in the EPROM and the DATA in the RAM!

EXEC.LIN From Example Program

```
 // Linker Input File For The HLARGE Model
 //
 // Shift user's interrupt vectors (inc. reset) to 0x40000
vectab(040000h)
 // Prevent User's Program Using Monitor's RAM
reserve(0f200h-0f5ffh)
 // Move user's C main registerbank above monitor's
REGBANK(0fd00h)
 // Fix classes for HLARGE model in free RAM
CLASSES(ICODE(042000H),
        FCODE(044200H),
        NCONST(044200H-047FFFH),
        HCONST(044200H),
        NDATA(050000H-053FFFH),
        NDATA0(050000H-053FFFH),
        FDATA(050000H),
        FDATA0(050000H),
        HDATA(050000H),
        HDATA0(050000H),
        XDATA(050000H),
        XDATA0(050000H))
// Put startup code sections into free RAM
CINITAB(44200h)
```

However for the example we will let the Target Tab's ROM and RAM boxes provide the necessary location information instead of an external .LIN control file , i.e. where the ROM and RAM are on the EVA16C board. Click the **Use Memory Layout From Target Dialog** to do this.

I there are special SECTIONS or CLASSES that need to go at particular addresses, they can be entered in the User Classes or Use Sections boxes. There are none required in the example.

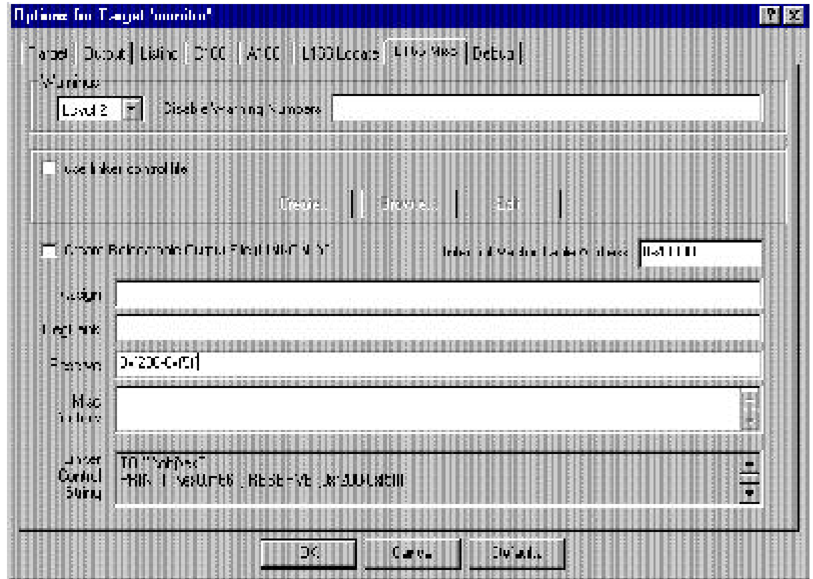


3.3.4.6 The L166 Misc Tab

The >v3.xx L166 linker is able to detect type mismatches between modules. For example, if a variable is declared as "unsigned char x ;" in module A and then in module B, it is externally referenced as "short x ; " , then L166 will flag a warning. Earlier L166 versions did not do this, with the consequence that a "word access to odd address" trap occured at run time, usually with embarassing results. In 99% of cases, a linker warning indicates a potential run time problem which may become an error just before a release date. The **Ignore Warnings** should not be selected without long and careful consideration and preferably only after counselling.

For the **EVA16C** board, the interrupt table must be shifted to the base of the user's code area at 0x40000. This is acheived by entering the address in the **Interupt Table Vector Address** box.

In the C167CR, the area from 0xF200 to 0xF5FF is reserved, according to the data book so this address range must be entered into the **Reserve** box.



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3.4 Building New Projects For The First Time

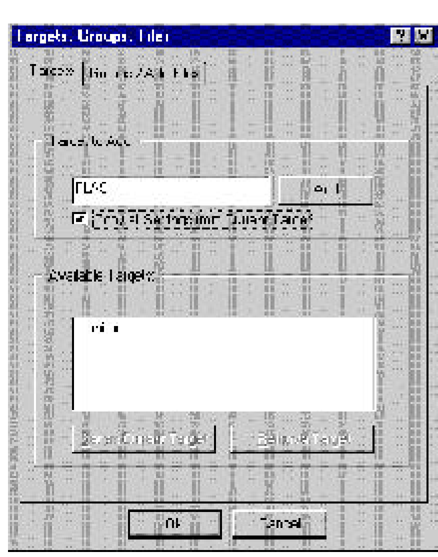
Now that all the configuration steps for the example program have been taken, the program must be compiled and linked.

Normally, the source files within the program will not already exist and so the usual approach would be to select File-New and then type in the source lines. From the Project menu, the **Make: Compile File** option would be taken to compile the file. Any errors or warnings found during compilation will result in a secondary ".ERR" window being created which gives brief details of the error. To view the source lines containing the problem, just double click the error message within the red bar and the editor will drop you onto the offending line.

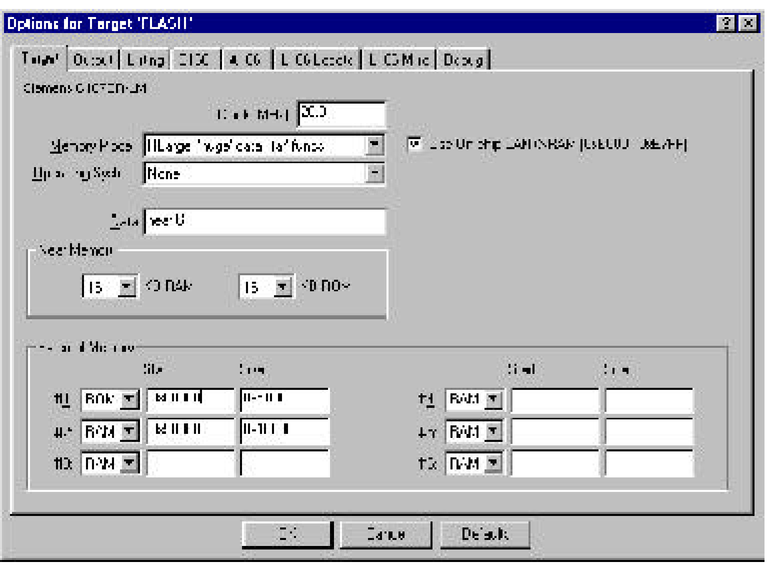
To build the program, select Project-Build or click the button on the toolbar. This will compile all changed files, link the objects and run the SP166KE.EXE symbol processor. Subsequent builds of the project can be made by clicking the Project-Rebuild icon in the toolbar.

3.5 Making Use Of The Multiple Target Facility

This project so far has been built to run under the ***HiTOP*** monitor. At some point the program will need to run standalone from FLASH ROM. This represents a new target which can be defined via the Targets, Groups, Files menu, accessible by right clicking on the existing monitor target in the files window. Add the target name FLASH and click "copy all settings from current target".



When running the program directly from FLASH, the user's code area needs to be moved to 0x0000, although the RAM address can remain the same at 0x50000.



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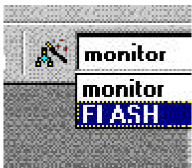
The interrupt vector table addresswill also need to be moved to 0x0000 in the L166 Misc Tab.

Finally, the new target can be selected from the Target box at the top right of the screen.



3.6 The Special C167 Instructions

As the C167CR is being used in the examples, enable the C167 code generator with **Enable 80C167 instructions**. This will allow the compiler to use the EXTP and EXTS instructions when addressing objects via pointers to increase efficiency. Only C166 users should cancel this option - all other C16x family members can use the C167 instruction set.

Note: Using the EXTS instruction will make the C167 behave more like a conventional CPU as whilst the access to far objects will be made simpler, any interrupts will be locked out. This point must be borne in mind in systems where deterministic interrupt latency times are important.

Example of EXTS sequence used for a huge pointer:

```
;       *huge_ptr = 0x55 ;
                                              ; SOURCE LINE # 19
     MOV   R6,#85
     MOV   R5,WORD huge_ptr+2
     MOV   R4,WORD  huge_ptr
     EXTS  R5,#1
     MOV   [R4],R6
```

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3.7 Register Masks And Global Register Optimization

As has been mentioned, C166 will attempt to place local data into registers to improve speed by making best use of the 100ns MOV Rw,Rw type instructions. It will only do this in a particular function, provided that no further functions are called. This limitation exists as there is no way that the compiler can know whether the called function will use registers that are already used by the caller. Thus to play safe, the calling function is not allowed to use register variables at all!

Fortunately, C166 uses the REGISTERMASK concept to overcome this limitation. These “masks” are generated in the list file by the compiler in the form of a code string, prefixed with ‘@’, within which is contained coded information on each function’s register usage. This new information can then be attached to the function prototypes to tell the compiler in advance about which registers any subsequently-called functions use and hence allow calling functions to use register variables themselves.

```
 ; FUNCTION locate_trigger_point (BEGIN  RMASK = @0x6DFF)
                            ; SOURCE LINE # 165
00F0 F68E2C03 R    MOV     trigger_count,ZEROS
                                            ; SOURCE LINE # 166
00F4 F68E0200 R    MOV     trigger_offset,ZEROS
                                            ; SOURCE LINE # 168
00F8 E00A          MOV     R10,#00H
```

As an example if function main() calls function func0() only uses registers R8 and R9, then its register mask can tell the compiler this so that it is free to use the remaining registers for locals withinmain(). This principle can be extended so that all the functions along a particular calling chain can pass back information on what regsiters are used further down the line. The net effect is that each function gets the maximum number of registers possible so that execution speed will be optimised. As has been said, it is crucial to getting best performance from a C166 family device that the maximum use is made of registers.

Up to C166 v2, it was up to the user to take the register mask from the list file, attach it to the appropriate function prototype and re-compile manually. Now in v2.xx and v3.xx the L166 linker will take all the registermasks for all functions and place them in the regfile, EXEC.REG. The new **uVISION** make function will automatically take the register masks for all functions in a system out of EXEC.REG and recompile any source file which could have its local register variable usage improved. This is why when we compile, the REGFILE(EXEC.REG) command is given. In effect, this compiler/linker system has a feedback path! This can result in automatic multiple-compile-link-compile cycles during which the overall size of the program will reduce noticeably after each pass.

With assembler coded functions, the user should manually work out the register mask and add it to the assembler function’s prototype at the top of the C source file.

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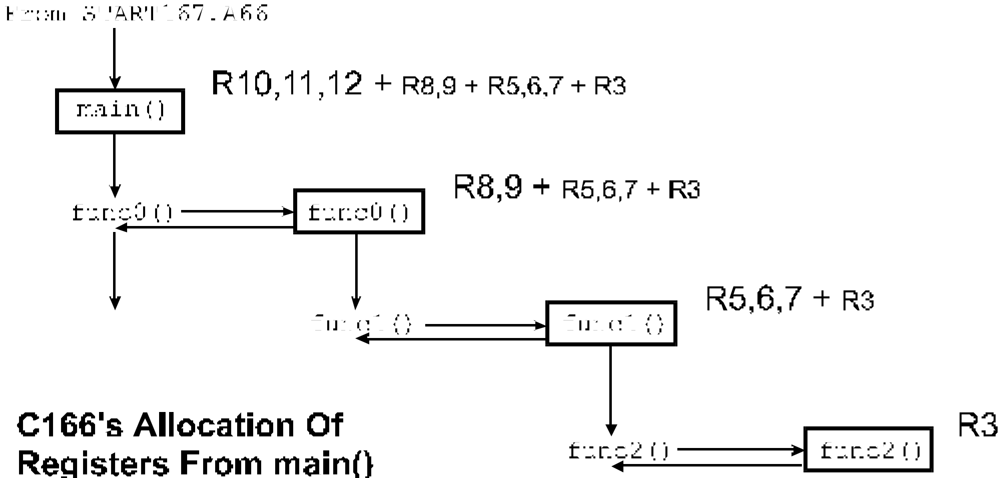
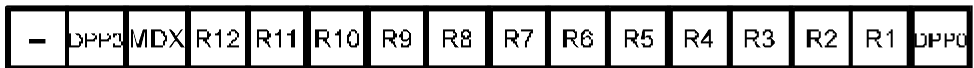


Functions written in assembler are assumed to have the worst case register usage and so any C functions calling assembler will not have any registers available to them. It is thus up to the user to manually generate the register mask and attach it to the function prototype that the calling module sees:

```
extern void asm_func0(void) @0x0010 ;   // The assembler function uses only R4
extern void asm_func1(void) @0x0018 ;   // The assembler function uses R4 & R3
extern void asm_func2(void) @0x0000 ;   // The assembler function uses all registers
```

Here is how to work out the register mask for your own assembler functions:

Bit Allocations In Register Mask



A one in the various fields in a register mask indicate the following:

MDX => Your assembler function uses the multiply/divide unit
R12-R1 => Your assembler function uses a general purpose register

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4. Using The *HiTOP* Monitor-Based Debugger

Whilst Keil's **DScope166** is a fairly reasonable monitor debugger, the Hitex ***HiTOP*** debugger is much easier to use. ***HiTOP*** has a true Windows user interface which makes it easier to get to know. Like any monitor debugger, there are certain things that you must be aware of to be able to use it successfully. Always bear in mind that this is not an in-circuit emulator and if your program crashes, it will probably take the monitor with it...

(i) You must always make sure that the global interrupt flag is enabled. ***HiTOP*** relies on using the serial port 0 interrupt to get control of the monitor after the user has typed "GO".

(ii) You may not use the serial port 0 or overwrite its interrupt vector.

(iii) Only the full in-circuit emulation version of ***HiTOP*** will support bit variables. Attempting to look at them with the monitor version in the watch window will result in a "parameter error". You must then delete the contents of the watch window and perform a system reset (SR button on toolbar) to clear this.

(iv) The monitor occupies the following memory on the EVA167 board:

```
EPROM:        0       - 0x1ffff
On-chip RAM:  0xfa00  - 0xfa3f
External RAM: 0x40200 - 0x41fff
```

You must make sure that your program never tramples on these areas! If you enure that any linker input file you use in the exercises has the following controls at the end of file, you will avoid accidentally doing this.

```
 // Linker Input File For The HLARGE Model
 //
 // Shift user's interrupt vectors (inc. reset) to 0x40000
vectab(040000h)

 // Prevent User's Program Using Monitor's RAM
reserve(0f200h-0f5ffh)

 // Move user's C main registerbank above monitor's
REGBANK(0fd00h)

 // Fix classes for HLARGE model in free RAM
CLASSES(ICODE(042000H),
        FCODE(044200H),
        NCONST(044200H-047FFFH),
        HCONST(044200H),
        NDATA(050000H-53FFFH),
        NDATA0(050000H-053FFFH),
        FDATA(050000H),
        FDATA0(050000H),
        HDATA(050000H),
        HDATA0(050000H),
        XDATA(050000H),
         XDATA0(050000H))

 // Put startup code sections into free RAM
SECTIONS(?C_INITSEC(044200h),?C_CLRMEMSEC)
```

EXERCISE 0: EX0

Subdirectory \166TRAIN\EX0\WORK

Objectives

To practice using the **uVISION**, compiler and linker controls, build the example program in example 0. This simple application prints messages to the LCD display.

Procedure

Go back to section 3.3 and perform the previously described steps to build the program. Once you have successfully built it, including the running of the SP166KE.EXE symbol processor, start ***HiTOP*** by clicking on its icon. Select file-load, TR and then RUN, via the greeen traffic light button on the ***HiTOP*** tool bar.

5. Using uVISION And *HiTOP* In Program Development

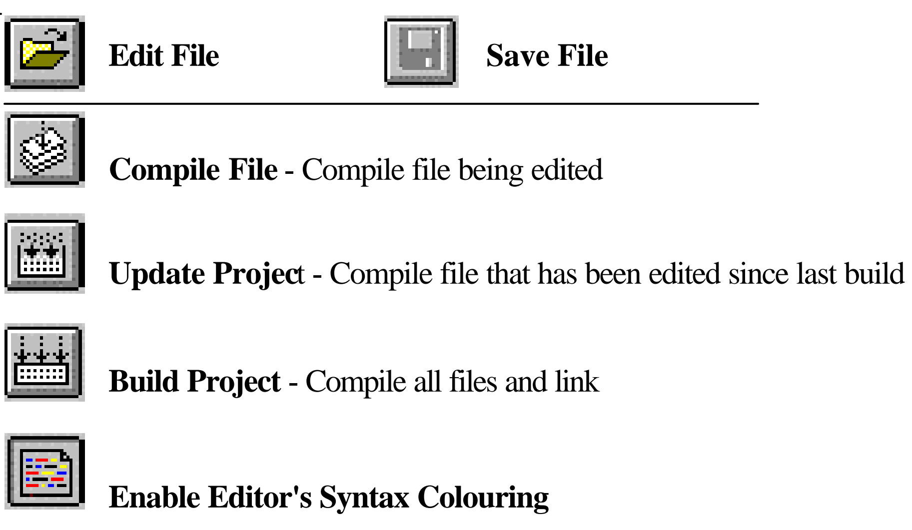
The graphics on the next few pages show a typical edit/compile/debug session using **uVISION** and ***HiTOP***. This includes using the tool bar buttons to compile, build and update projects.

EXERCISE 1: EX1

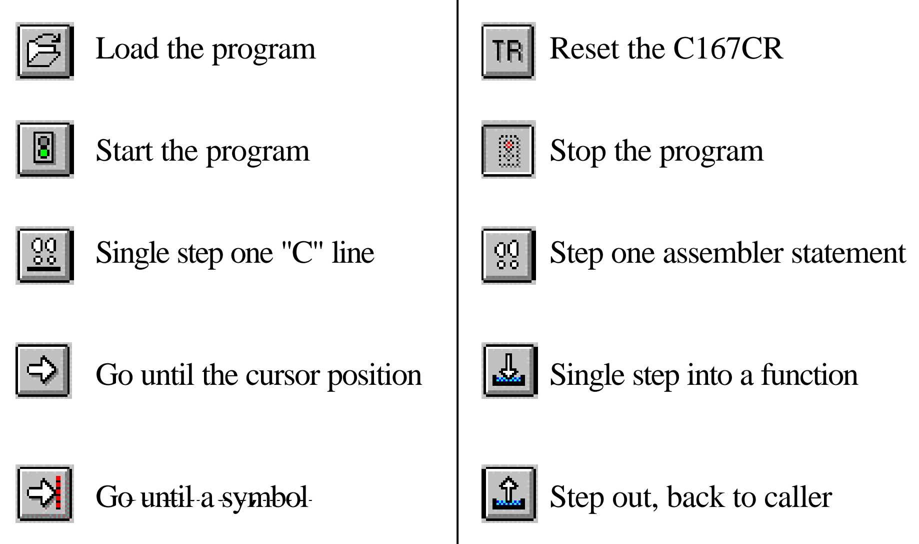
Using the (annoying!) example C166 program in "\166TRAIN.WIN\EX1\SOLUTION" to practice using **uVISION** and ***HiTOP***. Follow the steps shown in the frames one-by-one!

1. uVISION's And *HiTOP's* Toolbar Buttons

These are the most important features and you will need to use these repeatedly during the course - first **uVISION**....

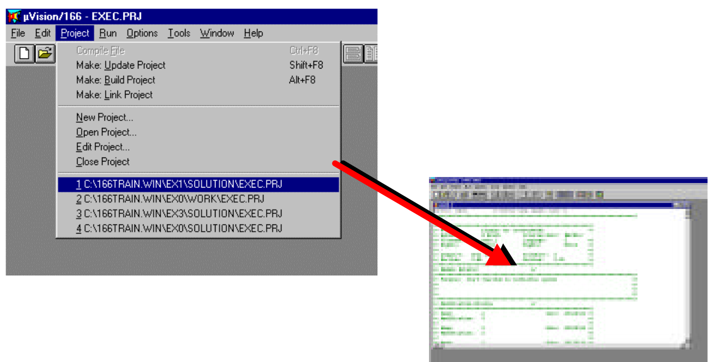


... and secondly ***HiTOP***...



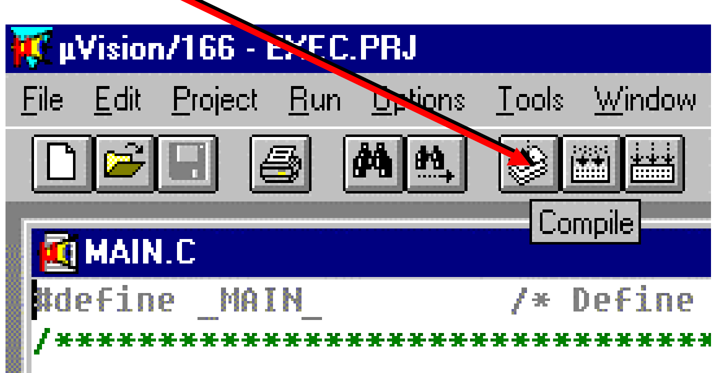
2. Open A Project

Select The Project "\166TRAIN.IWN\EX1\SOLUTION\EXEC.PRJ" from the Project Pull-Down



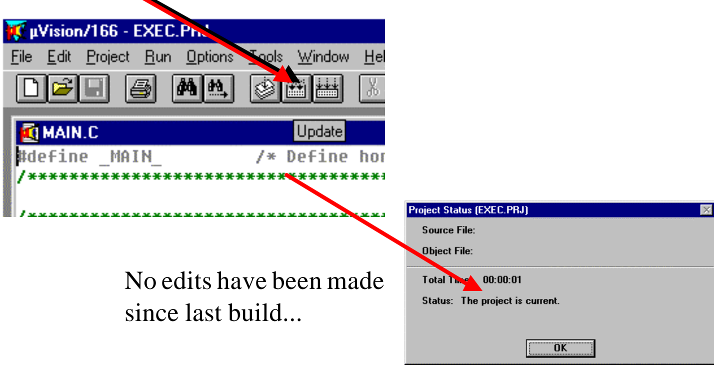
3. Compiling The Currently Open File

Click the Compile Icon and uVision will compiler the current file, MAIN.C



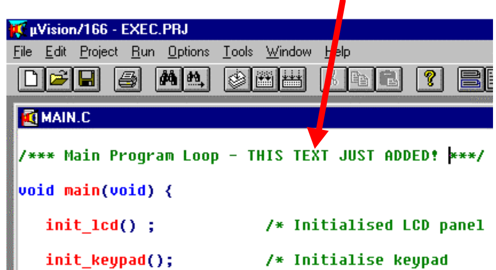
4. Update The Project

Click the Update Project Icon and uVision will report that project is up-to-date



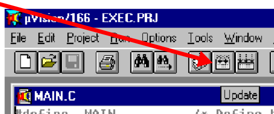
5. Compile Only Changed Files

Add some text to the comment line above main()...



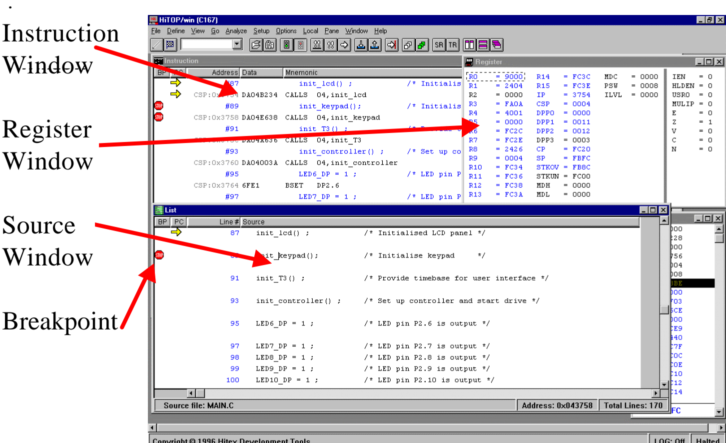
...now click on the Project Update Icon and uVision will recompile and build...

Note: The Update function automatically saves the modified file



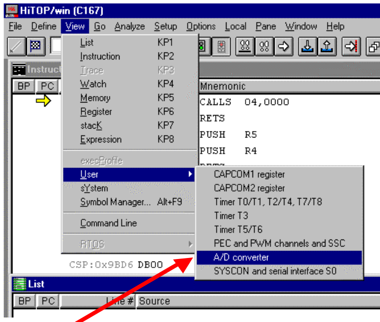
6. *HiTOP*'s Debugging Windows

Now that you have built a program, you can now debug it using the ***HiTOP*** debugger. Click on the ***HiTOP*** icon to start it...



7. Accessing C167CR Peripherals (ADC)

HiTOP is used to load the new program into the **EVA16C** for debugging and running. It can also be used to access the C167CR's peripherals...



Select "View-User-A/D converter" to show the 10-bit A/D converter window...

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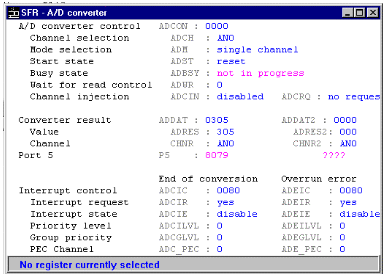
8. The A/D Converter Window

This is effectively the control panel on the C167CR's A/D converter. The voltage of the potentiometers on the training board can be measured...

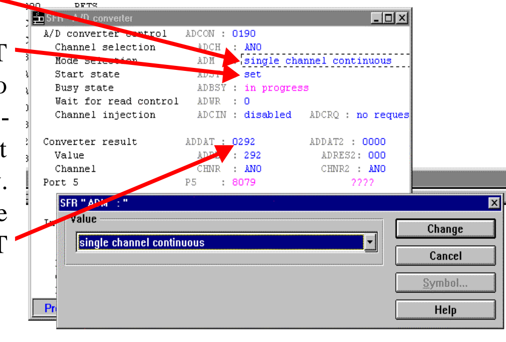


...Test whether the potentiometer on analog channel 0 is working...

9. Start A Conversion Of Channel 0

... click the "AMD" field and choose " single channel continuous" mode...

... and then the ADST field, choosing "set" to start the convertor running. It will convert every 9.7us indefinitely. The analog value can be read from the ADDAT field...



HiTOP can be made to read the latest value by pressing "ALT-F12"

10. *HiTOP*'s Toolbar Buttons

Load the program — Reset the C167CR

Start the program — Stop the program

Single step one "C" line — Step one assembler statement

Go until the cursor position — Single step into a function

Go until a symbol — Step out, back to caller

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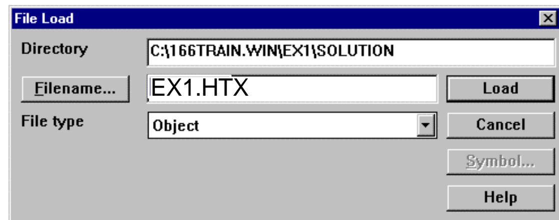
11. Loading The Program Into *HiTOP*

Click the icon and then ...

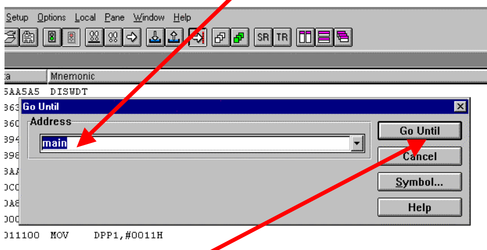


...click LOAD to load program...

12. Running The Program

Now click the TR icon to reset the program...

...and the click the icon. Type "main" into the address box...



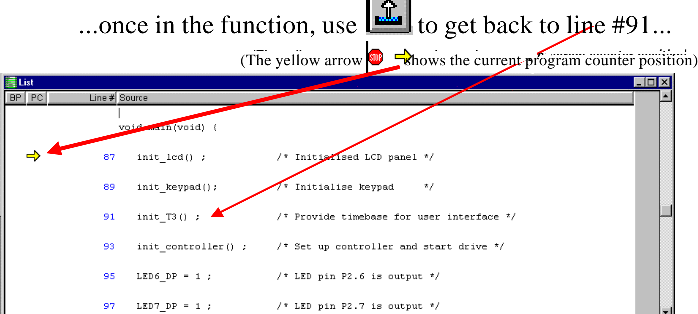
click "Go Until" to run the program to main()...

13. Single Stepping The Program

Click the icon to single step the call to "int_lod()"...
To drop into the function "int_keypad()", use the icon...

...once in the function, use to get back to line #91...

(The yellow arrow shows the current program counter position)



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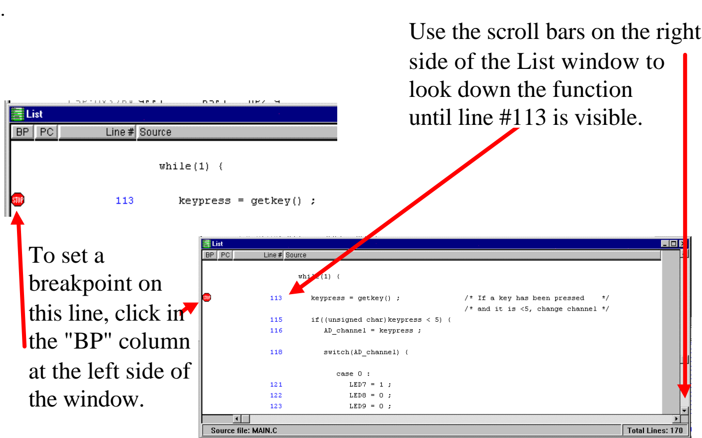
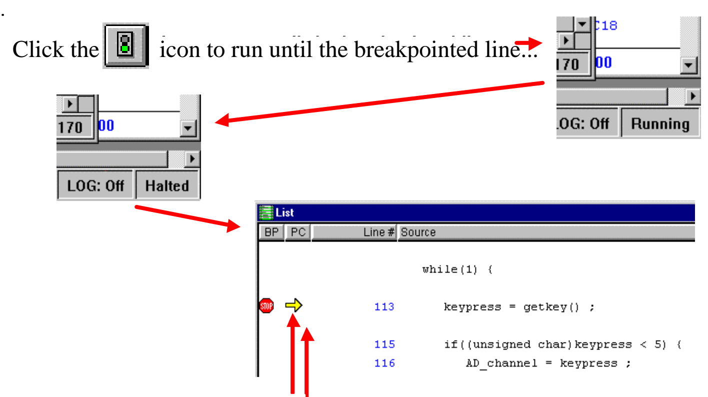
14. Debugging The Program - Breakpoints



15. Debugging - Run To A Breakpoint



The yellow arrow shows that the program has reached the breakpoint and stopped

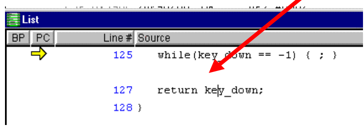
16. Debugging - Running/Stopping

To remove the breakpoint, click again in the "BP" column on the breakpoint...

...to run the program in real time, click the icon again...

to stop the program click the icon.

You will probably have stopped in the keypad driver...

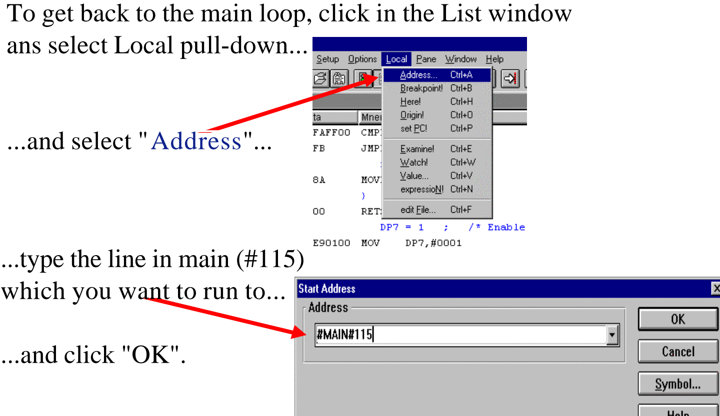


You will need to look at the main loop and run until a line within it...

17. Debugging - Looking At Other .C Files

To get back to the main loop, click in the List window ans select Local pull-down...

...and select "Address"...



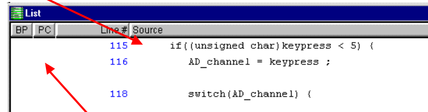
...type the line in main (#115) which you want to run to...

...and click "OK".

18. Debugging - Running To The Cursor Position

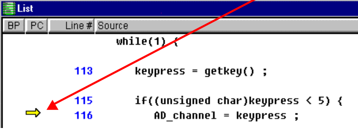
The List window will now show line #115.

...run to the cursor at line #116...



...by clicking in the "PC" column-note the new "GOTO arrow" mouse pointer!

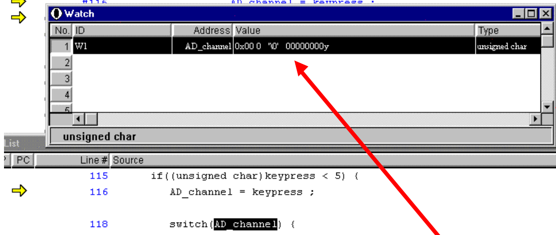
...line #116 is only executed when keys 0-4 are pressed. Press key "1" and the program should stop at the line #116...



19. Debugging - Looking At Variable Values

The variable "AD_channel" will soon be set to the value of the key just pressed...

...to look at this value, double-click the variable in line #118 and then select Local pull-down and Watch...

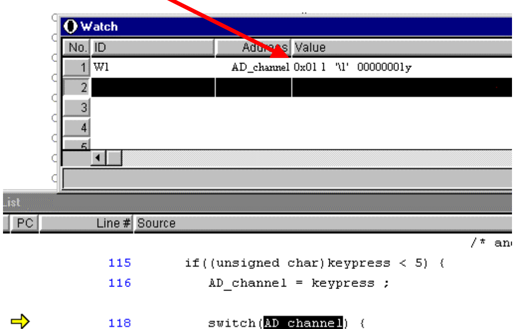


AD_channel will now be in the Watch window, with its value displayed...

20. Debugging - Looking At Variable Values

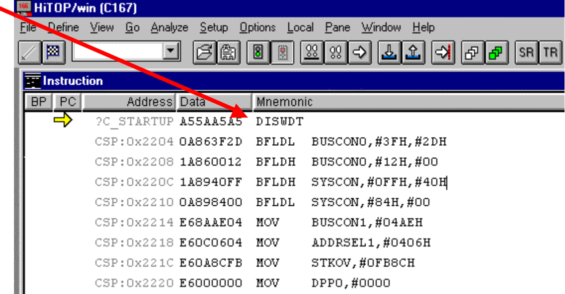
Execute a single step of line #116 with the icon...

AD_channel is now =1, the value of the key you pressed...



21. Debugging - Getting Back To The Start

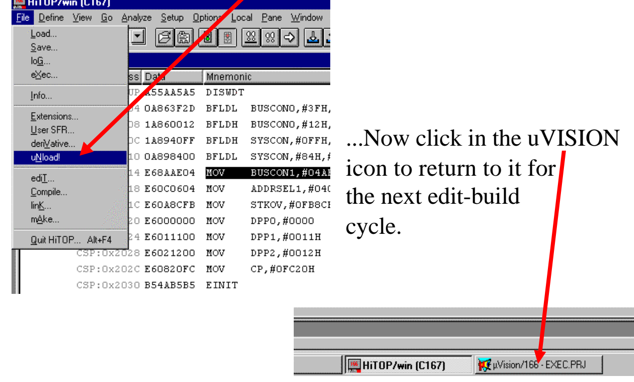
To reset the program, click the TR icon...



22. Returning To uVISION For Next Edit-Build

To release the symbol file, select uNload from the File menu...

...Now click in the uVISION icon to return to it for the next edit-build cycle.



And that is all you need to know to use ***HiTOP***!

6. Configuring The C Environment To Your CPU and Hardware

6.1 CPU-Specific Include Files

The Keil C compiler comes with a set of include files for all the C166 and C167 variants As there is only one register (serial port) more on the C165, this is not a major problem. The include files define the special function register set for a given variant.

These files are all stored in the \KEIL\C166\INC directory and may be directly included in your C program as shown below

```
#include <reg167.h>
```

It is through these files that C166 knows the addresses of the on-chip special function registers.

Extract Of reg167.h:

```
/* (c) Copyright KEIL ELEKTRONIK GmbH.  1993, All rights reserved. */
/* Register Declarations for 80C167 Processor */

/* A/D Converter */
sfr   ADCIC    = 0xFF98;
sfr   ADCON    = 0xFFA0;
sfr   ADDAT    = 0xFEA0;
sfr   ADEIC    = 0xFF9A;
sfr   ADDAT2   = 0xF0A0;
sbit  ADST     = ADCON^7;
sbit  ADBSY    = ADCON^8;
sbit  ADWR     = ADCON^9;
sbit  ADCIN    = ADCON^10;
sbit  ADCRQ    = ADCON^11;

/* Timer 0, Timer 1, Timer 7, Timer 8 */
sfr   CC0      = 0xFE80;
sfr   CC0IC    = 0xFF78;
sfr   CC1      = 0xFE82;
sfr   CC1IC    = 0xFF7A;
sfr   CC2      = 0xFE84;
sfr   CC2IC    = 0xFF7C;
sfr   CC3      = 0xFE86;
sfr   CC3IC    = 0xFF7E;
```

For the C167CS, a header file called "c167cs.h" should be used.

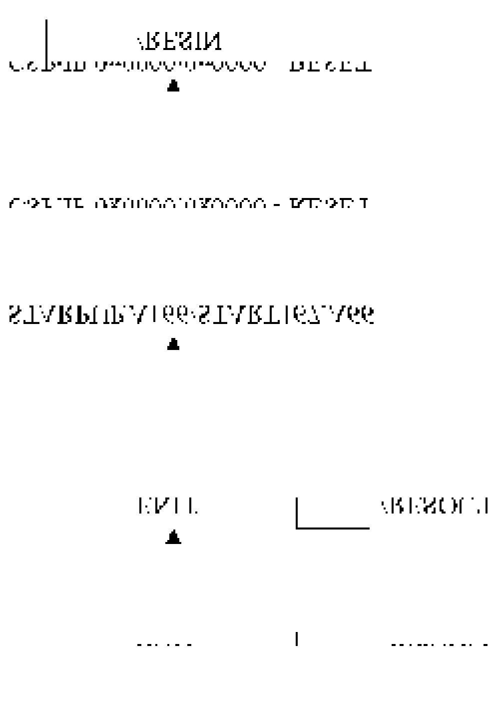
Example Of Use

```
temperature = ADDAT & 0x3ff ;  // get A/D value into 'C' variable

if(C) {    // Check the CPU's carry flag in the PSW

  x = 0xFFFF ;
  }
```

6.2 Configuring STARTUP.A66 And START167.A66

These files contain the code that gets you from the RESET vector at 0x00000 to the beginning of your C program at main().

Besides providing the RESET vector, they are used to initialise the C runtime environment and the CPU's fundamental registers such as SYSCON, BUSCON and any ADDRSELx and BUSCONx registers being used. STARTUP.A66 is used for the C166 and START167.A66 caters for the C165 and C167. In the case of the C166, a default STARTUP.A66 is automatically linked in that will provide a "safe" combination of run time settings and CPU configuration. C167/5 users must always link START167.OBJ as the last object file in the EXEC.LIN file. For any CPU, if the startup object file is not the last in the object file list, you may find some data is not initalised correctly.



The next sections cover in detail what is controlled by these files.

6.2.1 Configuring STARTUP.A66

The majority of these operations refer to the SYSCON register.

(i) Enable or disable WATCHDOG - default DISABLED

(ii) Enable/disable clearing of program variables at startup via the "CLR_MEMORY" and "INIT_VARS" SETs - default: ENABLED

(iii) Enable/disable initialisation of program variables before main() is reached - default: ENABLED.

Note: if you have a variable declared:

```
int x = 1 ;
```

This control decides whether the '1' is written to 'x' during the start up.

(iv) Configure the CPU registers that control the bus mode, waitstates etc..

MCTC - memory cycle time

Default : 1 wait state inserted

Setting 0-15 in this field will result in the CPU inserting the same number of waitstates being inserted. If the RDYEN is enabled, setting 0-7 waitstates will result in 0-7 waitstates being inserted after READY in an asynchronous mode goes low. If 8-15 waitstates are programmed, the READY is treated as synchronous

and 0-7 waitstates are inserted after the READY pin goes low. This change in the MCTC field was introduced at the BA step of the C166.

RWDC - Read/Write delay

Default: delay time of 0.5 states enabled. This is usually only required in some multiplexed bus mode designs. Not needed in non-multiplexed designs at all.

MTTC - Memory tristate time

Default: No tristate time inserted.

This is only required where the memory device has a data float time that is too long for the C166. This is the time that the device drives the bus after the /RD pin has gone high. It is unusual for this to be set and about 10% CPU performance increase can be had by switching if off (set to 1).

Bus Type - Bus type

These bits are usually left in the state set by the EBC0 and EBC1 pins on the CPU. Whilst they can be changed in software, is not really recommended!

CLKEN - Clock output pin

Default: disabled

If this bit is set, the CPU clock will be emitted on the CLKOUT pin, provided that you have previously set this pin to be an output in the appropriate DP register.

BYTDIS - byte high enable

Default: Enabled

Enabling this bit will allow the BHE pin to emit a signal which can be used to enable the high bytes in a word-wide memory system. A0 is used to enable the low byte device and BHE the high byte device.

SGTDIS - Disable segmented CPU mode

Default: Disabled

Unless the TINY model is used, this bit is clear so that the CPU runs in segmented mode i.e.; port 4 emits the A16-A17 address lines.

RDYEN - RDYEN - Enable ready

Default: disabled

Setting this bit will cause the CPU to look for the READY pin going low to show that the last memory access cycle has been completed.

BTYP_ENABLE - Allow software to modify the BTYP field and hence change the bus mode.

Default: Disabled; the bus type is set by the EBC pins.

BTYP0 - External Bus Configuration Control

These bits determined the bus mode used by the CPU when in single-chip mode.

```
0 = 8-Bit Non Multiplexed
1 = 8-Bit Multiplexed
2 = 16-Bit Non Multiplexed
3 = 16-Bit Multiplexed  <--- default mode
```

EXT_RAM

Default: Enabled

Causes the /WR pin to be set to output so that external RAM can be written.

STKSZ - Set system stack size

Default: 256 words

The required system stack size is set by the two bits in this field.

BUSCON1/ADDRSEL1

These two registers control a bus region which can have different characteristics to that set by SYSCON and the EBC pins. It is best to configure them using extra assembler instructions added after the set up of SYSCON. It is important that they are setup before the sections which initialise data. This is because any data contained in the ADDRSEL1 region will not be accessible until these registers have been set up.

6.2.2 Configuring START167.A66

These controls operate on SYSCON and BUSCON0. The functions of the C166's SYSCON are shared between these two registers on the C165/7.

MCTC0 - memory cycle time

Default : 1 wait state inserted. Setting 0-15 in this field will result in the CPU inserting the same number of waitstates being inserted. If the RDYEN is enabled, setting 0-7 waitstates will result in 0-7 waitstates being inserted after READY in an asynchronous mode goes low. If 8-15 waitstates are programmed, the READY is treated as synchronous and 0-7 waitstates are inserted after the READY pin goes low. This change in the MCTC field was introduced at the BA step of the C166.

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RWDC - Read/Write delay

Default: delay time of 0.5 states enabled. This is usually only required in some multiplexed bus mode designs. Not needed in non-multiplexed designs at all.

MTTC - Memory tristate time

Default: No tristate time inserted. This is only required where the memory device has a data float time that is too long for the C166. This is the time that the device drives the bus after the /RD pin has gone high. It is unusual for this to be set and about 10% CPU performance increase can be had by switching if off (set to 1).

BTYP_ENABLE - Allow software to modify the BTYP field and hence change the bus mode.

Default: Disabled; the bus type is set by the pull-down resistors on pins P0L6 and P0L7.

BTYP0 - External Bus Configuration Control

These bits determined the bus mode used bythe CPU when in single chip mode.

```
0 = 8-Bit Non Multiplexed
1 = 8-Bit Multiplexed
2 = 16-Bit Non Multiplexed
3 = 16-Bit Multiplexed
```

ALECTL0 - ALE Lengthening Control Bit.

Default: Disabled

If set, this bit will cause the ALE signal to be lengthened by 0.5 state times.

BUSACT0 - Bus active control bit

Default: Enabled

When enabled, the CPU will fetch instructions from external memory i.e., the bus will emit addresses and read/write data.

RDYEN0 - Enable ready

Default - disabled

Setting this bit will cause the CPU to look for the READY pin going low to show that the last memory access cycle has been completed.

RDY_AS - Decide whether /READY input is synchronous or asynchronous.

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Note: This bit is only valid if _RDYEN == 1.

_RDY_AS - if set to 1, /READY input is treated as synchronous otherwise /READY is asynchronous.

WRCFG - Write configuration control bit.

Default: Disabled (0)

If disabled, /WR and /BHE will operate as normal otherwise, /WR acts as /WRL (write for low byte device) and /BHE becomes /WRH (write for high byte device). This is useful when two 8-bit RAMs are used to produce a 16-bit memory.

CLKEN - Clock output pin

Default: disabled (0

If this bit is enabled, the CPU clock will be emitted on the CLKOUT pin, provided that you have previously set this pin to be an output in the appropriate DP register.

BYTDIS - byte high enable

Default: Enabled (0)

Enabling (clearing) this bit will allow the BHE pin to emit a signal which can be used to enable the high bytes in a word-wide memory system. A0 is used to enable the low byte device and BHE the high byte device.

XPEN - XRAM enable control

Default: Disabled (0)

SGTDIS - Disable segmented CPU mode

Default: Disabled (0)

Unless the TINY model is used, this bit is clear so that the CPU runs in segmented mode i.e.; port 4 emits the A16-A17 address lines.

```
STKSZ: Maximum System Stack Size selection  (SYSCON.13 .. SYSCON.15)
_STKSZ     EQU  0     ; System stack sizes
;                     ; 0 = 256 words (Reset Value)
;                     ; 1 = 128 words
;                     ; 2 =  64 words
;                     ; 3 =  32 words
;                     ; 4 = 512 words
;                     ; 5 = not implemented
;                     ; 6 = not implemented
;                     ; 7 = no wrapping (entire internal RAM use as STACK)
```

This startup file is to be used for the C165 and C167. Unlike the C166, you cannot rely on the linker to pull in a suitable default START167.A66 so you must always include it in your linker input file, EXEC.LIN.

6.2.3 Special Note On The CAN Pin Assignments On The C167CS

Although the configuration of the CANRx and Tx pins is not strictly speaking associated with START167.A66, they do come under the classification of "hardware setup", which must be considered at an early stage in a new design.

With the standard C167CR, the single CAN module uses address line A21 (P4.5) as the transmit line and A22 (P4.6) as the receive. This has the side-effect of limiting the C167CR to using just 20 address lines. However thenewer C167CS-LM has been upgraded such that it has two CAN modules whose IO pins can be reallocated to other pins.

The new three-bit wide IPC field in the PCIR register allows the user to assign the two CAN module as follows:

IPC Field (PCIR[10..08])	CAN1	CAN2	SDLM [1]	Comment
000	TxD = P4.6 RxD = P4.5	TxD = P4.7 RxD = P4.4	TxD = P4.7 RxD = P4.4	Default value of former derivatives
001	TxD = P4.6 RxD = P4.7	TxD = P4.6 RxD = P4.7	TxD = P4.7 RxD = P4.6	
010	TxD = P8.1 RxD = P8.0	TxD = P8.1 RxD = P8.0	TxD = P8.0 RxD = P8.1	
011	TxD = P8.3 RxD = P8.2	TxD = P8.1 RxD = P8.0	TxD = P8.2 RxD = P8.3	
100	Reserved	Reserved	Reserved	Do not use
101	Reserved	Reserved	Reserved	Do not use
110	Reserved	Reserved	Reserved	Do not use
111 [2]	TxD = Off RxD = Idle	TxD = Off RxD = Idle	TxD = Off RxD = Idle	

[1] Not supported by bondout processor C167E3 – AB / AA (DC >= 941).
[2] Reset Configuration, i.e. all Interfaces disconnected.

One major problem for users upgrading from the C167CR is that the default (RESET) state of the IPC field is binary '111', meaning that all CAN interfaces are disconnect. Thus C167CR programs will not run unmodified on a C167CS! To give compatibily, do the following:

```
#define Set_Default_CAN_IO  0xF8FF  /* Required to set up CAN io pins on C167CS */

/* Set Up CAN1 IO Pins (C167CS) */
/*------------------------------*/

CAN1_Control_Status |= CCE ;           // Enable access to bit timing register (and IPC field)
CAN1_Interrupt &= Set_Default_CAN_IO ; // Use standard C167CR Rx & Tx pin allocations on P4
CAN1_Control_Status = 0 ;              // End of CAN module initialisation
```

Where CAN_Interrupt is the CAN interrupt register at 0xEF02 for CAN2 or 0xEE02 for CAN2.

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6.3 The Two Stacks In C166

The basic design of the C166 was deliberately biased towards allowing structured languages like C run more efficiently than on older CPUs. The most useful instruction set feature is the provision of in effect, 16 stack additional stack pointers. These are a result of the MOV [Ri+], mem instructions which are ideal for creating local stacks.

In reality, C166 uses just one of the 16 potential stack pointers (i.e. general purpose registers), namely R0. The stack created by R0 is placed in a special section in NDATA called ?C_CUSERSTACK. The "user stack" with R0 as its user stack pointer is used by C166 for parameter passing and local automatic variables. When a function is called, any variables or other data that cannot be fitted into registers are "pushed" on to the user stack by the MOV [R0-], parameter instruction. The "R0-" causes R0 to point at the next free location on the user stack. Once in the called function, the parameter is moved off the user stack by the inverse instruction "MOV reg,[R0+]". Note that the R0+ moves the user stack pointer. As with the true system stack pointer SP, every MOV [R0-], xxxx is matched with a MOV xxx, [R0-] so that the user stack pointer is always restored to its original value after a function call.

6.3.1 Setting The Size Of The User Stack

Due to C166 placing up to 8 parameters and 15 locals in registers, it is fairly rare for the user stack to be used at all. If the optimizer is disabled, you will instantly see a large number of MOV [-R0],R11 type instructions as C166 starts to move things onto the user stack.

Warning: If C166's optimization is disabled, the user stack size is increased massively!

```
; FUNCTION interp_sub (BEGIN  RMASK = @0x2030)
;    unsigned char interp_sub(unsigned char x, unsigned char y,
                                           ; SOURCE LINE # 11
     MOV   [-R0],R11 <—— this all ends up on user stack
     MOV   [-R0],R10
     MOV   [-R0],R9
     MOV   [-R0],R8
     SUB   R0,#2
;                              unsigned int n, unsigned int d) {
;       unsigned char t ;
;
;       if(y>x)
                                           ; SOURCE LINE # 15
     MOVB  RL5,[R0+#2]                 ; x?00  <—— very slow
     MOVB  RL4,[R0+#4]               ; y?00
     CMPB  RL4,RL5
     JMP   cc_ULE,?C0001
;          {
                                     ; SOURCE LINE # 16
;          t = y-x ;
                                     ; SOURCE LINE # 17
     MOVB  RL5,[R0+#2]               ; x?00
```

Note: this habit of pushing everything on the user stack is why conventional processors like the 68000 and 8086 have relatively poor performance in C.

C166's register variables reducing the load on the user stack to zero and proof of why Keil produce the best C166 compiler you can get!

```
; FUNCTION interp_sub (BEGIN  RMASK = @0x2070)
;     unsigned char interp_sub(unsigned char x, unsigned char y,
                                               ; SOURCE LINE # 11
;—— Variable 'd?00' assigned to Register 'R11' ——
;—— Variable 'n?00' assigned to Register 'R10' ——
;—— Variable 'y?00' assigned to Register 'R9' ——
;—— Variable 'x?00' assigned to Register 'R8' ——
;—— Variable 't?01' assigned to Register 'RL6' ——
;                              unsigned int n, unsigned int d) {
;       unsigned char t ;
;
;       if(y>x)
                                               ; SOURCE LINE # 15
     MOV   R5,R8   <———— Very fast, 100ns
     MOV   R4,R9
     CMPB  RL4,RL5
     JMP   cc_ULE,?C0001
;          {
```

This can make the maximum extent of the user stack a great deal lower than might be expected. However, C166 will only use registers if the optimisation is at maximum. As can be seen, if the optimization is disabled, the user stack will suddenly grow and may well exceed the allocated space, resulting in a program crash.

The default user stack size is 1000H bytes and this is adequate for very large programs - the size is set in the startup.a66 file. It is sensible to leave the stack at this size until the bulk of your program has been written and then to examine the actual worst-case stack used. If you are using the registerbanks and register mask properly, you should be able to reduce this to 100H or less. This can be estimated by working out the maximum function/interrupt nesting and adding up the total number of MOV [R0-]s possible. Alternatively, the *teletest32/166* in-circuit emulator can be used to monitor activity in the designated ?C_USERSTACK area.

As was mentioned in the section on setting C166 compiler options, variables that end up on the user stack are considerably slower to access as there are no ADD, SUB or CMP instructions which can use the Rw,[R0 + #offset16] addressing mode. In other words, variables on the user stack must be moved off the stack into a register, operated upon and then moved back onto the stack.

A significant performance advantage for interrupt functions or those with a large number of local variables can therefore be had by forcing the compiler to put locals that cannot fit into registers (R1-R15) into (near) static RAM segments to create a "compiled" stack, as in the C51 compiler. The common ADD, SUB and CMP instructions all can operate directly on RAM so that there is little performance loss when compared to register variables. **Use static memory for non-register automatics** in the C166 Options menu will do this.

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Example Of STATIC Usage:

The entry to the example INTERP.C function shown above becomes as follows when the STATIC control is used. Note how the user stack instructions have disappeared...

```
?ND?interp?INTERP  SECTION  DATA WORD 'NDATA'
                 ORG 00H
y_break_point1?046  DSW  1
y_break_point2?047  DSW  1
   map_x1y2?049  DSW  1
  result_y1?054  DSW  1
    x_temp1?056  DSW  1
    y_temp2?058  DSW  1
?ND?interp?INTERP  ENDS

                  REGDEF   R0 - R15

      ?PR?INTERP  SECTION  CODE WORD 'NCODE'
; line 1: #pragma MOD167
; line 2:
; line 3: /*** Module-Specific Include File ***/
; line 4:
; line 5: #include <reg167.h>
; line 6: #include <interp.h>
; line 7:
; line 8:
; line 9: /*** Main Interpolation Routine ***/
; line 10: unsigned int interp(unsigned int x_value,

      interp  PROC  NEAR
      PUBLIC  interp
; FUNCTION interp (BEGIN  RMASK = @0x3FFE)
      PUSH  R13
      PUSH  R14
      PUSH  R15
;—— Variable 'map_base' assigned to Register 'R10' ——
      MOV  R2,R8
;—— Variable 'x_value' assigned to Register 'R2' ——
;—— Variable 'map_x2y1?050' assigned to Register 'R11' ——
;—— Variable 'result?053' assigned to Register 'R12' ——
;—— Variable 'y_offset?043' assigned to Register 'R13' ——
;—— Variable 'x_temp2?057' assigned to Register 'R14' ——
;—— Variable 'map_x1y1?048' assigned to Register 'R15' ——
; line 11:                         unsigned int y_value,
; line 12:                         unsigned int *map_base) {
```

Please note however, that any functions within modules compiled with this control will no longer be reentrant, i.e. the same function cannot be called both from an interrupt and a background function. In this case, the values acquired by "static" variables in the background call would be destroyed by those originating from the interrupt function. This control is best used as a #pragma STATIC with only those modules which contain functions which can be used non-reentrantly, such as interrupt routines.

6.3.2 Advanced Technique - Placing The User Stack In On Chip RAM

As has been said, the user stack is fixed in a section named ?C_CUSERSTACK, part of the NDATA class. However, it is quite simple to move it to other memory spaces. The most common action is to place it in the IDATA class so that it can be on-chip. As the user stack is rarely very large, IDATA should be able to contain it quite happily. However it is most usual these days fro it to be necessary to move the userstack on-chip.

A small modification is required to START167.A66 to achieve this, as shown below:

START167.A66 Modified To Put User Stack In On-Chip RAM

Here are the modifications you will need to make if you ever want to move the USER STACK on-chip:

Upper part of START166.A66 at line #479

```
?C_USERSTACK   SECTION   DATA PUBLIC 'NDATA'
```

Should be modified to:

```
?C_USERSTACK   SECTION   DATA PUBLIC 'IDATA'
;
```

... and further down the file...

```
; USTSZ: User Stack Size Definition
;  Defines the user stack space available for automatics.  This stack space is
;  accessed by R0.  The user stack space must be adjusted according the actual
;  requirements of the application.
USTSZ     EQU  100H ; set User Stack Size to 40H Bytes.
;
```

... and even further down the file, after the EINIT instruction at line #700...

Make R0 be loaded with DPP3 for an on-chip USER STACK, rather than DPP2, as at present...

```
     ...........EINIT
;
$IF (NOT TINY)
     MOV   R0,#DPP3:?C_USERSTKTOP   ; This was DPP2:?C_USERSTKTOP
$ENDIF
$IF TINY
     MOV   R0,#?C_USERSTKTOP
$ENDIF
```

If your have forgotten to reduce the size of the user stack to something small enough to fit in the on-chip RAM - the default 1000H bytes will cause L166 to issue a warning about the "IDATA class being out of group range".

Important: you must use the USERSTACKDPP3 and NOFIXDPP C166 compiler controls if the userstack is moved on-chip. This is to allow the compiler to correctly produce pointers to data that is on this stack. Failure to do this will result in undefined results. See section 12.6 for more details on the USERSTACKDPP3 control.

6.3.3 The System Stack

With the user stack taking care of function parameters and local variables, the system stack is used for storing return addresses, the current PSW and CP plus any general purpose registers in the current register bank used for local register variables. This stack is always located on-chip and defaults to 256 words in length (80C166) at 0xfbff down to 0xfa00. The required stack size is set in the START167.A66 file. Values of 32,

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64, 128 and 256 words can be selected via SYSCON. The CPU register "SP" has its top 5 bits hard-wired to '1', the stack is always in the range 0xf800 to 0xfffe, i.e. on-chip.

Setting The System Stack Size

```
; STKSZ: Maximum System Stack Size selection  (SYSCON.13 .. SYSCON.14)
_STKSZ     EQU  0    ; System stack sizes
;               ; 0 = 256 words (Reset Value)
;               ; 1 = 128 words
;               ; 2 =  64 words
;               ; 3 =  32 words
```

The C166 is endowed with two special registers, STKOV and STKUN, which set the top and bottom limits of the stack. The default value of STKOV (Stack overflow) is 0xFA00 whilst STKUN (Stack underflow) defaults to 0xF000, in-line with the default 256 words.

The address of the stack is defined by loading the STKOV register is startup.a66

```
 Setup Stack Overflow
_TOS  EQU   0FC00H                       ;top of system stack
_BOS  EQU   _TOS - (512 >> _STKSZ)        ;bottom of system stack

PUBLIC          ?C_SYSSTKBOT
?C_SYSSTKBOT    EQU   _BOS

           MOV   STKOV,#(_BOS+6*2)     ;INITIALIZE STACK OVFL REGISTER
```

L166 automatically reserves the appropriate on-chip memory and so no special actions are required by the user.

6.4 Setting Up The BUSCONx ADDRSELx Registers

The operation of BUSCON2,3,4 and ADDRSEL2,3,4 on the C165/7 is identical to the BUSCON1 and ADDRSEL1 on the C166. The big difference to the C166 is that there is a chip select pin for each ADDRSEL.   Thus, if an address is accessed in a region covered by an ADDRSELx/BUSCONx pair, the corresponding chip select (CSx) pin goes low to enable the appropriate memory (or other) device. This is a useful way of reducing the glue logic in a C165/7 system.

The most important thing to say about these registers is that you must initialise the ADDRSELx registers before the corresponding BUSCONx. This is to some extent common sense; the BUSCONx contains a BUSACT (bus active) bit which activates the bus characteristics over the preset ADDRSEL range.

Unexpected results can occur if you setup the BUSCONx first for the following reasons:

(i) The C167/5 data book warns that no two ADDRSEL registers must describe an overlapping region. As all the ADDRSELs are set to zero when coming out of RESET, enabling two BUSCONs will cause an overlapping condition.

(ii) The BUSCONx region bus characteristics may differ from those of the background SYSCON. If the BUSCONx is enabled while the ADDRSELx is set to zero, the area currently executing could be changed.

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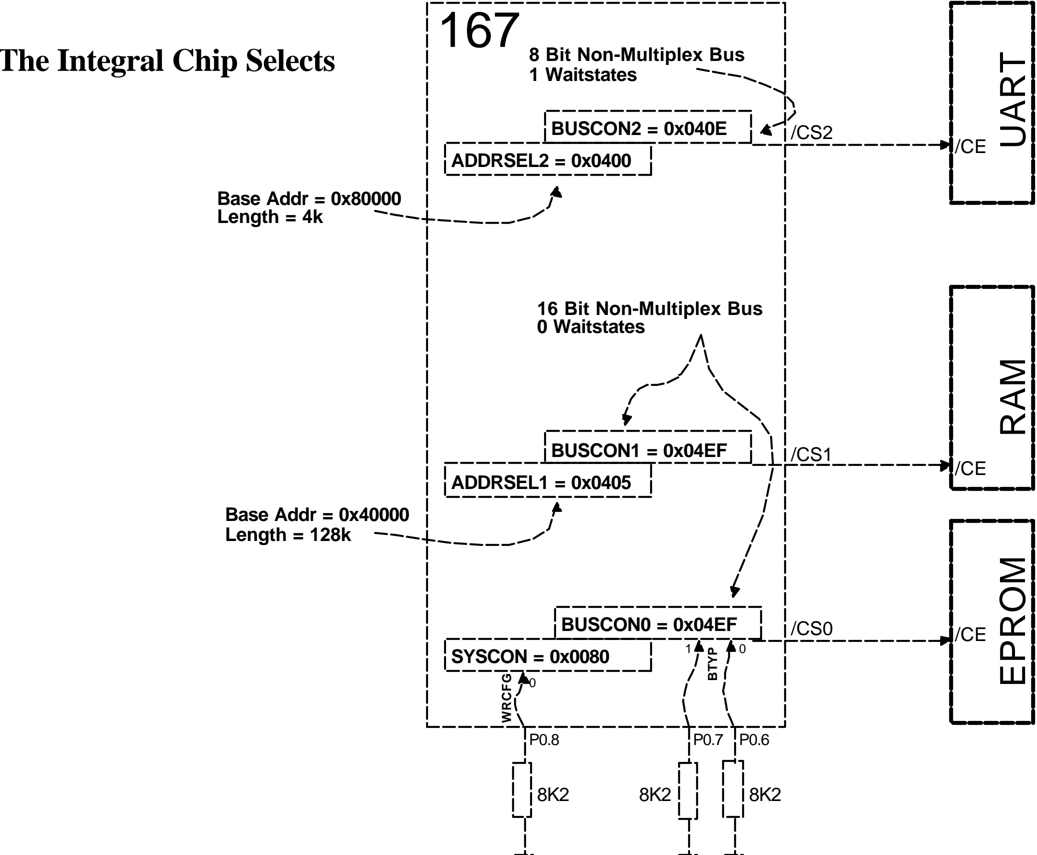
The code to initialise the BUSCONx and ADDRSELx must be placed in the startup.a66 or start167.a66, just after the BFLDH and BFLDL instructions that set up BUSCON0. It is not sensible to put the BUSCONx set up in C as any RAM areas described by a BUSCONx will not enabled and hence be zeroed or otherwise initialised by the C_STARTUP code in STARTUP.A66 or START167.A66.

The Integral Chip Selects



```
?C_RESET   PROC TASK C_STARTUP INTNO RESET = 0
?C_STARTUP:

$IF (WATCHDOG = 0)
           DISWDT                  Disable watchdog timer
$ENDIF

BCON0L          SET     (_MTTC0 << 5) OR (_RWDC0 << 4) OR ((NOT _MCTC0) AND 0FH)
BCON0L          SET  BCON0L AND (NOT (_RDYEN0 << 2))
BCON0L          SET  BCON0L OR (_RWDC0 << 4) OR (_MTTC0 << 5)
BCON0H          SET  (_ALECTL0 << 1) OR (_BUSACT0 << 2) OR (_RDYEN0 << 4)

           BFLDL BUSCON0,#3FH,#BCON0L
           BFLDH BUSCON0,#17H,#BCON0H

; **** Add ADDRSEL and BUSCON setups here! ****

           MOV  ADDRSEL1,#421H
           MOV  ADDRSEL2,#421H

           MOV  BUSCON1,#421H
           MOV  BUSCON2,#421H
SYS_H      SET  (_STKSZ << 5) OR (_ROMS1 << 4) OR (_SGTEN << 3)
SYS_H      SET  SYS_H OR (_ROMEN << 2) OR (_BYTDIS << 1) OR _CLKEN
; Setup SYSCON Register
```

6.5 Special Notes On The Startup Files

START167.OBJ and STARTUP.A66 must be last in the list of object files in the .LIN linker input file! If not, any initialised data will fail to be initialised properly!

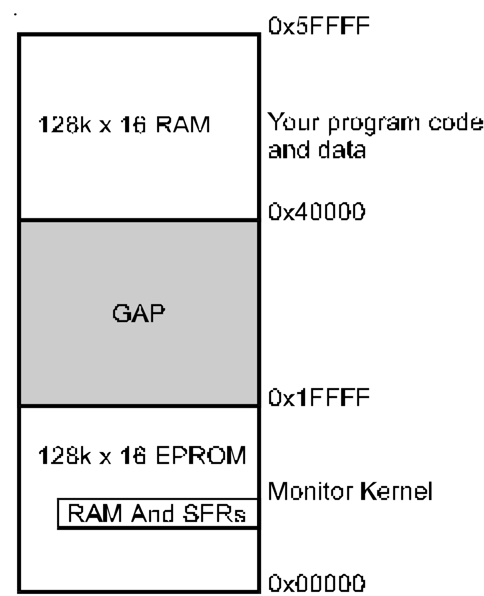
When assembling these files, you must indicate the memory model of the C program with the command line parameter:

```
A166 STARTUP.A66 SET(SMALL)
```

Failure to do so will result in the linker issuing a type-mismatch in the symbol "main" between MAIN.C and START167.A66.

The standard STARTUP.A66 and START167.A66 files are stored in \C166\LIB. If you need to modify them, make a local copy of it in your working directory and add startup.obj or start167.obj to the linker line.

EVA16C Memory Map With *HiTOP*



6.6 EVA16C Board CPU Setup Requirements (via BUSCON0 and chip select 0)

EPROM: 0-0x3FFFF	**START167.A66 CONSTANT**
2 waitstates	_MCTC0 = 2
1 memory tristate time	_MTTC0 = 0
No read/write delay	_RWDC0 = 1
No /READY	_RDYEN0 = 0
Bus type selected externally by pull-down resistors on Port P0L6/7.	_BTYP_ENABLE = 0
No ALE lengthening	_ALECTL0 = 0
Normal operation of /WR and /BHE	WRCFG_ENABLE = 0
	_WRCFG = 0
Stack size 64 words	STK_SIZE = 2
XRAM enabled	_XPEN= 1
Segmentation enabled	_SGTDIS = 0
Watchdog disabled	WATCHDOG = 0
(NB: We are using the HLARGE model)	

RAM: 0x40000-0x5FFFF (via ADDRSEL1/BUSCON1 and chip select 1)

1 waitstate	_MCTC1 = 1
16 bit non-multiplexed bus	_BTYP1 = 2
No /READY	_RDYEN1 = 0
0 memory tristate time	_MTTC1 = 1
Read/write delay enabled	_RWDC1 = 0
No ALE lengthening	_ALECTL1 = 0
Chip select 1 active	_BUSACT1 = 1
	BUSCON1 = 1
Chip select 1 is an address chip select	_CSREN1 = 0
	_CSWEN1 = 0

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EXERCISE 2: EX2

Objective:

Configure the START167.A66 file to suit the EVA16C development board.

Procedure:

The program in EX2\WORK is from the EX0\SOLUTION and will form the basis for this exercise. The "clean" START167.A66 has been copied directly from C:\KEIL\C166\LIB. Your task is to modify it as follows:

(i) The user stack size will need to be reduced from 1000H to 040H bytes.

(ii) The default system stack size needs to be reduced to 64 words.

Extract From START167.A66 - Setting The User And System Stack Size

```
; STKSZ: Maximum System Stack Size selection  (SYSCON.13 .. SYSCON.15)
;  Defines the system stack space which is used by CALL/RET and PUSH/POP
;  instructions.  The system stack space must be adjusted according the
;  actual requirements of the application.
$SET (STK_SIZE = 0)  <---- Edit this
;     System stack sizes:
;       0 = 256 words (Reset Value)
;       1 = 128 words
;       2 =  64 words
;       3 =  32 words
;       4 = 512 words
;       5 = not implemented
;       6 = not implemented
;       7 = no wrapping (entire internal RAM use as STACK, set size with SYSSZ)
; If you have selected 7 for STK_SIZE, you can set the actual system stack size
; with the following SSTSZ statement.
; SSTSZ    EQU  200H ; set System Stack Size to 200H Bytes
; USTSZ: User Stack Size Definition
;  Defines the user stack space available for automatics.  This stack space is
;  accessed by R0.  The user stack space must be adjusted according the actual
;  requirements of the application.
USTSZ EQU  1000H; set User Stack Size to 1000H Bytes.  <---- Edit this
;
```

(iii) The EVA16C memory map has the RAM which holds your program code and data on chip select 1 (CS1#). You will need to set BUSCON1 and ADDRSEL1 to map this chip select and hence the RAM to 0x40000 for a length of 128kb. There are some EQU's in START167.A66 that will help you do this - see page 57:

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Extract From START167.A66

```
; BUSCON1/ADDRSEL1 .. BUSCON4/ADDRSEL4 Initialization
; ====================================================
;
;  BUSCON1/ADDRSEL1
; — Set BUSCON1 = 1 to initialize the BUSCON1/ADDRSEL1 registers
$SET (BUSCON1 = 0)  <---- Edit this
;
; Define the start address and the address range of Chip Select 1 (CS1#)
; This values are used to set the ADDRSEL1 register
%DEFINE (ADDRESS1) (100000H)      ; Set CS1# Start Address (default 100000H) <---- Edit this
%DEFINE (RANGE1)   (1024K)        ; Set CS1# Range (default 1024K = 1MB) <---- Edit this
;
; MCTC1: Memory Cycle Time (BUSCON1.0 .. BUSCON1.3):
; Note: if RDYEN1 == 1 a maximum number of 7 waitstates can be selected
_MCTC1      EQU 1    ; Memory wait states is 1 (MCTC1 field = 0EH). <---- Edit this
;
; RWDC1: Read/Write Signal Delay (BUSCON1.4):
_RWDC1      EQU 0    ; 0 = Delay Time     0.5 States <---- Edit this
```

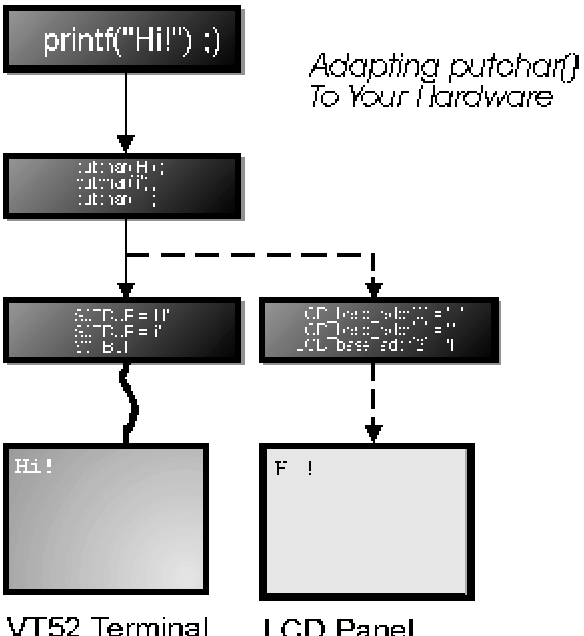
Other modifications required concern the number of waitstates ("memory cycle time"), read-write delay etc.. Set up the START167.A66 to match the EVA167 hardware configuration given in section 6.6.
Further edit START167.A66 to achieve this.

Hint! If you want to know what BUSCON1 and ADDRSEL1 should be, use the "BUSCON" window in HiTOP and enter the configuration and take the values HiTOP calculates...

6.7 Configuring The Runtime Environment

6.7.1 Adapting printf() To Other Output Devices

The printf() on a PC compiler prints to the PC screen. On an C166, there is no such device. To meet the ANSI standard, a full printf() is provided which is directed to serial port 0 on the C166. To allow other output devices such as LCD screens to be driven from printf(), the source code for putchar() is supplied in the libraries directory. It is via the putchar() function that printf() ultimately transfers characters to be transmitted to a real output device. By adapting the supplied putchar(), you can attach printf() to the output device in your system. The only other step to take is to link the new putchar() into the program by placing it in the project file list (see Project-Edit Project in uVISION). A typical application might be to allow floating point numbers to be conveniently written to an LCD panel using printf()'s simple-to-use data formatting features.



Note! We have cheated somewhat as to access the LCD display in exercise 0, a modified putchar() was used!

Example:

A modified putchar() which writes printf()'s output to an LCD display register.

```
char far *LCD_DATA_REG = 0x38000 ;

char putchar(char c) {

   *LCD_DATA_REG = c ;
   return(c) ;
   }
```

If you are puzzled about the pointer to the imaginary LCD, do not worry as we will cover absolute address pointers later on...

6.7.2 Configuring scanf() For Other Devices

In the same way that printf() writes to real devices via putchar(), scanf() derives its input from a function called _getkey(). The standard getkey() expects to get its input from serial port 0 and this is what the default libraries supply. We have supplied a modified getkey() in \166TRAIN.WIN\SOFTUART.

The principles behind adapting scanf() to your hardware are identical to those used for printf() so we will not dwell on them further.

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EXERCISE 3: EX3

Objective:

Direct printf() to LCD panel to print out the value of a seconds counter, created by Timer 7 (T7).

Procedure:

The supplied PUTCHAR.C is the default one from Keil. Any program which calls printf() and which does not have a PUTCHAR.C in the project file list will use a similar PUTCHAR.C that is stored in the ANSI library and is directed to serial port 0.

You must edit this PUTCHAR.C to modify the putchar() function to use the "write_lcd()" and "read_lcd()" to drive the LCD display. We have already removed the contents of putchar() that were directed to the 167's serial port transmit registers, S0TBUF. Remember to add it to the file list in the project otherwise the default putchar() will still be used!

Here are the functions for the LCD that you will need to put into putchar():

(a) When the character 'c' received by putchar() is newline '\n' then move cursor back to home position:

```
write_lcd(0x02,LCD_REG);   // Move print position back to top left corner by writing
                            // 0x02 to LCD data register
```

(b) If the character is not a newline '\n', print character to current cursor position on LCD:

```
write_lcd(c,LCD_DATA);     // Print character to LCD data register
```

(c) In MAIN.C, function main(), use timer T7 to generate a one second interval between printing of the seconds count to the LCD

- Use the C167 data book to work out value that must be written to T78CON register to make timer T7 increment at a rate of 1/512 of the 20MHz CPU oscillator frequency to give an overflow every 1.6777 seconds.

- Use the T7REL register to make the T7IR overflow flag become set once per second. The value to use will be 1/1.6777*65536 . Note that as T7 always counts up, you must negate the result before putting it into T7REL.

- Start T7 by setting the T7R ("timer 7 run") flag.

- The `"while(!T7IR) { ; }"` loop will stop the printf() to the LCD occurring more than once per second.

7. Inter-Module Linkage

Sooner or later you will want to use a procedure or global variable that is defined in another module. This external quantity is made accessible by the "extern" keyword.

Example of Usage

```
extern unsigned char temp;   // A char variable defined in another module
extern void schedule(void);   // A function defined in another module
```

So in a given module, you need to add all the external globals and procedures you are going to use. You then run the linker which will resolve all the external symbols This leaves ample room for some really great errors! There is a better way.

7.1 An Intelligent Include File Method That Will Avoid Many Program Build Errors

The most common error in defining external global is mismatching types. Even though L166 v3.xx will flag a warning if any mismatches occur, it is best to prevent them happening in the first place! With the large number of special keywords in C166, having everything defined only once will make maintenance easier should, for example, a variable need to be moved from sdata to idata.

Module main.h

```
unsigned char temp;
```

Module timer_0.h

```
extern unsigned int temp;
```

You have a 50% chance here of creating a class B hardware trap (word access to odd address) if `temp` ends up an odd address! This sort of problem can be prevented by only defining the object in one include file as follows;

Intelligent Include File

```
File: modulea.h
_________________________________
#ifdef  _MODULEA_

unsigned char far temp = 0;
int test_function(char *)


#else

extern unsigned char far temp;
extern int test_function(char *) ;

#endif
```

Source Modules

File: main.c

```
#define  _MAIN_
#include  <modulea.h>

void main(void {
  ........
  ........
   }
```

File: modulea.c

```
#define  _MODULEA_

#include  <modulea.h>

int test_function(char *s) {
   int x ;

   return(x) ;
   }
```

Any other module that uses modulea.c's globals or functions can then include the modulea.h header file but since the defined module name is different the external versions of the definitions will be visible to the compiler.

Note! This program construction method guarantees that there is only one real definition of each individual data object and one function prototype for each function. Thus many potential typing errors will be instantly eliminated. This approach makes program maintenance and modification very much easier, especially on large systems. As an example, if the typequalifier for a particular global variable has to be changed, only one .h file needs to be edited. uVISION's MAKE will spot which source files include the edited .h file and re-compile them automatically.

Whilst we recommend that you use this program construction method, it is not compulsory!

8. The C166 Data Page-Addressing And Code Segmentation

To go any further, we really ought to examine the way in which the C166 addresses its 256k or 16MB address space. Whilst it is possible to write C166 programs without any detailed knowledge of this, the serious 166 user cannot really avoid getting to know the most important CPU addressing feature, the four data page pointers (DPPs).

8.1 The Data Page Pointers

8.1.1 A Fast Way of Addressing a Large Data Memory Space

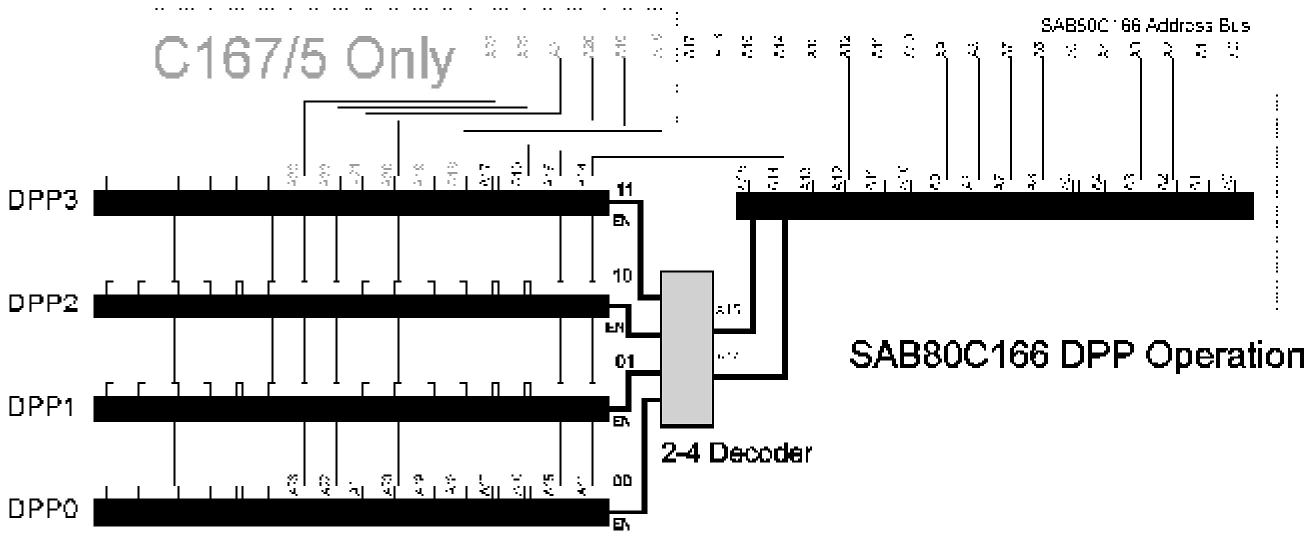
As a word machine, the C166 can deal with 16-bit quantities very efficiently, regardless of whether it involves emitting an address or reading an item of data. In the NONSEGMENTED mode, the CPU only has to work with 16-bit addresses, 64k being the limit of this mode. However, to address the full 256kb or (16mb of the C167 and C165), 18- or 24-bit addresses must be generated.

To keep data and opcode access times in the C166 to a minimum, a segmented or "paged" addressing arrangement is employed. For opcode accesses, 64kb segments are used, similar to the CS: segments familiar to 8086 users. For data accesses in the C166, the memory space is divided into 16kb data segments or pages which are controlled by four Data Page Pointers (DPPs). In contrast to the 8086's ES: SS: and DS: registers, there are 4 DPPs in the C166. These are used in an ingenious way to allow the entire 256k (or 16MB for C165/7) memory space to be addressed.

Summary:

```
i8086                :   SAB80C166
————————————————————————————————————————————————————
CS = Code segment   :    CSP  = Code segment pointer
DS = Data segment   :    DPP0 = Data page pointer 0
SS = Stack segment :    DPP1 = Data page pointer 1
ES = Extra segment :    DPP2 = Data page pointer 2
                    :    DPP3 = Data page pointer 3
```

8.1.2 The DPPs expressed diagrammatically



Put simply, any 18-bit data address is actually formed from a combination of 14-bit address offset with respect to a single Data Page Pointer. The data page pointer effectively drives the top four address lines (A14-A17) in a C166 and the top 12 lines in a C167. This allows a fast generation of the address as the C166 only has to manipulate 14-bit address, even though 18- or 24-bits of memory may be being accessed.

8.1.3 Example Of Using DPPs

Get data from location 0xC001

```
MOV   DPP2,#03   ;  Set DPP2 to page 3 (page base address = 3 * 16k
NOP              ;  Allow change of DPP to take effect
MOV   R0,#08001H ;  Load address into R0
MOVB   R1,[R0]    ;  Use indirect addressing relative to DPP2

Real 18 bit address = DPP2 * Page Size + R0 & 0x3FFF
```

Where Page Size = 16k (0x4000)

This is the basis of all C166 off-chip data addressing. Note that the C167 has alternative modes, based on the EXTS instruction.

8.2 Using The DPPs

With the memory space being addressed via Data Page Pointers with a 16kb range, some strategy is required to allow data at any address in the 16MB range to be accessed. After reset, the DPPs are set to 0,1,2,3 respectively, meaning that no address outside the first 64kb can be addressed. The DPP values can be modified freely by the user to allow higher addresses to be accessed.

The fact that a 16kb range can be addressed without changing a DPP, suggests that one class of data objects could be placed in a fixed 16kb range. By way of an example, take an address range at 0x4000. By setting DPP2 to 0x0001, a 16kb range from 0x4000 to 0x7FFF can now be addressed without changing the DPP2.

To get data from address 0x4010 into R1:

Coming out of reset...

```
MOV   DPP2,#01  ;
```

In program...

```
MOV   R1,DPP2:4010H  ;
```

Any of the 16kb in the range can be addressed without any DPP value being changed. This is obviously a very efficient method of addressing data.

To cover the entire 16MB address range though, requires the DPP value (i.e. the page in which the data lies) to be recalculated before each access. Here’s an example, using DPP0 as the page pointer:

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To get data from address 0x14000 into R1:

```
MOV  DPP0, #PAG(0x14000) ;  Put the page no. of 0x14000 into
                         ;  DPP0 (i.e. find page = 0x14000/0x4000)
MOV  R1,DPP0:0x14000      ;
```

Accessing the on-chip special function registers at 0xff00 is usually done via DPP3: at reset, this DPP is set to 3, meaning that it covers the range of page 3, i.e. 0xc000-0xffff. Data outside the 16kb range covered by DPP0 at anyone time can be accessed by recalculating the value of DPP0 before each access.
Thus far, we have allocated DPP2 to point at 0x4000, DPP3 to 0xC000 and DPP0 to cover all addresses in the memory space. In fact, this is exactly how C166 uses the four DPPs:

Variable data in a 16kb range that is addressed via a fixed DPP2 is termed "near"
Data covered by DPP3 (page 3) is termed "system"
Data accessed via a constantly recalculated DPP0 is termed "far", "huge" or "xhuge" *(166 only)*
Variable data in a 16kb range that is addressed via a fixed DPP2 is termed "near"
Constant data in a 16kb range that is addressed via a fixed DPP1 is also termed "near"

EXERCISE 4: \EX4

Which physical addresses will be accessed in the following examples? You need to be able to understand addresses presented in the following formats to debug C166 code.

Note: MOV reg,reg is a WORD move (16 bits)
MOVB reg,reg is a BYTE move (8 bits)

Assume that the DPPs are set up as follows:

```
DPP0 = 08
DPP1 = 01
DPP2 = 04
DPP3 = 03
```

(i) Assume DPP1 = 01

```
MOV   R1,DPP1:02010H              ADDRESS = ___________________________
```

(ii) Assume R4 = 0x8002 ;

```
MOV   R1,[R4]                     ADDRESS = ___________________________
```

(iii) Assume R4 = 0xFF00

```
MOV   R1,[R4]                     ADDRESS = ___________________________
```

(iv) Assume DPP2 = 0x4

```
MOV  R4,DPP2:00000H               ADDRESS = ___________________________
```

(v) Assume R4 = 0x4202

```
MOV  R1,[R4]                      ADDRESS = ___________________________
```

(vi) Assume R4 = 0x0102,R5 = 0x4

```
EXTS R5,#1
MOV R2, [R4]                      ADDRESS = ___________________________
```

(vii) Assume R5 = 0x0201

```
MOV  R1,[R5]                      ADDRESS = ___________________________
```

Bonus Question:

Why will the access (vii) fail? What will happen?

8.3 Code "Segments"

While data accesses are made via DPPs, opcode fetches are made on the basis of 64k segments. Thus when a CALL or JUMP is made in assembler, if the call is within the current segment then the destination address is simply a 16 bit offset from the current segment base, held in the CSP (code segment pointer) register. If no segment number is given, execution speed is faster. It also means that subroutines (i.e. C functions) must be grouped together in segments, unless they are called using a “segmented” call. (CALLS).

Functions which are outside the current code segment are called with a CALLS and must be terminated with a RETS. Such functions are termed “far” in C166.

Example

Call a function at 0x18000, i.e. 0x8000 offset in code segment 0x01:

```
CALLS  01,08000H ;
```

Functions which are called without giving a destination segment number are termed “near”.

It is how C166 mixes the foregoing classes of data and function types that is the basis of the memory models.

The amount or ROM and RAM in your system, plus the balance between code and data will largely determine which model is the best choice.

Definitions

near functions - functions can only be called from within the same segment

far functions - functions can be called across 64kb segment boundaries

near data - data in a single 16kb range, addressed by a single DPP (DPP2) which never changes.

far data - data anywhere in 256kb (or 16MB) memory space but no single object may be over 16kb.

huge data - data anywhere in the memory space but no single object may be over 64kb in size

xhuge - data anywhere in the memory space of unlimited size.

Type qualifier - Special keyword which when included in a data object definition can influence where it ends up in memory.

8.4 DPP Usage Summary

```
DPP0 - Far/Huge/Xhuge
DPP1 - Near constants
DPP2 - Near data
DPP3 - System RAM/SFRs
```

9. C166 Compiler Memory Models

Choosing which memory model to use in your project is perhaps the first and most decision to make. It is wise to give it careful consideration as changing models halfway through a project can be quite tricky and time consuming. However, if a program still runs correctly after a model change, then it is probably fairly solid, especially as regards its use of pointers.

The term “model” simply refers to how you want C166 to group together data objects and whether it is to use segmented or non-segmented function calls. To understand why different memory models are required, it is essential to understand the underlying structure of the C166 family, covered in the previous section.

However, to choose a model, you can use the following guidelines to help:

Definitions

default memory space - area (near or far) where data declared without type qualifier will end up:

CLASS - physical memory region occupied by data which share the same type qualifier; i.e near, far or huge.

Example:

```
int test_var ;     // Variable will go into near, far or huge space, depending on
                      memory model.

int far test_var ;  //    Variable will go into far data area, regardless of
                          prevailing memory model.
```

TINY:

In this model, the CPU runs in segmented mode (SGTDIS = 0 in SYSCON). This means that all program and data must lie within the first 64K. A16 and A17 are inactive and can be used as simple IO pins. The DPP registers stay at their reset values of:

```
DPP0 = 0
DPP1 = 1
DPP2 = 2
DPP3 = 3
```

All function calls must be within the same segment i.e. near. The TINY model is rarely used, being reserved for true single-chip FLASH 166 designs which cannot exceed 32KB in size.

SMALL:

The CPU runs in segmented mode so that A16 and A17 are active. All function calls are within segment “near” and all data defaults to “near” and thus is within a 16kb range. Code size is effectively limited to 64kb and data limited to 16kb variables and 16kb constants. However, by using the far and huge keywords in data declarations, overall data size can be expanded to any size.

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MEDIUM:
The CPU runs in segmented mode so that address lines above A15 are active. All function calls are now “far” and all data is within a 16kb range and defaults to “near”. Code size is unlimited and data limited to 16kb variables and 16kb constants. However, by using the far and huge keywords in data declarations, overall data size can be expanded to any size. This is perhaps the most useful model as it gives no restriction on code sizes but data still defaults to fast “near” addressing.

COMPACT:
This is the reverse of MEDIUM as data defaults to “far” and functions default to near. This is useful for programs with small amounts of code but large data.

LARGE:
This model treats all function calls as “far” and data objects likewise. It suits large applications and is perhaps the safest choice if the final program characteristics are not easily estimated.

HLARGE:
Only available with MOD167. It is the same as LARGE but the default for variable declarations is huge. In C166 v3.xx, huge addressing is handled more efficiently than far and so this model is to be preferred to LARGE in C167 applications.

HCOMPACT:
Only with MOD167. It is the same as COMPACT but the default for variable declarations is huge. In C166 v3.xx, huge addressing is handled more efficiently than far and so this model is to be preferred to COMPACT.

Note: *For C167 applications with large amounts of data, the HLARGE model combined with the HOLD control to force small objects (char, int, short, long) into the NEAR or IDATA areas gives the easiest development route. This is particularly true of programs ported from 16-bit PC compilers as the characteristcs of the default huge pointer type are identical.*

9.1 Summary Of C166 Type Qualifiers That Determine Placement Of Data

9.1.1 Default Data Object Placement Overriding

The chosen memory model determines the location of data objects. However, in many cases, it is useful to override this default placement. An example in a SMALL model program might be to put a large array into the huge data area so that all the fast near data area is not used up. The “huge” type qualifier is used to acheive this. The syntax for using type qualifiers is:

```
<type> <typequalifier> <objectname> = <initialisation value>
```

Example

```
int huge example_var = 0 ;
```

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9.1.2 C166's Type Qualifiers Summary

(i) near

Purpose: Allow data to be forced into reasonably fast access area.
Overall size of all near data: 16kb
Largest single object: 16kb
CLASS name: NDATA, NDATA0

Example 1

```
int near near_var = 0 ;
```

(ii) far

Purpose: Allow a large number of small arrays to be grouped together. This keyword is best replaced by huge on the C167 as far is less efficient for handling arrays and other large objects.

Overall size of all far data: 16MB
Largest single object: 16kb
CLASS name: FDATA, FDATA0

Example 2

```
int far big_array[0x2000] ;
```

(iii) huge

Purpose: Allow use of large data objects

Overall size of all huge data: 16MB
Largest single object: 64kb
CLASS name: HDATA, HDATA0

Example 3

```
int huge very_big_array[0x8000] ;
```

(iv) xhuge

Purpose: Allow very large data objects to be utilised

Overall size of all xhuge data: 16MB
Largest single object: 16MB
CLASS name: XDATA, XDATA0

Example 4

```
int xhuge humongous array[0x40000] ;
```

(v) idata

Purpose: Force data into on-chip RAM. This RAM is always addressed at full speed, regardless of the external bus type or wait-states etc..

Overall size of all idata objects: determined by CPU type
Largest single object: 16kb but not realisable in practice
CLASS name: IDATA, IDATA0

Example 5

```
int idata fast_data = 0 ;
```

(vi) bdata

Purpose: Combined word and bit-addressable data. Can be used in conjunction with sbit control to allow bit addressing of individual bits in an int.

Overall size of all bdata objects: 256b
Largest single object: 256b
CLASS name: BDATA, BDATA0

Example 6

```
int bdata bit_flag_word = 0 ;
```

(vii) sdata

Purpose: Force data into the area between 0xc000 and 0xffff, to be addressed via DPP3 which is always set to page 3. Useful for addressing PEC pointers and memory-mapped IO at 0xc000. On the C167CD/SR, sdata objects can be used to fill the XRAM area.

Overall size of all sdata objects: 0x3000 approx.
Largest single object: 0x3000 approx.
CLASS name: SDATA, SDATA0

Example 7

```
int sdata fast_data = 0 ;
```

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9.2 Controlling Constant Data

To date, we have really only talked about variable data that will end up in RAM. Of course, in any embedded system, substantial amounts of constant data will be required. This can range from look-up tables to character strings used in printf ("Hello") statements. Naturally, constant data should be placed into ROM in a true embedded system.

Constant data can be near, far and huge like variables and the memory model controls which is used in the same way. Thus a SMALL model program will have all its constant data placed into a near constant area and a LARGE program have it in a far constant area.

As with variables, it is possible to override the default placement of constants:

Example 1

```
#pragma LARGE

int near const constant_data = 0x20 ;   // Put this in the NCONST class
```

Example 2

```
#pragma SMALL

int const far constant_array[] = { 0x20,0x20,0x34,0x89... } ;   // Put this in FCONST class
```

Example 3

```
#pragma SMALL

int const far constant_array[] = { 0x20,0x20,0x34,0x89... } ;   // Put this in FCONST class
```

The most common use of const is to define constant strings and look-up tables. Note that any string in a printf("string") statement will end up in the near (NCONST) or far (FCONST) area, depending on the memory model.

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EXERCISE 5: EX5

Objective:

(i) Illustrate how constant data in C166 behaves differently to that on PC and other C platforms.
(ii) Special points to note when overriding default data placement with far keyword and using strcpy() and other library functions.

Procedure:

Open the project in \166TRAIN.WIN\EX5\WORK and edit MAIN.C. Create a global pointer called "*const_ptr" and make it point to a constant string, "message[]". Use the "far" keyword to make this a far string, overruling the default for the SMALL model being used. Create a buffer in RAM called message_buffer[].

```
char const message[] = { "\nHello World" } ;  // A string in EPROM
char const * const_ptr = &message[0] ;         // A pointer that points to the string

char message_buffer[0x20] ;
```

Use the strcpy() library function to copy the string into the RAM buffer and then printf() it via the putchar() modified to output to the LCD, as in exercise EX3.

```
strcpy(message_buffer, const_ptr) ;   // Get message
printf("%s",message_buffer) ;          // Transmit message
```

Consider especially how you will get the *const_ptr itself into EPROM as this requires an obscure aspect of C! Do not ignore any warnings emitted by the compiler as they usually indicate trouble.

9.3 Setting Up The DPPs

The user does not have to take any steps to set up the DPP registers as they are taken care of during the startup phase in STARTUP.A66 or START167.A66

START167.A66 Extract

```
EXTRN?C_PAGEDPP1 : DATA16
EXTRN?C_PAGEDPP2 : DATA16

MOV  DPP1,#?C_PAGEDPP1         ; NEAR CONST PAGE
MOV  DPP2,#?C_PAGEDPP2         ; NEAR DATA  PAGE
```

Here is how they are allocated:

DPP0 is left at its reset value (0) as it is always recalculated before use.
DPP1 is set to the base address of the near constant area (NCONST class)
DPP2 is set to the base address of the near data area (NDATA0 class)
DPP3 is set to the base address of the system or “sdata” area (SDATA class)

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9.3.1 Special Allocation Of DPP's To Create Customised Memory Models

The standard allocation of DPP1 to NCONST, DPP2 to NDATA can be overridden by the DPPUSE control in L166 v2.54 or later. Applications for this might be to create a NCONST area of above 16kb for large look-up tables, destined for EPROM etc. This can be acheived by the reallocation of DPP0: In the C167 and C165, DPP0 is not used for far/huge/xhuge data accesses as the EXTx instructions are to be preferred. Thus DPP0 could be combined with DPP1 to give a 32k linearly addressible region, here from 0x38000 to 0x3ffff.

```
DPP0 = 0x0E   => address 0x38000 - 0x3bfff (NCONST)
DPP1 = 0x0F   => address 0x3c000 - 0x3ffff (NCONST)

DPP2 = 0x04    => NDATA at 0x10000-0x13fff
DPP3 = 0x03   => SDATA at 0xc000-0xffff
```

L166 Input File For 32kb NCONST:

```
main.obj,
start167.obj
to exec
DPPUSE(0=NCONST(0x38000-0x3ffff),2=NDATA(0x10000))
```

Taken to extremes, in the C167 with its 4k on-chip RAM, the NDATA and SDATA areas could be combined, starting from 0xf000, leaving DPP0-2 available to create a 48k linear NCONST area.

```
DPP0 = 0x0E    => address 0x34000 - 0x37fff (NCONST)
DPP1 = 0x0F    => address 0x38000 - 0x3bfff (NCONST)
DPP2 = 0x04    => address 0x3c000 - 0x3ffff (NCONST)

DPP3 = 0x03    => SDATA at 0xc000 - 0xffff
```

L166 Input File For 48kb NCONST:

```
main.obj,
start167.obj
to exec
DPPUSE(0=NCONST(0x34000-0x3ffff),3=NDATA(0x10000))
```

DPPUSE() Syntax:

```
DPPUSE(<dppnr>=<groupname>(range),  <dppnr>=<groupname>(range))
```

<dppnr> is the number of a DPP register (0 for DPP0, 1 for DPP1, 2 for DPP2, 3 for DPP3).

<groupname> is the name NDATA for the NEAR DATA group or NCONST for the NEAR CONST group.

<range> is the address range where the group should be placed.

Examples:

```
DPPUSE(0=NDATA (18000H-23FFFH), 3=NCONST (0C000H-0EFFFH))
```

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In this example you are using DPP0, DPP1, and DPP2 for accessing the NDATA group. DPP0 is loaded with the value 6 pointing to address 18000H. DPP1 is loaded with the value 7 pointing to the address 1C000H. DPP2 is loaded with the value 8 pointing to address 20000H. With these DPP values, the address range 18000H - 23FFFH may be accessed with short (16-bit) addresses rather than using a far or huge addressing. For the NCONST group, the DPP3 register is used. For efficent access to 166/167 SFR registers of the 166/167 this register must be loaded with 3. This accesses in the range 0C000H - 0FFFFH.

```
DPPUSE (1=NDATA (18000H-1BFFFH), 2=NCONST (8000H-0EFFFH))
```

In this example the register DPP1 is used to access the NDATA addresses. The register DPP1 is therefore loaded with the value 6 for the address range 18000H - 1BFFFH. The DPP2 and DPP3 registers are used for accessing NCONST addresses. DPP2 is loaded with the value 2 pointing to address 08000H. DPP3 is loaded with the value 3 pointing to address 0C000H. This allows the address range 8000H - 0EFFFH to be used for NCONST objects.

Notes:
(i) The L166 generates a proper initilization for all DPP registers. The DPP registers are assigned in ascending order to the named groups. L166 always assigns for an address range several DPP registers if the range does not fit within one 16KB PAGE.

(ii) The DPP3 register must always contain the value 3. Whenever the DPP3 register is used for the NDATA or NCONST group, the address range must fit into PAGE 3 of the 166 address space (address range 0C000H - 0FFFFH).

(iii) An address range for NDATA and NCONST must always be stated. It is not possible to re-assign just one group.

(iv) The DPPUSE control also ensures that correct CLASS definitions for NDATA and NCONST are generated and eliminates the need for the CLASSES statement to include NCONST and NDATA.

9.3.2 Special Memory Maps Possible With C166 v3.00

The size of the near and near const areas permitted by the default C166 memory models can be modified by the use of the DPPUSE() control in the L166 linker. C167/5 users have a greater degree of flexibility in this respect as DPP0 is not used for far/huge/xhuge accesses. Perhaps the commonest use for this feature is to increase the size of the fast-access near (NDATA class) area. In many applications, 16kb is not large enough and so DPP1 can be reallocated to NDATA, alongside the default DPP2 to create a 32k NDATA - DPP0 can then be assigned to NCONST to give a default 16k region.

EXERCISE 5A: \EX5A

The \EX5\WORK\ directory contains the files "MOD0.C" and "MOD1.C" which generate about 30k of near constant data. The file MAIN.C holds some simple statements which access this data. Use the DPPUSE() control to produce a linker input file, "EXEC.LIN" which will locate the program to make a 32k near constant (NCONST) area which can run on the **EVA167CR**. Use ***HiTOP*** to verify that DPP0 and DPP1 have consequetive values to give a 32k linear area.

9.4 Automatic Placement Of Data

The HOLD Directive

By using the individual type qualifiers, the default memory spaces for data can be overridden. C166 can provide some help with this task via the HOLD() directive. One of the advantages of the COMPACT and LARGE models is that code can be added without regard to which segment functions are in as all calls are far. The downside is that all data is far and hence slower to access.

The HOLD directive allows the user to tell C166 to put all objects of less than a stated size into a particular memory space.

Example:

In a LARGE model program, all the chars, ints and longs are to be placed into the faster near data class. This will leave all large objects like structures, arrays etc. in the far data area.

```
#pragma LARGE

#pragma HOLD(near,4)   //  Put all objects of 4 bytes in length or under into the
                           near data class.
```

9.5 CLASSES And SECTIONS

Classes are groups of like data objects. All the near data objects from all modules (source files) in an entire program are collected together into a single block and given a CLASS name like "NDATA". This name is handle by which the user may control the address at which the data objects will be placed by the linker.

9.5.1 How Type Qualifiers Relate To Class Names In C166

near objects

NDATA - near data which is not initialised by C166's startup phase
NDATA0 - near data which is zeroed out by C166's startup phase

far objects

FDATA - far data which is not initialised by C166's startup phase
FDATA0 - far data which is zeroed out by C166's startup phase

huge objects

HDATA - huge data which is not initialised by C166's startup phase
HDATA0 - huge data which is zeroed out by C166's startup phase

xhuge objects

XDATA - xhuge data which is not initialised by C166's startup phase

XDATA0 - xhuge data which is zeroed out by C166's startup phase

idata objects

IDATA - idata data which is not initialised by C166's startup phase
IDATA0 - idata data which is zeroed out by C166's startup phase

bdata objects

BDATA - bdata data which is not initialised by C166's startup phase
BDATA0 - bdata data which is zeroed out by C166's startup phase

9.6 The Difference Between NDATA0 And NDATA

9.6.1 The NOINIT #pragma

As may be gathered, C166 will create two varieties of each data class; NDATA and NDATA0 plus FDATA and FDATA0 etc. These should always be placed by the user at the same addresses as the basic NDATA and FDATA classes. The reason for the distinction is that the "0" suffixed classes are cleared to zero and initialised by STARTUP.A66 before main() is reached. The CLRMEM constant in START167.A66 determines whether this clearing occurs or not.

START167.A66 Extract

```
; The following code is necessary to set RAM variables to 0 at start-up
; (RESET) of the C application program.
;

$IF (CLR_MEMORY = 1)

           EXTRN?C_CLRMEMSECSTART : WORD
Clr_Memory:
```

The initialisation consists of either clearing to zero or the writing of start values given in a variable's declaration, i.e.:

```
int far xvar = 0x02 ;
```

Objects destined for the FDATA and NDATA classes are those declared whilst a #pragma NOINIT control is in force. This is usually done where the data is held in non-volatile memory from the last time the program was run.

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For example:

```
MODULE = MAIN

int far var ;           // Zeroed before main()
int far var1 = 2 ;       // '2' written into variable before main()

#pragma NOINIT   // Inhibit zeroing/initialisation

int far nonvolvar ;      // Not zeroed before main

#pragma INIT  // Restore zeroing/initialisation

int ordinary_var ;
```

SECTIONS and CLASSES Produced As A Result Of This

(i) nonvolvar ends up in SECTION ?FD?MAIN%FDATA
(ii) var and var1 end up in SECTION ?FD0?MAIN%FDATA0

The precise address at which the classes are located is determined by the CLASSES and SECTIONS controls in L166. We will cover this in detail in the next sections.

9.7 Modules And SECTIONs - Placing Things At Absolute Addresses

SECTIONs allow the data from individual modules (source files) to be placed by the linker. Thus the near constant data (NCONST class) from a certain module can be precisely placed at a user-defined address. This is useful for placing a look-up table in a FLASH EPROM, remote from the main program EPROM.

Consider the following example:

A far integer is declared in a module MAIN.C:

```
int far testvar;
```

This causes C166 to create a "SECTION" called ?FD0?MAIN%FDATA0. As may be gathered, the section name is constructed as per:

```
?<classshortname>?>module name>%<classname>.
```

The <classshortname> is an abbreviation for the full class names as per:

Class Name	Short Name At File/Module Level
NDATA0	ND0
FDATA0	FD0
NDATA	ND
NCODE	PR
FCODE	PR
NCONST	NC
FCONST	FC

And so on...

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Note that the section names generated for the executable code is always “PR”. The conversion to NCODE and FCODE is made by the linker, depending on which memory model is current.

Example

A "huge" integer is declared in a module MODA.C:

```
int huge testvar1 ;
```

The resulting section is ?HD0?MODA%HDATA0. To fix the program's classes at the correct addresses, the CLASSES control is used when running L166:

For example:

EXEC.LIN Linker Input File (non-uVision):

```
main.obj,&
moda.obj &
to exec &
CLASSES(HDATA(0x8000),
        HDATA0(0x8000))
```

This fixes the huge data (HDATA & HDATA0) classes at 0x8000. A further level of control over placement is possible using the SECTIONS() command. This allows the addresses of a particular module’s own data and code classes to be fixed within the host classes range.

For example:

```
main.obj,&
moda.obj &
to exec &
CLASSES(HDATA(0x8000),
         HDATA0(0x8000)) &
SECTIONS(?HD0?MODA%HDATA0(0xA000))
```

Note: The "host class" here is HDATA

This puts the huge data class at 0x8000 but puts the huge data objects from module MAIN.C at 0xA000. L166 will then arrange huge data objects from other modules automatically so as to leave 0xA000 free.

On the C167/5 with their 16MB address space, it often desirable to split HDATA and FCODE classes across several ranges. This might be required if you have for example, two ROM devices at different addresses. Commonly, this might be a 32k boot EPROM at 0x0000 and a 128k application FLASH EPROM at 0x40000. The CLASSES control can be used to allow the linker to fill both regions thus:

```
main.obj,&
moda.obj &
to exec.abs &
CLASSES(FCODE(0-0x7fff,0x40000-0x5ffff),
         HDATA(0x8000),
         HDATA0(0x8000)) &
SECTIONS(?HD0?MODA%HDATA0(0xA000))
```

In the same way, HDATA can also be split. Be aware though that splitting the near code (NCODE) can be risky and you must make sure that you do not try to split it across a 64k segment boundary. As near function calls have no built-segment number, your program will crash!

9.7.1 Special Note On Windows95 and NT4

Windows95 and NT4 allow file names that can be more than 8 characters long and contain spaces. As C166 uses the module (i.e. filename) to form the SECTION name, you must not use these types of filename! Please stick to using MS-DOS compatible filenames at all times.

9.8 Coping With The Special Sections "?C_CLRMEMSEC" And "?C_INITSEC".

These are special sections created by C166 to hold the initial values of RAM variables. When you declare a variable int x = 0x80, the 0x80 is actually placed in ROM-based look up table. During the startup.a66, this ROM data is transferred to its final resting place in RAM. Left to its own devices, L166 will place these near the bottom of memory, on the assumption that this must be EPROM. On systems where the program is at, for example, 0x40000, as might happen on an EVA167/5, it is up to the user to put these into the correct area.

This is simply achieved by using the sections control in L166. They are best kept together; the only point to watch is that the size of the two sections will vary according to how much initialised data there is in your program. Thus, it is quite possible that they will grow such that they will overlap. The linker will issue a warning to which you must respond. If you ignore the warning, you may find some initialised data fails to be set up properly before you reach main().

Example:

```
main.obj
start167.obj
to exec
VECTAB(0x40000)
CLASSES(NCODE(0x40400),NCONST(0x40400),NDATA(0x48000))
SECTIONS(?C_CLRMEMSEC(0x42400),?C_INITSEC)
REGFILE(exec.reg)
```

Alternativly the new CINTTAB control can be used.
Example:

```
main.obj,
start167.obj
to exec
VECTAB(0x40000)
CLASSES(NCODE(0x42000),NCONST(0x44000),NDATA(0x50000))
CINITTAB(0x42400)
```

9.9 Placing Real Data At Fixed Addresses

Example Of Using The SECTIONS() Control

A common situation where the sections control can be used is when a structure or array needs to be placed at a particular address. For example, a structure describing the registers in a memory-mapped real time clock at 0x5ff00 can be placed over the appropriate addresses by the following method:

(i) Declare structure in a special module RTCdef.c which contains nothing else:

```
#pragma NOINIT

struct time { int hours ;
               int minutes ;
              int second ; } ;

struct time far RTC ;
```

(ii) Use the sections command to fix structure over real time clock when linking.

EXEC.LIN Linker Input File

```
RESERVE(0x04-0x1FF)
VECTAB(0x40000)
SECTIONS(?FD?RTCDEF%FDATA(0x5ff00))
```

The RTC structure will now be at address 0x5FF00, the base address of the real time clock chip. Note that any section that is to follow ?FD?RTCDEF in memory is simply appended after a comma.

The SECTIONs control will allow far, huge and xhuge sections to be located outside the range of any CLASSES control for FDATA, HDATA and XDATA as these types of data have no restriction on where they are located. Sections from IDATA, SDATA, NDATA, NCONST and BDATA cannot be located outside the class range, and a L166 linker error will result.

Note: The sections control can also be thus:

```
SECTIONS(S1(0x40000),S2,S3,S4,S6(0x50000),S7,S8)
```

Where S1, S2, S3 etc. are section names in ascending address order.

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How to work out the SECTION name...

Filename: MODA.C

Variable Name	`unsigned short huge hvar1 ;`
Section Name	?HD0?MODA%HDATA0

Abbreviated Class Name: **HD0** Filename: **MODA** Class Name: **HDATA0**

To give a section name of:

?abbreviated class name?FILENAME%CLASSNAME

EXERCISE6: EX6

Objective:

Use the L166 linker's SECTION() control to place a structure representing the data registers in an imaginary real time clock chip at 0x5FF00 so that the physical registers are aligned with the C variables of the same name. Thus the structure element "seconds" will have the same address as the seconds register in the real time clock. In addition, the real time clock chip has 128 bytes of RAM, offset by 128 from the base address of the time registers.

RTC Device Memory Map

0x00 - 0x1F: RTC time and control registers
0x80 - 0xFF: Non-volatile RAM area

Note the entire clock is offset to 0x5FF00.
As the data in the clock's registers and RAM must not be cleared at power-up, the data initialisation must be inhibited.

Procedure:

(i) The "intelligent include file" method has been used to construct the example. Edit NONVOL.H to add a structure with the correct attribute (idata, huge, far etc.) to allow it to be accessed, even though it is not near the normal program data in the `near` area.

(ii) In addition, use the #pragma NOINIT control in NONVOL.H to prevent C166 from zeroing the stored time data after reset. In RAM.H, use this control to make sure that the non-volatile variables are also preserved.

(iii) Edit the L166 tab to add the new SECTIONs produced by NONVOL.C and RAM.C to the "User Sections" box. Note: you cannot have more than one SECTIONS() in the linker file. The SECTION containing the time registers needs to be located at 0x5FF00 and that holding the RAM variables at 0x5FF80. Remember that the sections control can be thus:

```
SECTIONS(S1(0x40000),S2,S3,S4,S6(0x50000),S7(0x60000),S8)
```

Where S1, S2, S3 etc. are section names in ascending address order....

There is no need to edit MAIN.C as this is complete.

(iv) Once the program has been built, load it into ***HiTOP*** and go until main().
(v) Use the Examine function to confirm that the structure is at 0x5FF00.
(vi) Now run the program by clicking the green traffic light button
(vii) Press the RESET on the EVA167 board and then click the SR (Setup-System reset) toolbar button in ***HiTOP*** to re-establish communication with the monitor.
(viii) Reload the program, run until main() and check that the data you put in the structure is still there...

9.10 Using The RENAMECLASS Control

An alternative approach is to use the RENAMECLASS control to produce a special class which converts FDATA0 to a new class name such as RTC_ADDR. The new class is located at the required address by the adding it to the existing CLASSES control.

Example:

(i) Declare structure in a special module RTCdef.c which contains nothing else:

```
#pragma RENAMECLASS(FDATA=RTC_ADDR)  // Give subsequent FDATA objects a new class name
#pragma NOINIT

struct time { int hours ;
              int minutes ;
              int second ; } far RTC ;
```

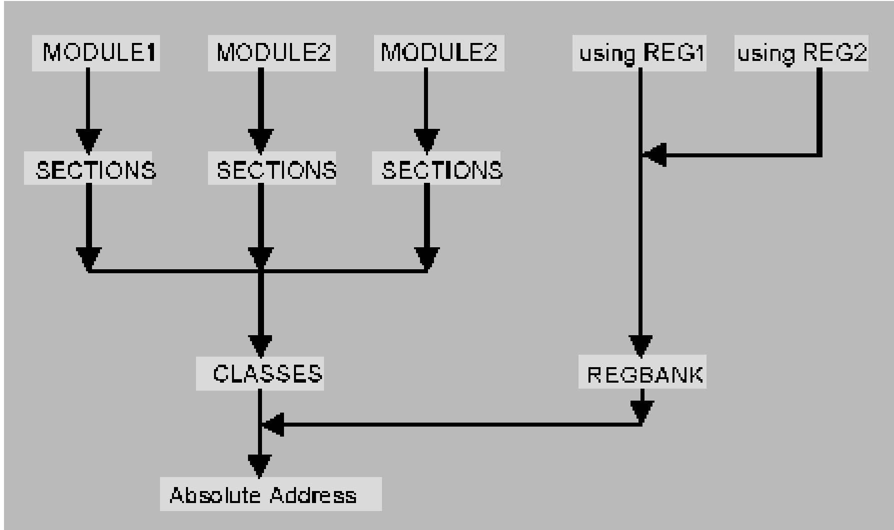
Note: ***(i) The memory model must be stated before the RENAMECLASS pragma.***
(ii) As the data class is not to be cleared during initialisation, the class name is FDATA not FDATA0.

(ii) Use the CLASSES command to fix structure over the real time clock when linking.
EXEC.LIN Linker Input File

```
VECTAB(0x40000)
CLASSES(RTC_ADDR(0x5ff00))
```

The RENAMECLASS approach is better for those instances where a number of modules will each be defining data objects that must all be collected together and placed in a non-volatile RAM, for example.

9.11 Summary Of Placing Objects At Fixed Addresses With The Linker:



EXERCISE 7: EX7

Objective:

Modify the previous exercise to make use of the "#pragma RENAMECLASS" approach.

0x00 - 0x1F: RTC time and control registers
0x80 - 0xFF: Non-volatile RAM area

As the data in the clock's registers and RAM must not be cleared at power-up, the data initialisation must be inhibited. The address of the clock is 0x5FF00 and the RAM area 0x5FF80.

Procedure:

The program is very similar to EX6. However, in NONVOL.H and RAM.H , you will need to add the RENAMECLASS control to create the new classes called "RTC_ADDR" and "NONVOLRAM" respectively. Edit the EX7.LIN to add the new class names to the existing CLASSES() control.

There is no need to edit MAIN.C as this is complete.

1. Once the program has been built, load it into ***HiTOP*** and go until main().
2. Use the Examine function to confirm that the structure is at 0x5FF00.
3. Now run the program by clicking the green traffic light button
4. Press the RESET button on the EVA167 board and then click the SR (Setup-System reset) toolbar button in ***HiTOP*** to re-establish communication with the monitor.
5. Reload the program, run until main() and check that the data you put in the structure is still there...

9.12 The ORDER Pragma

In the case where data is being declared which will exist in a non-volatile memory or a memory-mapped IO device, it is useful if the position of the particular data item is located in the same place as it appears in the C source file, i.e. the order in memory matches the order in the source file.

Example

Module TUNE0.C

```
#pragma  ORDER
int const near pressure_sensor_gain = 0x1101 ;
int const near pressure_sensor_offset = 0x7123 ;
int const near pressure_sensor_temp_coeff_offset = 0x4280 ;
```

Linker Input File

```
.
.
.
SECTIONS(?NC?TUNE0%NCONST(0x100000))  // Base constants at 0x100000
```

In EPROM Memory:

```
Address             Significance
_____________________________________________
0x100000  -  pressure_sensor_gain
0x100002  -  pressure_sensor_offset
0x100004  -  pressure_sensor_temp_coeff_offset
```

9.13 The ASSIGN Linker Control

Where the previously described methods of fixing data objects at defined addresses are not suitable, it is possible to assign an absolute address to a public symbol using the ASSIGN control. This generates a typeless public symbol which can be used by C166.

Example

```
ASSIGN(pressure_sensor_gain(0x100000))    // Generate a symbol at 0x100000
```

9.14 The #pragma pack(1) Control

The basic word-orientated structure of the 166 means that word (unsigned short) elements will always be on a word boundary. However, if the 166 is communicating with, for example, a 486 PC's ISA bus through dual-port RAM, any C structures could be byte aligned. Thus, a word element could start at an odd address, as is possible in x86 processors. The pack(1) directive forces the compiler to place word elements at such an address. It is important to be aware that the compiler will generate considerably more code when accessing structures when this control is in effect and so it should only be used on those structures that really need it!

Example:

```
#pragma pack(1)   /* alignment is BYTE for the following structures */

struct s1  {
  int  i1;     // i1 has offset 0
  char c1;     // c1 has offset 2
  int  i2;     // i2 has offset 3
  char c2;     // c2 has offset 5
  int  i3;     // i3 has offset 6
  char z1;     // z1 has offset 8
};

#pragma pack()    /* reset to default: WORD alignment */

struct s2  {
  int  i1;     // i1 has offset 0
  char c1;     // c1 has offset 2
  int  i2;     // i2 has offset 4
  char c2;     // c2 has offset 6
  int  i3;     // i3 has offset 8
  char z1;     // z1 has offset 10
};
```

Note: If the application contains struct pointers to byte-aligned structures created with `#pragma pack(1)`, you must also use the `#pragma BYTEALIGN` directive.

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Example:

```
#pragma pack(1)   /* alignment is BYTE for the following structures */
#pragma  BYTEALIGN

struct s1  {
  int  i1;      // i1 has offset 0
  char c1;      // c1 has offset 2
  struct s2  {
    int  i2;      // i2 has offset 3
    char c2;      // c2 has offset 5
    int  i3;      // i3 has offset 6
  } s2;
  char z1;      // z1 has offset 8
} s1;


struct s2 *s2p;

void main (void)  {
  s2p = &s1.s2;    // this is a pointer to a bytealign struct
  s2p->i2 = 0;     // this is an access to a bytealign int
}
```

9.15 Using "SECTIONS" With The C167CR CAN Peripheral

The CAN peripheral at 0xEF00 can be addressed via C variables situated over the real control and data registers. This can be acheived with the following souce file, used in conjunction with the given linker input file. As already explained, the advantage of this approach is that unlike the pointer-based method used later, L166 physically places these data objects at 0xEF00, so preventing anything else accidentally end up there and causing problems. CAN_REGS.C and CAN_REGS.H can be found in the \166TRAIN.WIN\USEFUL directory, in case you need them later.

How It Works

The ORDER control tells C166 and L166 to place the objects in memory in the order in which they appear in the source file. The NOINIT control stops START167.A66 from zeroing out the CAN peripheral, which could have undesirable side effects! Finally, the RENAMECLASS control allows the sdata keyword to produce a CLASS with a distinctive name that L166 can place at the appropriate address.

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CAN_REGS.C

```
#pragma ORDER
#pragma NOINIT
#pragma RENAMECLASS(SDATA = CAN_REGS)

#define CAN_REGS_C

#include "can_regs.h"

unsigned short volatile sdata CAN_Control_Status;
unsigned char sdata CAN_Interrupt;
static unsigned char sdata reserved;
unsigned short sdata CAN_Bit_Timing;
unsigned short sdata CAN_Global_Mask;
unsigned short sdata CAN_Upper_Global_Mask;
unsigned short sdata CAN_Lower_Global_Mask;
unsigned short sdata CAN_Upper_Last_Mask;
unsigned short sdata CAN_Lower_Last_Mask;
struct MESSAGE_OBJECT sdata CAN_Object[15];
```

CAN_REGS.H

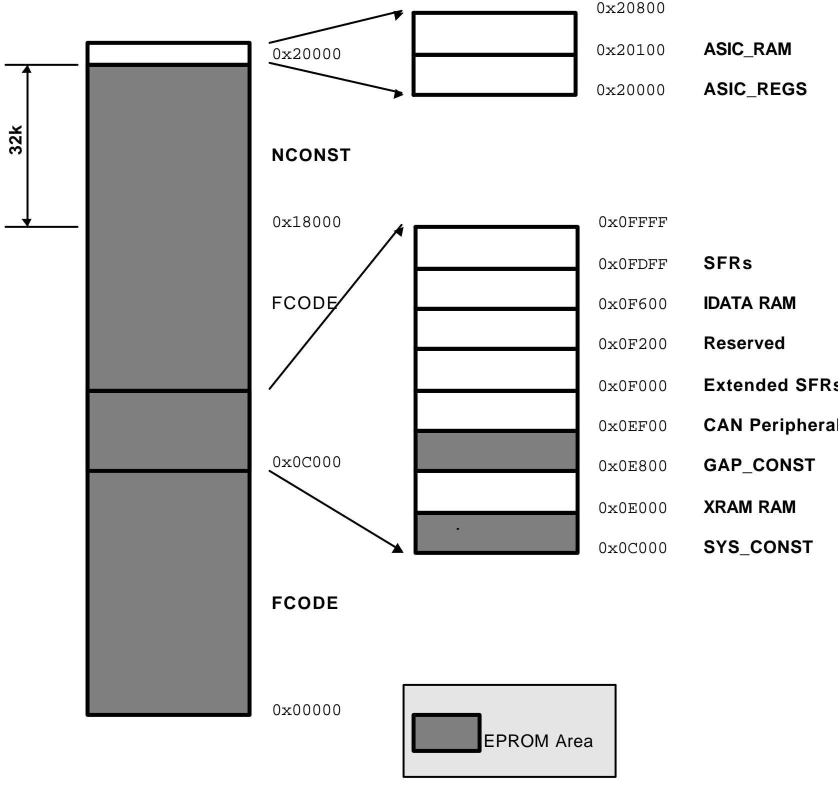
```
struct MESSAGE_OBJECT { unsigned short volatile control;
                          unsigned short upper_arb;
                          unsigned short lower_arb;
                          unsigned char config;
                           unsigned char volatile data[8
```

EXEC.LIN Linker File

```
CLASSES(ICODE(0x200),
         NCODE(0x1000),
         NCONST(0x2000),
              SDATA(0xE000),
              SDATA0(0xE000),
              NDATA(0x40000),
              NDATA0(0x40000))
SECTIONS(?SD?CAN_REGS%CAN_REGS(0xEF00))
```

9.16 Constructing A Memory Map For Small C167CR Systems

With increasing use of the C167CR in high volume products, the commonest memory configuration is a C167CR plus just a single 16-bit FLASH EPROM. The 4k of on-chip RAM means that with careful software design, no little or no external RAM is required. Here we will have a look at how C166 and L166 can best be used to populate the memory space of this type of minimal design with code and data.



9.16.1 A Typical Small System Memory Map

The example C167CR system consists of the CPU, a FLASH EPROM and an ASIC. The ASIC has 0x100 bytes of special function registers plus 0x100 bytes of RAM. Overall, the system has the following memory map:

```
EPROM           0-0x1FFFF
XRAM RAM        0x0E000 - 0x0E7FF
IDATA RAM       0x0F600-0x0FDFF
ASIC registers  0x20000-0x20100
ASIC RAM        0x20100-0x201FF
```

Inevitably in a no RAM system, there will be no variable area of anything like the 16k maximum for NDATA. As the whole application is very time-critical, accesses to all data must be a single instruction. In this particular example, there is around 32k of constant data in the form of look-up tables which had to be in PROM. As this data has to be accessed frequently from fast interrupt routines, the whole of this constant area is treated as near (NCONST). In the final application, this region represents the calibration data for the system and is

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likely to subject to regular field updates. Ideally, it should be kept separate from another group of "system" constants which are only set by the programmer.

```
temp = near_const_val ;

MOV  R1,DPP0:#near_const_val  ;  A near access

temp = far_const_val ;

MOV  R4,SEG #far_const_val   ; A far access
MOV  R5,SOF #far_const_val   ;
EXTS #1,R4                   ;
MOV  R1,[R5]                  ;
```

The important point is that this type of fast, single instruction data access can occur in any region covered by a DPP.

Experienced C166 users may be wondering how a 32k near constant area can be created when the usual near limit is 16k. In version 3.00 onwards, the flexible reallocation of DPP values allows consequentive DPPs to be set to consequentive values, with the result that linear areas of greater than a single 16k page size can be created.

One peculiarity of the design is that there is an area of RAM in an ASIC which is far removed from the IDATA and XRAM but which still needs to be accessed by single instructions.

9.16.2 Constructing Linker Input File

Ultimately the linker input file determines where everyting ends up and we will now go through this in detail:

(i) The Constant Areas

The 32kb near constant area is based at 0x18000. The constant data is created by ordinary statements such as:

```
int const near map_0_0[] = {
            0 , 1 , 2 , 3 , 4 , 5 , 6 , 7 , 8 , 9 , 10 , 11 , 12 , 13 , 14 , 15 ,
            0 , 1 , 2 , 3 , 4 , 5 , 6 , 7 , 8 , 9 , 10 , 11 , 12 , 13 , 14 , 15 ,
             0 , 1 , 2 , 3 , 4 , 5 , 6 , 7 , 8 , 9 , 10 , 11 , 12 , 13 , 14 , 15 ,
           } ;
```

The sum total of such statements is just under 32kb. Normally, DPP1 would be set to 0x18000/0x4000 = 6 by setting the NCONST classes entry to 0x18000. Here, the DPPUSE() control in the linker input file forces DPP0 and DPP1 to 6 and 7 respectively to create a 32k linear area. The SECTIONS() control is used to prevent the NCONST from the two modules that declare the data spilling over a page boundary - C166 x2.90 cannot generate more than 16k of NCONST per module although v3.00 can.

```
& // Create a 32k near constant area with DPP0, DPP1
DPPUSE(0=NCONST(0x18000-0x1ffff),2=NDATA(0x20000-0x23fff))
&
SECTIONS(?C_INITSEC(000400h),
          ?NC?MOD0%NCONST(0x18000),
          ?NC?MOD1%NCONST(0x1c000),...
```

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Due to a quirk in the C167CR on-chip memory map, there is a region from 0x0C000 to 0x0DFFF which is within scope of DPP3, set to its default of 3. There is a second smaller gap between the top of the XRAM at 0x0E7FF and the bottom of the CAN peripheral at 0x0EF00, **although it should be noted that this could be used in future CPU versions for additional XBUS devices**. As both these areas are occupied by EPROM, they can be used as additional constant areas. The fact that DPP3 covers this area means that single instruction near access can be made. The trick is to declare the constant objects as “const” but use the RENAMECLASS control to rename the NCONST data produced to a custom name, here “SYS_CONST”. This control is of the general format:

```
#pragma RENAMECLASS(OLD_CLASS=NEW_CLASS)
```

MODULE: SYSCONST.C

```
#pragma  RENAMECLASS(NCONST=SYS_CONST)

/*** Constants Destined For 0xC000 - 0xDFFF ***/

char const test0 = 0x1000 ;
char const thermistor_map[] = { 2,2,1,1,1,1,1 } ;
```

The new class is then placed at 0x0C000 by the linker line:

```
& // Fix classes for SMALL model
&
CLASSES(IDATA(0xF600),
        ICODE(000600H),
        NCODE(000800H),
        SYS_CONST(00C000H),....
```

The small gap just above the XRAM is filled in a similar manner....

MODULE: GAP.C

```
#pragma  RENAMECLASS(NCONST=GAP_CONST)

/*** Place constants between XRAM and CAN Peripheral ***/

char const test1 = 0x1000 ;
char const gap_map[] = { 2,2,1,1,1,1,1 } ;
```

...and placed with...

```
& // Fix classes for SMALL model
CLASSES(IDATA(0xF600),
         ICODE(000600H),
         NCODE(000800H),
         SYS_CONST(00C000H),
         GAP_CONST(00E800H),...
```

(ii) Allocating The RAM Areas

The XRAM is located at 0x0E000 and thus within the range of DPP3. Data destined for this region are known generally as “SDATA” and the sdata keyword is used to tell C166 to generate single instruction accesses via DPP3, as shown below:

```
MODULE: XRAM.C

#pragma RENAMECLASS(SDATA = XRAM_DATA)
#pragma  NOINIT

/*** Variables Destined For XRAM At 0x0E000 ***/

int sdata XRAM_var0 ;
int sdata XRAM_var1 ;
int sdata XRAM_var2 ;
int sdata XRAM_var3 ;
int sdata XRAM_var4 ;
```

As before, the classes control is used to fix these objects in the XRAM:

```
CLASSES(IDATA(0xF600),
         ICODE(000600H),
        NCODE(000800H),
        SYS_CONST(00C000H),
         GAP_CONST(00E800H),
         XRAM_DATA(0x0e000-0x0e7ff))
```

So far, DPP0 and DPP1 have been set to cover the area from 0x18000 to 0x1FFFF and DPP3 is covering the XRAM and constant areas. Normally, DPP2 would cover the near data (NDATA) region and in this example, it is used to access the ASIC registers and RAM at 0x20000.

```
& // Create a 32k near constant area with DPP0, DPP1
DPPUSE(0=NCONST(0x18000-0x1ffff),2=NDATA(0x20000-0x23fff))
```

Like before, the RENAMECLASS control is used to convert NDATA objects into, in this case, the ASIC registers. The aim is to make sure that the ASIC special function registers are overlaid by appropriately named variables. To make sure that the order of the variables corresponds with the physical locations in the ASIC, the #pragma ORDER control is used. In addition, as these registers are not to be zeroed at power-up, the #pragma NONIT control is added.

```
MODULE: ASIC_REG.C

#pragma ORDER
#pragma NOINIT
#pragma RENAMECLASS(NDATA = ASIC_REGS)

/** These Variables Need To Be Physically Placed Over The Real ASIC Registers ***/

int volatile asic_REG0 ;
int volatile asic_REG1 ;
int volatile asic_REG2 ;
char asic_REG3 ;
long asic_REG4 ;
int volatile asic_REG5 ;
int volatile asic_REG6 ;
int volatile asic_REG7 ;
int volatile asic_REG8[0x08] ;
int volatile asic_REG9 ;
int volatile asic_REGA ;
int volatile asic_REGB ;
int volatile asic_REGC ;
```

The volatile keyword is used to stop the C166 optimizer from removing references to these registers in the source code - it serves to tell the compiler that “this variable may change without any direct CPU action”.

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The data destined for the ASIC RAM is declared as straight forward NDATA. In the design, the ASIC RAM contents is preserve through power-down and is thus non-volatile. The NOINIT control prevents it being cleared and the ORDER control ensures that between successive program builds, the variables remain fixed.

MODULE: ASIC.C

```
#pragma  NOINIT
#pragma  ORDER

/*** Data Destined For ASIC RAM ***/

int near asic_var0 ;
int near asic_var1 ;
int near asic_var2 ;
```

To prevent the ASIC RAM objects from entering the ASIC regs area, both the SECTIONS and CLASSES linker controls are used to keep them apart:

```
SECTIONS(?C_INITSEC(000400h),
         ?NC?MOD0%NCONST(0x18000),
          ?NC?MOD1%NCONST(0x1c000),
          ?ND?ASICREG%ASIC_REGS(0x20000)
         ) &
&
& // Fix classes for SMALL model
CLASSES(IDATA(0xF600),
         ICODE(000600H),
         NCODE(000800H),
         SYS_CONST(00C000H),
         GAP_CONST(00E800H),
         NDATA(0x20100-0x201ff),
        XRAM_DATA(0x0e000-0x0e7ff)) &
&
```

Finally, the .M66 file shows where everything actually ended up:

```
DPP REGISTERS RE-ASSIGNED
-------------

  DPP   VALUE   C166 GROUP
   ========================
   0    0006H   NCONST
   1    0007H   NCONST
   2    0008H   NDATA

  C166 GROUP   START     STOP
   ==============================
  NCONST       018000H   01FFFFH
  NDATA        020000H   023FFFH


MEMORY MAP OF MODULE:  EXEC (MAIN)

START      STOP       LENGTH     TYPE   ALIGN     TGR GRP    COMB   CLASS    SECTION NAME
================================================================================
000000H    000003H    000004H    –     –     –    –     –     * INTVECTOR TABLE *
000400H    000405H    000006H    HDATA  WORD      –     –     GLOB   –       ?C_INITSEC
000600H    000633H    000034H    CODE   WORD      –     –     PRIV   ICODE    ?C_STARTUP_CODE
000800H    000885H    000086H    CODE   WORD      –     1     PUBL   NCODE    ?PR?MAIN
00C000H    00C007H    000008H    DATA   BYTE      –     3     PUBL   SYS_CO   ?NC?SYSCONST
00E000H    00E009H    00000AH    DATA   WORD      –     2     PUBL   XRAM_D   ?SD?XRAM
00E800H    00E807H    000008H    DATA   BYTE      –     3     PUBL   GAP_CO   ?NC?GAP
00F200H    00F5FFH    000400H    –     –     –    –     –     * RESERVED MEMORY *
00F600H    00F651H    000052H    DATA   WORD      –     2     PUBL   IDATA    ?ID?MAIN
00F652H    00F691H    000040H    DATA   WORD      –     –     PUBL   IDATA    ?C_USERSTACK
00FA00H    00FBFFH    000200H    –     –     –    –     –     * SYSTEM STACK *
00FD00H    00FD1FH    000020H    DATA   WORD      –     –     –     *REG*    ?C_MAINREGISTERS
018000H    01BDFFH    003E00H    DATA   WORD      –     3     PUBL   NCONST   ?NC?MOD0
01C000H    01FDFFH    003E00H    DATA   WORD      –     3     PUBL   NCONST   ?NC?MOD1
020000H    02002FH    000030H    DATA   WORD      –     4     PUBL   ASIC_R   ?ND?ASICREG
020100H    02011FH    000020H    DATA   WORD      –     4     PUBL   NDATA    ?ND?ASIC
```

From SYCONST.C
From XRAM.C
From GAP.C
From ASICREG.C
From ASIC.C

9.17 Relocating Functions Into RAM

Traditionally C166 programs have been completely static in that all the addresses of variables and functions are defined at the linking stage. However the needs of FLASH EPROM programming require the user to take special steps which require some rather obscure techniques!

One of the basic characteristics of FLASH is that instructions cannot be fetched from it whilst it is being programmed. In those cases therefore where an application placed in FLASH on the production line needs to be updated in the field, some means is required of temporarily executing instructions from some other memory device is required. Another common example would be where a FLASH needs to be checksummed. It is very rare for an emdedded system to contain two normal ROM devices so invariably this "other memory device" will be an external RAM or more usually the C167's own on-chip idata RAM at 0xF600.

In C166 v4.06 onwards, a special mechanism has been added to allow particular functions to be stored in the ROM in the usual way at for example 0x1000 but to be constructed so that they can be executed at an address such as 0xF600 in the idata area. The exact procedure is:

(i) Write function in the normal way in just the one module (file)
(ii) Configure the SECTIONS statement in the linker to set the execution address to be 0xF600
(iii) Use the SROM_PS() macro to work out the base address of the function in ROM and its destination address in RAM, plus its length
(iv) Copy the function using the hmemcpy() with the above addresses as parameters to the target address
(v) Call the function in the usual way

Function Relocation Example:

Copy a function stored in ROM at 0x1000 into RAM at 0xF600 and then call it. Do not reserve any space in the RAM for the function so that it just overwrites whatever was there.

Module containing function destined for RAM: **IDFUNC.C**
Module containing copying process for function destined for RAM: **MAIN.C**

MAIN.C

```
#include <srom.h>      // Contains macros for function relocation process

// Create external reference to address of code SECTION in IDFUNC.C via macro

SROM_PS(IDFUNC)      // Needed for macros used in hmemcpy() below

// Copy function(s) in module IDFUNC.C into the idata RAM

hmemcpy(SROM_PS_TRG(IDFUNC), SROM_PS_SRC(IDFUNC), SROM_PS_LEN(IDFUNC)) ; // Copy code in
                                                                          // IDFUNC.C into
                                                                          // idata
```

Where the parameters to hmemcpy() are:

```
SROM_PS_TRG(IDFUNC)    // Find the TaRGet address in RAM for the copy of the function in IDFUNC
SROM_PS_SRC(IDFUNC)    // Find SouRCe address in ROM for the copy of the function in IDFUNC
SROM_PS_LEN(IDFUNC)    // Find the LENgth of the code in ROM to copy of the function in IDFUNC
```

IDFUNC.C

```
void idata_relocated_function(void) // This function stored in ROM but runs in RAM
   {
    // Empty function!!
   }
```

Finally, in the linker control file add:

```
SECTIONS(?PR?IDFUNC%FCODE (0xF600)[!0x1000]) // Store function in IDFUNC.C to ROM at 0x1000
                                             // with destination address as 0xF600.  Do not
                                             // reserve space at 0xF600 for it. (ROM address
                                             // does not need to be stated)
```

In this case, no space was reserved in the RAM for the function due to the '!' control in the square brackets.

Generalised Form Of The SECTIONS Control For Function Relocation

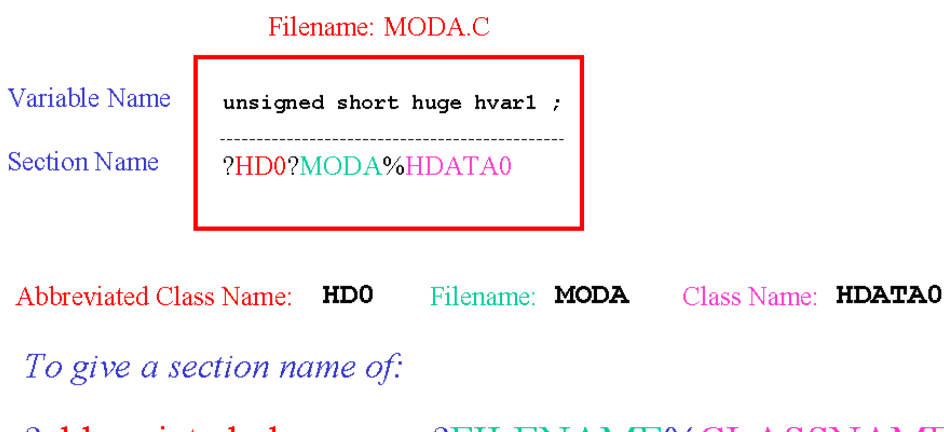
```
SECTIONS(section name (runtime address)[<!> storage address]
```

If it is necessary to reserve space in the RAM for the copied function, the SECTIONS control becomes:

```
SECTIONS(?PR?IDFUNC%FCODE (0xF600)[0x1000])  // Store function in IDFUNC.C to ROM at 0x1000
                                             // with destination address as 0xF600.
                                             // Reserve space at 0xF600 for it. (ROM address
                                             // does not need to be stated)
```

Note: SECTIONS that are manipulated in this way are always placed into a special CLASS called SROM, although this does not have any special significance in practice. It could be used though for grouping all relocated functions in ROM together into a block which can then be located using something like "`CLASSES(SROM(0x1000))`". The function is called in the normal way. Any symbol information required for debugging the function will be correcty aligned with the destination address in RAM

How to work out the SECTION name...



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EXERCISE 9: EX9

Objective:

It is required to perform a 16-bit checksum on the FLASH ROM devices fitted to the EVA16C training board. The checksumming function must be executed from the C167CR IDATA RAM at 0xF600, although it will be stored at 0x43800. Location 0x7FFFE has been pre-programmed with the correct checksum value of 0xA591. If the checksum calculated does not match this value, wait in a loop forever otherwise return to the caller.

Procedure:

The 16-bit checksum is calculated by summing up all the locations in FLASH area, one word (two bytes) at a time:

```
{
checkum += *ROM_ptr++ ; // Add up all the locations, one word at a time
}
```

Where `ROM_ptr` is a pointer to the FLASH which is incremented after each addition.

The FLASH is split into two ranges, separated by the C167CR's on-chip RAM and SFRs:

```
0x00000 length 0x0C000
0x10000 length 0x30000
```

These ranges are stored in a structure which contains two arrays that represent the start and end addresses of the areas:

```
struct FLASH { unsigned long base_addresses[No_Of_FLASH_Areas] ;
               unsigned long area_length[No_Of_FLASH_Areas] ; } ;

struct FLASH const FLASH_Map = { { 0x00000, 0x10000 },     // Addresses suitable for C167CS-LM
                                 { 0x0C000, 0x30000 } } ;
```

A function `idata_relocated_function(void)` is copied into IDATA RAM in `main()` using:

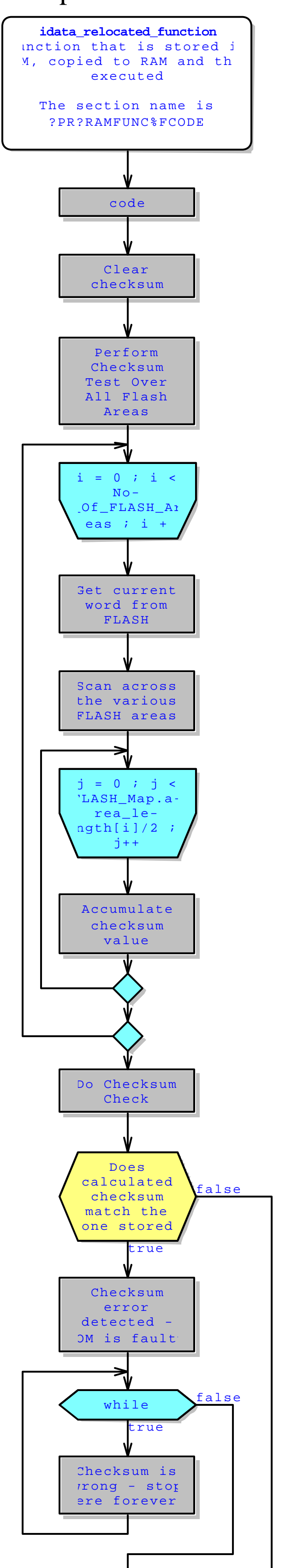
```
hmemcpy(SROM_PS_TRG(filename.c), SROM_PS_SRC(filename.c), SROM_PS_LEN(filename.c)) ;
```

where "filename.c" is the name of the file that contains the checksumming function. The address of executable code SECTION of filename.c containing the function has been made known to the `hmemcpy()` via:

```
SROM_PS(filename.c)
```

which appears above main(), wherein the `hmemcpy()` is located.

When called, the function sums up the words over the two FLASH ranges and then compares the result with a pre-calculated checksum at 0x7FFFE - see the DA-C flowchart overleaf.



The linker control file SECTIONS control places the function at 0x43800 but sets its run time address to 0xF600:

```
SECTIONS( // CODE SECTIONS to be relocated
          ?PR?filename%FCODE (0xF600)[!0x43800])
```

Exercise EX9 Checklist

MAIN.C:

(i) Make sure the header file containing the macros required for the hmemcpy() target and source address calculations is present.

(ii) Create external references to the target and source addresses and length of the SECTION in RAMFUNC.C that contains the function to be relocated.

(iii) Complete the hmemcpy() to include the above target and source addresses and length so that the copy will take place.

RAMFUNC.C:

(iv) Do nothing - it is complete! The actual function that is relocated is written in an entirely normal fashion.

EX9.LIN:

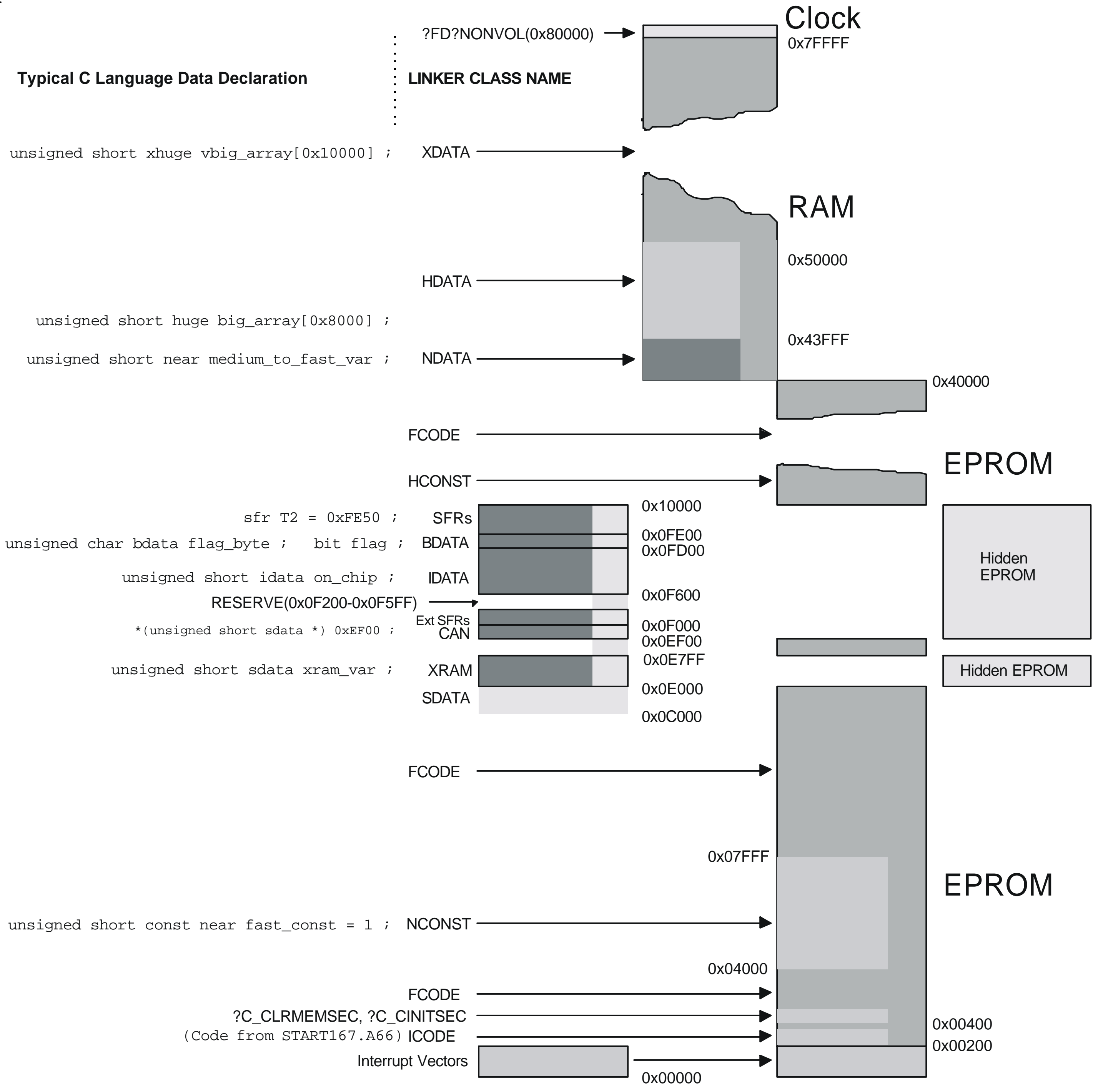
(v) Complete the SECTIONS control to store the function in RAMFUNC to 0x43800, setting the run time address to 0xF600. Refer to page 99 in the notes for a refresher on how to work out the Code SECTION name for RAMFUNC.C. Do not reserve space at 0xF600 for it though. Build the program.

(vi) Load the program into Hitop and run it until `main()`. Open a memory window at address 0xF600 and then run the program until the call to `idata_relocated_function(void)`. Check that the destination address of the call is 0xF600. Single step into the function and run it until the line:

```
if(*ROM_checksum != checksum)
```

Single step this and see what happens!

Checksumming function as a flowchart - produced with the DA-C


Typical C Language Data Declaration
LINKER CLASS NAME
?FD?NONVOL(0x80000)
Clock
0x7FFFF
unsigned short xhuge vbig_array[0x10000] ;
XDATA
RAM
0x50000
HDATA
unsigned short huge big_array[0x8000] ;
0x43FFF
unsigned short near medium_to_fast_var ;
NDATA
0x40000
FCODE
EPROM
HCONST
sfr T2 = 0xFE50 ;
SFRs
0x10000
unsigned char bdata flag_byte ;
bit flag ;
BDATA
0x0FE00
0x0FD00
Hidden
EPROM
unsigned short idata on_chip ;
IDATA
0x0F600
RESERVE(0x0F200-0x0F5FF)
*(unsigned short sdata *) 0xEF00 ;
Ext SFRs
CAN
0x0F000
0x0EF00
0x0E7FF
Hidden EPROM
unsigned short sdata xram_var ;
XRAM
0x0E000
SDATA
0x0C000
FCODE
0x07FFF
EPROM
unsigned short const near fast_const = 1 ;
NCONST
0x04000
FCODE
?C_CLRMEMSEC, ?C_CINITSEC
(Code from START167.A66)
ICODE
0x00400
0x00200
Interrupt Vectors
0x00000

EXERCISE 8: EX8

Objective:

Practice making linker control files (.LIN) to suit typical memory maps found in C167CR designs.

Procedure:

Construct a linker file to match the memory map shown. The example program is based on that from exercise EX3 but it is only the linker control file EXEC.LIN that you need to edit. MAIN.C contains some data declarations which will make sure that each of the classes will have something in them! The class names you will need to include in your CLASSES() control are given in the centre column of the diagram.

```
unsigned short xhuge vbig_array[0x10000] ; // 20000 byte array
unsigned short huge big_array[0x8000] ;    // 10000 byte array
unsigned short near medium_to_fast_var ;   // Near data
unsigned char const near fast_cont = 1 ;   // Near constant object
unsigned short bdata flag_word = 0 ;       // 16 flag bits
unsigned short idata on_chip = 0 ;         // Data in on-chip IDATA RAM
unsigned short const sdata extra_const = 2 ;  // More near constants in sdata area
sbit flag_X = flag_word^8 ;                 // A special flag bit in "flag_word"
bit flag0 = 0 ;                             // A single bit flag
```

Note that there is a real-time clock chip at 0x80000 as in exercises 6 and 7. Use the appropriate entry in the SECTIONS control to locate it at 0x80000.

10. Non-ISO/ANSI Code Saving Tricks

It is possible to save code by using the CPU's Carry flag directly as a check for the result having exceeded the capacity of an integer. If the sum of two integers is > 0xFFFF, the C flag will be set and this can be checked in C and action taken.

Example

```
unsigned int z ;
unsigned int x = 0x8000 ;
unsigned int y = 0x8000 ;

z = x + y ;

/*** If Sum > 0xffff then limit to 0xffff ***/
if(C) {
    z = 0xffff ;
   }
```

A similar trick can be performed with the overflow flag and a multiply to check if the product of two ints is over 0xFFFF;

EXERCISE 10: EX10

Perform the calculation

```
unsigned int = (unsigned int * unsigned int)/unsigned int, i.e. a = (x * y) / z ;
```

and check the result.

Use these values: x = 0x100 ; y = 0x100 ; z = 0x100

The correct ISO/ANSI Cway to perform this calculation is:

```
int x,y,z ;

z = ((unsigned long)x * (unsigned long)y)/(unsigned long)z ;
```

In current versions of C166, the following code will result:

```
;    a = ((unsigned long)x * (unsigned long)y)/(unsigned long)z ;
                                               ; SOURCE LINE # 20
     MOV  R5,WORD y
     MOV  R4,WORD x
     MULU R4,R5
     MOV  R6,WORD z
     DIVLU R6
     MOV  R4,MDL
     MOV  WORD a,R4
```

C166 spots that this is a 16-bit scaling calculation and performs all operations in line.

If the following is used, a lot more code results and what's more, it does not work.

```
a = (unsigned long)(x * y)/z ;
                                        ; SOURCE LINE # 16
 MOV   R5,WORD y
 MOV   R4,WORD x
 MULU  R4,R5
 MOV   R4,MDL   <—— loss of high word data!
 MOV   R6,R4
 MOV   R7,#0
 MOV   R4,WORD z
 MOV   MDL,R6
 MOV   MDH,R7
 DIVLU R4
 MOV   R4,MDL
 MOV   WORD a,R4
```

The moral of this is that in any major calculation it pays to check the .SRC file to see exactly what the compiler has done!

10.1 Special Note On Bits In Structures

From C166 v3.06, it is possible to have a bit flag as part of a structure in C166. This is covered in the next section with ISO/ANSI C bitfields.

10.2 Bit Fields And Flags In C166

Bit fields can be very useful in embedded C programming, especially when dealing with serial data. In C166 v3.06 it is possible to put bit fields into the bdata memory so that the compiler can use bit intructions to access the data.

Here is an example of using a bit structure: Serial data is shifted into the bit structure via a pointer. The second part moves the various bit fields into discrete bits and words for later processing. The single bit quantities field0 and field1 are accessed via bits while field2 and field3 require word operations.

MAIN.C

```
#pragma MOD167
#include <reg167.h>

/*** Create bit structure that has four fields ***/

struct bf { unsigned int field0 : 1 ;
            unsigned int field1 : 1 ;
            unsigned int field2 : 4 ;
            unsigned int field3 : 10 ; } ;
```

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```
struct bf bdata indata ;  // Create bit structure in bit-addressible area

unsigned int *buffer_ptr ;  // Create an int pointer to bit structure

bit field0 = 0 ;
bit field1 = 0 ;
unsigned int field2 = 0 ;
unsigned int field3 = 0 ;

void main(void) {

   /*** Put data into serial buffer from serial port ***/

   buffer_ptr = (unsigned int *) &indata ;  // Point at structure
   while(!S0RIR) { ; }
   S0RIR = 0 ;
   *buffer_ptr = (unsigned int) S0RBUF ;     // Move data from serial port to bit structure

   while(1) {
      field0 = indata.field0 ;  // Extract bit that constitutes field0
      field1 = indata.field1 ;  // Extract bit that constitutes field1
      field2 = indata.field2 ;  // Extract nibble that constitutes field2
      field3 = indata.field3 ;  // Extract 10 bits that constitute field3
      }
   }
```

As you can see, C166 makes a pretty good job at breaking the bit fields into individual parts

SRC File:

```
; line 29:    while(1) {
?C0007:
; line 30:        field0 = indata.field0 ;  // Extract bit that constitutes field0
     BMOV field0,indata
; line 31:        field1 = indata.field1 ;  // Extract bit that constitutes field1
     BMOV field1,indata+1
; line 32:        field2 = indata.field2 ;  // Extract nibble that constitutes field2
     MOV  R5,WORD indata
     MOV  R4,R5
     SHR  R4,#2
     AND  R4,#15
     MOV  WORD field2,R4
```

10.3 Simple Bit Flags

To implement general flags, the use of bits is recommended as these make direct use of the BDATA RAM area.

A simple bit flag can be declared as:

```
bit test_flag = 0 ;
```

and may be either global or local.

In all respects, they can treated exactly as per normal data types.

10.4 The _testset_() And _testclear_() Intrinsic Functions

The C166 has a useful set of bit-orientated functions, the most powerful of which is the JNBS bit,rel instruction. This jumps if a bit is clear then sets it. C166 will ordinarily not use this but by using the _testset_() intrinsic function, C166 can be forced to use it. The opposite of this instruction is the JBC bit,rel which has the corresponding intrinsic function _testclear_().

Example Of _testset_():

```
#include  <intrins.h>

bit test_flag ;

void main(void) {

   /* Use Normal Approach */

   test_flag = 0 ;

   if(test_flag == 0) {
       test_flag = 1 ;
       P5 = 0xff     ;
       }

   /* Use Intrinsic Function */

   test_flag = 0 ;

   if(_testset_(test_flag)) {   // If bit clear, set it and set P5 to 0xFF

       P5 = 0xff     ;
      }
     }
```

EXERCISE 11: EX11

Enter the above program and compile with the SRC switch to see how the _testset_() function has been used.

10.5 Intrinsic Functions

There are a number of special 80C166 assembler instructions which are not normally used by C166. For the sake of speed, it is sometimes useful to get direct access to these but putting them as in-line code.

As an example, unlike the normal C166 '>>' functions, _irol_() allows direct usage of an 80C166 instruction set feature, in this case the ROL (rotate left) instruction. This yields a much faster result than would be obtained by writing one using bits and the normal >> operator. There are also _crol_ and _lror_ intrinsic functions for char and long data as well.

Intrinsic functions are inherently non-portable but as they are normally only used in very time-critical interrupt functions, this is not a real problem.

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Other Intrinsic Functions

`_nop_()`

Adds an in-line NOP instruction to generate a short and predictable time delay. The only extra step necessary is to include “intrins.h” in the C166 source file.

`_idle_()`

Puts theC167CR into idle mode by putting an IDLE instruction in-line.

`_pwrdn_()`

Puts the C167CR into power down mode.

`_srvwdt_()`

Generates an in-line SRVWDT instruction to service the on-chip watchdog timer.

`_sof_()`

This function converts a DPP:offset address in the first 64kb into a single 16-bit pointer. This is primarily used to initialise PEC pointers.

`_trap_()`

This forces a TRAP instruction in-line. If the parameter is 0, the SRST (software reset) instruction is generated.

`_diswdt_()`

Causes the DISWDT instruction to be in-line.

`_einit_()`

Forces the EINIT instruction in-line. Note that an EINIT is already contained in START167.A66 so this must be removed! This intrinsic function is usually used for bootstrap loader programs.

`_iror_()`

Uses the ROR instruction to perform a right rotate on the given integer.

`_atomic_()`

If the MOD167 #pragma control is in force, this yields an in-line ATOMIC instruction to inhibit all interrupts for a number of instructions. This function is most often used to ensure coherent 32-bit reads.

Example Of _atomic_(): Our dual timer method of making a 32-bit input capture measurement of a slow pulsetrain is used to generate an unsigned long value "`time_for_180`" in the CC0 interrupt service routine. This value is to be used by a background loop routine. A local copy of variable will be made by the latter so that if the CC0 interrupt occurs during the routine, the top word of data will be coherent with the

lower word. As the 166 is a 16-bit machine, the 32-bit data moves required could be invalid if `"time_for_180"` changed between reading the top and bottom words. The _atomic_() function can guarantee this will not happen:

```
#include <intrins.h>

_atomic_(2) ;                           // The next line takes two instructions
                                        // - no interrupt can get in here.
time_for_180_snapshot = time_for_180 ; // Now an indivisible 32-bit instruction
```

NOTES

```
_bfld_()
```

Allows direct access to the BFLDL and BFLDH C166 instructions.
These are very useful for setting and clearing single or groups of bits in a word.

```
_bfld_(address, OR mask , AND mask) ;
```

Bits that are set in the OR mask can be set to values specified by bits in AND mask

```
Example Of _bfld_()

// Set CAPCOM channel 3 to -ve edge triggering on timer 1

_bfld_(CCM0, 0xF000,0xC000) ;

// Set CAPCOM channel 0 to +ve edge triggering on timer 0

_bfld_(CCM0, 0x000F,0x0001) ;
```

10.6 The volatile Keyword

The registers in a memory-mapped real-time clock chip can change without the CPU taking any action. C166 will assume that if a location has not been operated on in C then it cannot have changed. This can cause the optimizer to remove data accesses that it considers redundant! In the case where a clock register is being continually checked, the optimizer may remove some accesses with undesirable side-effects.

Example:

```
unsigned int far *milliseconds = 0x38000;   // Pointer to RTC register

time = *milliseconds ; ->(1) // Get RTC register value
x = array[time++] ;

time = *milliseconds ; ->(2) // Second register access optimized out!
y = array[time++] ;
```

The example fails because the compiler's optimiser assumes that because no write occurred between (1) and (2), *millisec cannot have changed. Hence all the code generated to make the second access to *millisec is optimised out! The solution is declare *milliseconds as "volatile" thus:

```
unsigned int volatile far *milliseconds = 0x8000 ;
```

Now, the optimiser will not try to remove subsequent accesses to the register as volatile indicates that the data at the location may change automatically and so inhibits its normal action.

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11. Accessing Absolute Addresses

11.1 The MVAR and MARRAY Macros

UARTS, ports and real-time clock devices are often added to 80C166's as memory-mapped devices. The registers of the different devices will appear at fixed locations in the far data space.

The simplest way of mapping variables to absolute locations in C166 is by the use of the MVAR and MARRAY macros. These macros are used as follows:

```
#include "absacc.h"
#define  rtc_seconds  MVAR(int,0x3f000)
```

the symbol may then be used as follows:

```
current_time[4] = rtc_seconds;
```

Alternatively, MVAR may be used thus:

```
unsigned int value ;

value = MVAR(unsigned int,0x3f000) ;
```

The only requirement is that the header file "absacc.h" must be included at the top of the source file as shown above. This contains the prototype for the macros.

MVAR is intended for accessing memory-mapped IO that is in a range covered by a DPP. In most casess, such IO will be located high in the address space where it is unlikely that NDATA or NCONST will be. Therefore the HVAR macro is more useful as it is based on huge accesses and so can point to any address.

```
#define HVAR(object, addr)   (*((object volatile huge *) (addr)))
```

11.1.1 Things To Be Aware Of With This Method

There are two major problems with the MVAR and MARRAY macros that limit their use to very simple situations:

(i) They are really just casts to a pointer except that it is not obvious how they work by looking at the source,
i.e.:

```
#define MVAR(object, addr)   (*((object volatile *) (addr)))
```

(ii) They are only suitable for accessing absolute addresses that are fixed at compile time and will not have to
change at run time.

EXERCISE 12: EX12

Objective:

Read the value of the memory-mapped DIL switch and print it to the LCD display.

Procedure:

The 8-bit DIL switch is enabled by the 167's chip select 4 (/CS4). To read it, the chip select 4 must be configured to become active low when the 167 emits address 0x100000 so that the DIL switch is able to drive the D0-D7 data lines. Thus the value of the switch can be used by software.

(i) START167.A66 must be modified to set up BUSCON4 and ADDRSEL4 to make /CS4 become active from 0x100000 to 0x100FFF, using an 8-bit non-multiplexed bus. Three waitstates must be used on this 4kb memory region. All other settings such as MTTC4, RWDC4 can be ignored.

(ii) In MAIN.C, use the HVAR macro from ABSACC.H to create a means of addressing the switch at 0x100000. We have provided `"#define DIL_Switch ..."` for this purpose.

(iii) Read the value of the memory-mapped DIL switch and print it to the LCD display. Note that the necessary modified PUTCHAR.C is already in place to allow printf() to drive the LCD.

Note: General form of Macro = HVAR (type, address)

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12. Pointers In C166

Like variables, pointers too are influenced by the underlying paged data addressing. Pointers to data in the near data area unsurprisingly called termed "near pointers". They may point at any object in the near data area and as might be expected from the 16k pages, no single object may be over 16k. A near pointer in C166 is itself 16-bits, with the top two bits fixed at 02 to indicate DPP2.

12.1.1 The Various Pointers In C166

far pointers are less restricted in that the object being pointed at can be at any 18- or 24-bit address but the size of the object being pointed at must be limited to 16kb. As the value of DPP0 is calculated each time the pointer is used, far pointers are thus somewhat slower than near pointers. The 16kb limit only causes problems if you try to increment a pointer over this range, as might happen when using a pointer to access a large array. The reason for the limit is that when incrementing a far pointer, when the offset exceeds 0x3fff, the DPP0 is not incremented and the offset simply wraps-around to zero again. Far pointers occupy 32-bits (two words)

huge pointers (and objects) can be up to 64k in size as the overflow into the next page is *not* catered for. However, as C166 does not allow an overflow from a 16- to 24-bit offset, huge pointers will just wrap-around once they have been incremented more than 64kb from their start-point.

xhuge pointers remove the 64kb limitation and allow objects of any size to be addressed without restriction. They are however relatively slow, unless you are using the C167/5.

The final pointer type, **sdata**, is very much C166 family-specific. This is a pointer which is always points into the system area, indicated by DPP3, between 0xc000 and 0xffff. sdata pointers are 16-bits in size and are best used for pointing at internal RAM objects or IO mapped into the 0xC000 region.

Performance Hint! If you are using a global pointer in a loop, always try to make a local copy of the pointer; C166 will put this into a register and consequently execution speed will be much higher.

12.1.2 Summary Of Pointer Declarations

Declare a near pointer:

```
int near *near_ptr ;
```

Declare a far pointer:

```
int far *far_ptr ;
```

Declare a sdata pointer:

```
int sdata *s_ptr ;
```

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12.1.3 Special Note On #pragma MOD167 For C167/5 Users

The #pragma MOD167 can be used to speed up huge pointer accesses especially by using the EXTS seg,off instruction. Here is an example of the standard DPPx-related approach and the EXTS version with MOD167:

MOD167 Huge Pointer Access

```
;        *hptr = 0x55 ;
                                                    ; SOURCE LINE # 19
      MOV   R6,#85
      MOV   R5,WORD hptr+2
      MOV   R4,WORD hptr
      EXTS  R5,#1
      MOV   [R4],R6
```

R5 holds the 64kb segment number and R6 holds the offset into the segment. In effect, this a full 32-bit access being equivalent to MOV [R5:R4],R6.

Normal Huge Pointer Access

```
;        *hptr = 0x55 ;
                                                      ; SOURCE LINE # 15
      MOV   R4,#85
      MOV   R3,WORD hptr+2
      MOV   R2,WORD hptr
      CALLA cc_UC,?C_HSTOREI
```

Note that the MOD167 version eliminates the library function call an consequently improves speed greatly.

12.2 Variable Pointers To Absolute Addresses

Pointers in RAM are useful for accessing addresses which are only known at run time or which are liable to change dynamically. They are to be preferred to the MVAR() approach. As decreed by ANSI C, pointers can be defined and intialised in a single statement at file level (i.e. outside any function) or declared and then initialised at run time, within the body of a function.

The convention is:

```
<type> <const/volatile> <typequalifier> * <dataname> = (<type> <const/volatile>) <address>;
```

Example:

```
/*** Define and initialise pointer in single statement - file level ***/

char far *pointer = (char far *) 0x30000 ;

/*** Define pointer only - file level ***/

char far *pointer ;

// at run time...

pointer = (char far*) 0x30000 ;
```

The <typequalifier> before the'*' determines what the pointer is able to point at. The use of the program construction method outlined previously can help prevent this.

```
/*** Define Far Array In FDATA0 ***/

char far fararray[] = { "Hello from far data" } ;

/*** Define near pointer ***/

char near  *near_ptr ;

/*** Make near Pointer Point At Far Object ***/

near_ptr = fararray ;  // This will fail as a near pointer cannot point at a far object.
```

Warning! Mismatches between far and near objects do not always immediately show themselves as a lucky combination of DPPx values can allow the erroneous pointer to work. Suddenly changing the address of host class of the target object or altering the memory model will often show up this problem. However, the appearance of the "pointer truncation" warning will always indicate a problem.

12.3 Placing The Pointer Itself

Pointers defined with nothing between the '*' and the <dataname> are located by default in the data class determined by the memory model. It is entirely possible to force the pointer itself into a specific memory space. By putting a type and typequalifier after the '*', the pointer can be placed. This is most frequently required when is desired to put a pointer into EPROM, i.e. a constant class. Jump tables or tables of function pointers fall into this category also.

Example 1 - Put a far constant pointer to a constant string into EPROM itself

```
char const far * const fixed_string[] = { "String in EPROM " } ;
```

Example 2 - Put a far constant pointer to a ram variable into EPROM

```
char far ram_variable = 1 ;  // Variable in far RAM

char far * const fixed_string[] = &ram_variable ;  // Set up a pointer in EPROM to ram
variable
```

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EXERCISE 14: EX14

Objective:

Illustrate important points when using pointers to do memory tests and checksums etc..

Procedure:

The program consists of two files which you must modify. MAIN.H contains the declaration of a pointer ("*mem_ptr") which will be made to point at the base of the test area of 0x50000. You must ensure that it has the attributes that will allow it to scan across the 128k memory test area, and that it is not itself within the range of the test!

In MAIN.C, you must make *mem_ptr point to 0x50000. You must then make it write 0x5555 into each location and then read it back again to ensure that the data has not been corrupted by a faulty RAM. If the data read does not match that written, a bit flag called "error_fl" must be set. The write and read of a pattern to each location should be within a for() loop which makes 0x10000 loops. This is because the memory pointer is to a word (short), it will be incremented by *two* on each loop. At the end of the memory test loop, printf() a pass or fail message to the LCD display.

Notes:

(i) Make sure that your DATA classes are not in this area otherwise the memory test will destroy its own variables! *mem_ptr is especially at risk from overwriting.

(ii) Ensure that the compiler's optimizer does not remove the read back of the test data: the compiler assumes that if it writes data, it will not change. Therefore, as the data is read back immediately, it will optimize out the read operation completely!

(iii) Ensure that the storage class qualifier (near, far etc.) that you use when declaring the pointer is able to scan over 128k locations.

BEWARE: We have laid some traps for you....pay particular attention to the attributes and location of *mem_ptr!

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Memory Test Outline

```
void main(void) {

   unsigned long i ;
   unsigned short temp, mem_contents ;

   init_lcd() ;
   IEN = 1 ; // Needed for HiTOP167
   mem_ptr = (unsigned short _______  ________*) 0x50000 ;

   for(i = 0 ; i < 0x10000 ; i++) { // 0x10000 words!

      *mem_ptr = 0x5555 ;
      temp = *mem_ptr ;

      if(temp != 0x5555) {
         error_fl = 1 ;
         }

      }
```

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12.4 Jumping To Variable Addresses

In the same way that data pointers can be set to addresses at runtime, so can function pointers. This can be useful when calling functions which reside in a different C166 program in the same system, as could be found in FLASH EPROM + boot EPROM designs.

Example:

Generate a call to a constant address:

```
((void (far*) (void)) 0x8000) () ;       // Call to a constant address
```

Jump to variable address:

```
unsigned int jump_addr ;     // A variable holding intended jump address

jump_addr = 0x8000 ;                         // Set up target address
((void (far*) (void)) jump_addr) () ;       // Call to a variable address
```

Here is a useful macro which will cast any constant or variable to a function pointer:

```
#define LTOF(func) ((void (far*) (void)) func)
```

Example

```
#define LTOF(func) ((void (far*) (void)) func)

jump_addr = 0x50000 ;
LTOF(jump_addr) () ;  // Call 0x50000

;
;    LTOF(0x50000)() ;
                                                ; SOURCE LINE # 68
     MOV  R4,#0
     MOV  R5,#5
     CALL ?C_SCALLI
;    }
```

Caution! Due to the limitation that near functions must be within the current segment, jumps like these should always be cast as far.

12.5 Pointer Casting And Conversions

It is entirely possible to turn a simple C data type (int, long) into a pointer. However, you must be aware of the number of bytes required to form the pointer in each case:

near pointers

One word carrying information on offset from DPP2 page number, 0-0x3fff

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far, huge, xhuge pointers

Two words carrying information on the page number in the upper word and offset from page base in the lower.

sdata pointers

One word carrying information on offset from page number 3 (DPP3), 0xC000-0xFFFF

To make a near pointer, an unsigned int can be used:

Example

```
int near near_address = 0x4000 ;
int y = 0x8000 ;

y = *(unsigned char near * ) near_address ;
```

You must make very sure though with conversions to near pointers that the address is actually in the near data area!

To make a far pointers, the source data must be of type long as only this type has sufficient bytes to accommodate the pagenumber:offset information.

Example

```
unsigned long address = 0x38010 ;
unsigned char test ;

test = *(unsigned char far * ) address ;
```

Be warned though that this on-the-fly casting from long to pointer is very inefficient and it is always better to use a proper pointer type, as the following shows:

```
int var ;
unsigned long faddr = 0x30010 ;
int far *fptr = (int far *) 0x30010 ;
```

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Use a proper pointer type:

```
var = *fptr ;
     MOV   R5,WORD fptr+2
     MOV   DPP0,R5
     MOV   R4,WORD fptr
     MOV   R4,[R4]
     MOV   WORD var,R4
```

Cast from long to pointer:

```
;    var =  *(int far*) faddr ;
     MOV   R4,WORD faddr
     MOV   R5,WORD faddr+2
     ADD   R4,R4
     ADDC  R5,R5
     ADD   R4,R4
     ADDC  R5,R5
     MOV   DPP0,R5
     SHR   R4,#2
     MOV   R8,[R4]
     MOV   DPP0,#12
```

Note! The conversion from long to a pointer is not like Microsoft C (MSC) for the 80x86. The calculation of the 166's page number is made during the cast at run-time, hence all the extra code produced above. In MSC, the long must have the segment number already in the right place. In the above example, rather than containing 0x30010, the long would have to have held 0x3000 0010! This could cause problems when converting MSC programs to the 166.

12.6 Pointers To Local Data

It is possible to create pointers to local data (i.e. automatics), although it is not really good practice. If the user stack has been moved into the IDATA on-chip RAM, you must use the USERSTACKDPP3 compilation control. This will force C166 to use DPP3 as the base for the pointer so that it can happily point to the user stack in IDATA rather than via DPP2 into the NDATA area.

```
#pragma USERSTACKDPP3    // Force compiler to use DPP3 when finding
                         // address of local array

void func1(char a, char b) {

    char rx_buffer[0x20] ; // This array will be on user stack
    char *rx_ptr ;

    rx_ptr = &rx_buffer[a] ;  // Point to ath object in local array
```

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12.7 Addressing The C167CR CAN Peripheral Via Pointers

The standard REG167.H does not contain any mention of the CAN module's registers. Whilst the CAN registers superficially appear to be sfr's like T0, CC1, S0TBUF etc. they are in fact memory-mapped IO ports by virtue of the fact that they are not addressed by SFR addressing modes. This distinction may be somewhat academic but they are usually addressed via constant pointers to SDATA, rather like the PEC SRCP and DSTP pointers - SDATA is the 16k region covered by DPP3 from 0xc000 to 0xffff.

The following include file uses SVAR macros to produce constant SDATA pointers to the CAN registers. It has taken from the RTX166 operating system CAN library and can be found in the USEFUL subdirectory.

CAN167.H Header File

```
/* Siemens 80C167C CAN register layout  */
/* 22-JUL-94 / EG                       */

/* Addresses of CAN General Registers */
/* ------------------ */

/* Control/Status Register */
#define         ADR_CAN_CTL_STAT        0xEF00

/* Interrupt Register */
#define         ADR_CAN_INTID           0xEF02

/* Bit Timing Register */
#define          ADR_CAN_BIT_TIMING      0xEF04

/* Global Mask Short */
#define         ADR_CAN_MASK_SHORT      0xEF06
/* Upper Global Mask Long */
#define         ADR_CAN_UMASK_LONG      0xEF08
/* Lower Global Mask Long */
#define         ADR_CAN_LMASK_LONG      0xEF0A

/* Upper Mask of Last Message */
#define          ADR_CAN_UMASK_LAST      0xEF0C
/* Lower Mask of Last Message */
#define         ADR_CAN_LMASK_LAST      0xEF0E

/* Masks for control/status reg (ADR_CAN_CTL_STAT)                 */
/* Attention: apply for WORD reads of this reg only !              */
#define         BOFF_MSK        0x8000
#define         EWRN_MSK        0x4000
#define         RXOK_MSK        0x1000
#define         TXOK_MSK        0x0800
#define         LEC_MSK         0x0700
#define         CCE_MSK         0x0040
#define          EIE_MSK          0x0008
#define          SIE_MSK          0x0004
#define         IE_MSK          0x0002
#define          INIT_MSK         0x0001
#define          RES_ALLCTL       0x5555

/* Masks for field 'msg_ctl' of the 15 CAN objects */
#define         INTPND_MASK             0x0001
#define         RXIE_MASK               0x0004
#define         TXIE_MASK               0x0010
#define         MSGVAL_MASK             0x0040
#define         NEWDAT_MASK             0x0100
#define         MSGLST_MASK             0x0400
#define         CPUUPD_MASK             0x0400
#define         TXRQ_MASK               0x1000
#define         RMTPND_MASK             0x4000

/* Masks for field 'msg_cfg' of the 15 CAN objects */
#define         XTD_MASK                0x0004
#define         DIR_MASK                0x0008

/* Structure for a single CAN object */
/* A total of 15 such object structures exists (starting at EF10H) */
struct t_can_obj {
   unsigned int  msg_ctl;
    unsigned long arbitr;
    unsigned char msg_cfg;
   unsigned char msg[8];
   unsigned char dummy;
};

#define SVAR(object, addr)   (*((object sdata *) (addr)))
#define SARRAY(object, base) ((object sdata *) (base))

/* end of header file */
```

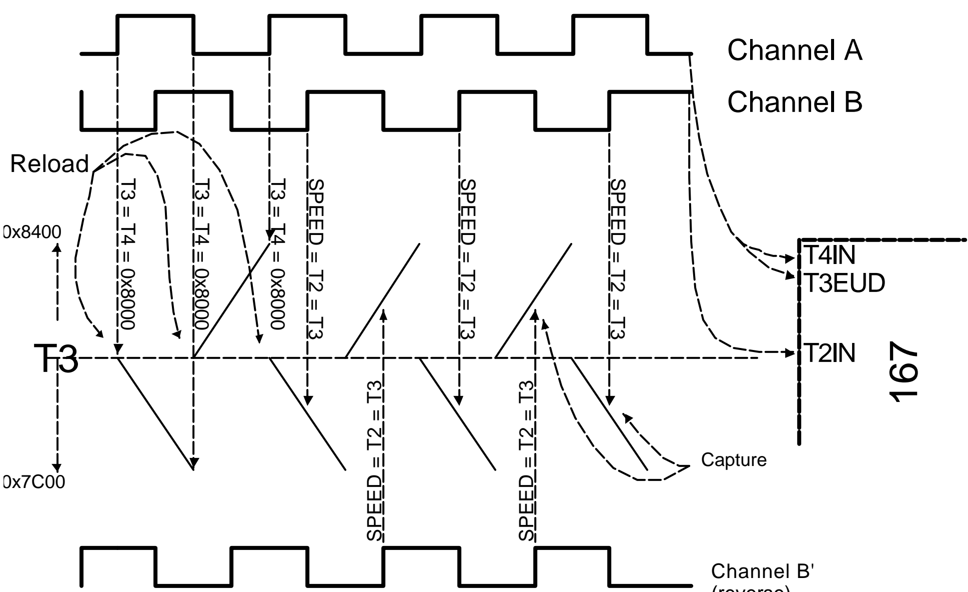
MAIN.C Test Source File

```
#include <reg167.h>
#include <canreg.h>

#define CAN (SARRAY (struct t_can_obj, 0xEF10))  /*
Structure for CAN message area */

main ()  {
  int i;

  i = SVAR (int, ADR_CAN_CTL_STAT);
  SVAR (int, ADR_CAN_BIT_TIMING) = i;
  CAN[0].msg_ctl = i;
  CAN[1].arbitr = 0x12345678;
}
```

13. Using Peripherals With Zero Software Intervention

It is quite possible to set up a C167 peripheral to perform a complete function with no CPU activity required to complete the task. This is particularly true of general purpose timer blocks 1 and 2 (GPT1 and GPT2). These units comprise simple building blocks of timers, output and input pins which can be used to automate pulse measurement or generation tasks.

As an example, we will consider how GPT1 can be used to implement a decoder for a quadrature shaft encoder, as might be used to measure the speed and direction of an AC motor drive.   Register T4 will always contain the value of the input speed + 0x8000. Subtracting this number from T4 will yield a number representing the speed, including its direction, i.e. positive implies forwards and negative implies reverse. A common trick used here is to feed one of the quadrature channels into *two* pins of the C167, namely T4IN and T3EUD.



Here is how it is done:

(i) T4IN loads the contents of T4 into free running timer 3 with 0x8000 on every edge of channel A. Thus T3 keeps counting either up or down from 0x8000 on every cycle.

(ii) T3EUD, also on channel A, causes T3 to count up when channel A is high and down when channel A is low.

(Iii) T2IN captures value of T3, on channel B +ve edge, 90 degrees after T3 was set to 0x8000 by T4IN. Thus T2 contains a signed number representing the instantaneous speed, when 0x8000 is subtracted from it.

EXERCISE 15: EX15

Objectives

Implement the quad decoder, as described above. Use it to measure the speed in Hz of the quadrature signal being generated by the C515C CPU on the 167IO board.

Procedure

1. Configure Timer 4 to reload T3 on either a rising or falling edge on the T4IN pin.
   Preload Timer 4 with 0x8000.
2. Configure Timer 2 to capture T3 on a rising edge on the T2IN pin
3. Compile the program and run it under ***HiTOP***.
4. The LCD display will report the measured speed and direction of the input signal. What is the frequency? Is it running forwards or backwards?

Note: Put the C515C DIL switch to position '00000001' to start the quadrature generator and make sure that link LK2 on the training board is inserted.

Advanced Feature

We have provided a mechanism to cause the speed measured to go to zero if the quadrature input disappears: if Timer 3 ever overflows, the input edges must have been absent for a considerable time and so we consider the the encoder to have stopped.

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14. The General Purpose Registers, Register Variables And Registerbanks

One of the fundamental features of the C166 CPU core are the general purpose registers and the concept of register banks. The 1kb (or 2kb) internal RAM can be viewed as a series of single words or alternatively as a collection of 64, 16 word-long registerbanks. These registerbanks can start at any address in the internal RAM area. The base of the current registerbank is indicated by the CP (context pointer) register.

14.1 The Context Switch

The C166 includes a "switch context" instruction which causes the current registerbank base address held in the CP register to be stacked and a new CP value inserted. This allows the current registerbank to be changed in a single cycle and can be very useful for providing a fresh set of working registers to an interrupt function, whilst leaving the background loop's registerbank in tact. Once the interrupt has completed, the original CP value is restored and the interrupted program can continue.

The current register bank forms the scratch-pad memory for local data and function parameters. Like a good assembler programmer, C166's optimiser will try to keep intermediate data values in registers to prevent the loss of speed caused by moving working data off-chip - any data accessed via the MOV Rw, Rw type instructions are guaranteed to be 100ns. C166 therefore tries to allocate all local data to registers, up to a limit of 15 registers per function. This gives a huge increase in performance and you should try to keep as much data local as possible, even down to making local copies of global data that is to be frequently accessed. There are some very devious tricks that you can do to make automatics (locals) appear to be static which we will cover later.

The allocation of variables to registers is entirely automatic and whilst the ANSI type qualifier "register" is compiled, it has no effect. You just have to trust the compiler's judgement on this one!

C166 permits the user to exercise considerable control over how the registerbanks can be used via the USING and REGBANK controls.

14.1.1 Useful Definitions Concerning Registerbanks

Registerbank - a group of 16 word locations in the internal RAM whose base address is contained in the Context Pointer register (CP).

Automatic data - Variables which are created on entry to a function and destroyed on exit. They are defined at the top of the function which uses them and no other function may access them.

Local data - as per automatic.

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14.2 Interrupts In C166

It is possible to write interrupt functions directly in C166 without the need to use assembler entry and exit code. The interrupt function type is the key to this. By adding this keyword to interrupt function definitions, C166 will ensure that the current registerbank is stacked on entry, restored on exit and a RETI placed at the end of the function. These actions constitute a "stack frame". The interrupt vector necessary to get to the service function is generated automatically - the numerical argument to the interrupt keyword will cause the compiler to generate a JMPS at an address given by:

```
vector location = n * 0x4 + offset,
```

where n is the number appearing after the interrupt keyword, here "0x10" and offset is the argument to the VECTAB control in the linker. This offset defaults to zero if no VECTAB() control is given at link time.

```
void timer0_int(void) interrupt 0x10 {

   }
```

Here is an example of a stack frame:

```
      timer0_int  PROC  INTERRUPT = 16
      GLOBAL   timer0_int
; FUNCTION timer0_int (BEGIN  RMASK = @0x0012)
;     void timer0_int(void) interrupt 0x10 {
                                          ; SOURCE LINE # 13
      SCXT DPP3,#3
?C0006:
      PUSH R1
      PUSH R4
       PUSH  R7
       PUSH  R9
       PUSH  R10

/*** Interrupt Code ***/
;
;?C0005:
       POP   R10
       POP   R9
       POP   R7
      POP  R4
      POP  R1
?C0007:
      POP  DPP3
      RETI
; FUNCTION timer0_int (END    RMASK = @0x0012)
      timer0_int  ENDP
           ?PR?T  ENDS
```

The interrupt function that created this stack frame used R1 and R4 as general working registers hence it PUSHes them on entry and POPs them on exit. In this case, the time to do this is small but on a more complex interrupt routine, up to 15 registers might be used. This is obviously undesirable from the point of view of the apparent interrupt latency but is the traditional approach taken in conventional CPUs. C166 does use some intelligence in that it only stacks those registers actually used by the interrupt. However, as been mentioned, the 166 core has a fast means of switching to a new register bank i.e. the SCXT instruction. It is the USING control in C166 that allows the C programmer to exploit this hardware feature.

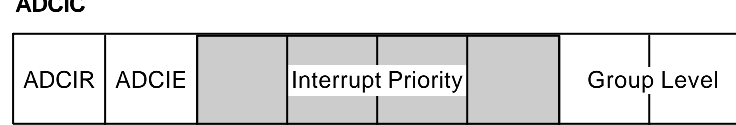
14.3 The VECTAB Linker Control

Under normal circumstances, the interrupt table will be placed at zero. However, when using some monitor debuggers or if a boot-EPROM plus FLASH type system is being used, the vector table may need to be shifted to some other address. The most common example is the EVA167 board where the region from 0-0x1ffff is occupied by the monitor EPROM and the user's program is located at 0x40000. The monitor holds a dummy vector table at zero which simply redirects the vectors up to the RAM region at 0x40000.

By using VECTAB(0x40000) in the linker input file, the vector table base of the user's program can shifted to 0x40000. This has already been used as it is essential when using the EVA167 and EVA165 boards.

14.4 Macros That Simplify The Setting Of Interrupt Priorities

The user must set the interrupt priority level (ILVL) and the group level (GLVL). The former is slightly incovenient as the priority field is two bit offset from the base of the register:



To make source code more comprehensible, here are some macros with parameters in the INTMAC.H that you can use to set interrupt priorities and group levels. They can be found in the \166TRAIN.WIN\HEADERS directory.

```
/*** Interrupt Priority Setting Macros ***/

#define  Set_Priority_15(reg)    (reg |= 0x3C)
#define  Set_Priority_14(reg)    (reg |= 0x38)
#define  Set_Priority_13(reg)    (reg |= 0x34)
#define  Set_Priority_12(reg)    (reg |= 0x30)
#define  Set_Priority_11(reg)    (reg |= 0x2C)
#define  Set_Priority_10(reg)    (reg |= 0x28)
#define  Set_Priority_09(reg)    (reg |= 0x24)
#define  Set_Priority_08(reg)    (reg |= 0x20)
#define  Set_Priority_07(reg)    (reg |= 0x1C)
#define  Set_Priority_06(reg)    (reg |= 0x18)
#define  Set_Priority_05(reg)    (reg |= 0x14)
#define  Set_Priority_04(reg)    (reg |= 0x10)
#define Set_Priority_03(reg)   (reg |= 0x0C)
#define Set_Priority_02(reg)   (reg |= 0x08)
#define Set_Priority_01(reg)   (reg |= 0x04)

#define Set_Group_Lvl_0(reg)   (reg &= 0xfc)
#define Set_Group_Lvl_1(reg)   (reg = (reg & 0xfc) | 0x01)
#define Set_Group_Lvl_2(reg)   (reg = (reg & 0xfc) | 0x02)
#define Set_Group_Lvl_3(reg)   (reg = (reg & 0xfc) | 0x03)
```

These are used as follows:

```
Set_Priority_01(<interruptcontrolregister>) ;
```

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Example

Set the priority of the T3 overflow interrupt to 02:

```
void timer3_init(unsigned int baudrate) {
      T3CON = 0 ;       // 0.4us per count, timer mode, count up
      Set_Priority_02(T3IC) ;
      T3IE = 0 ;        // No interrupts until char coming in or
                        // to be sent
      }
```

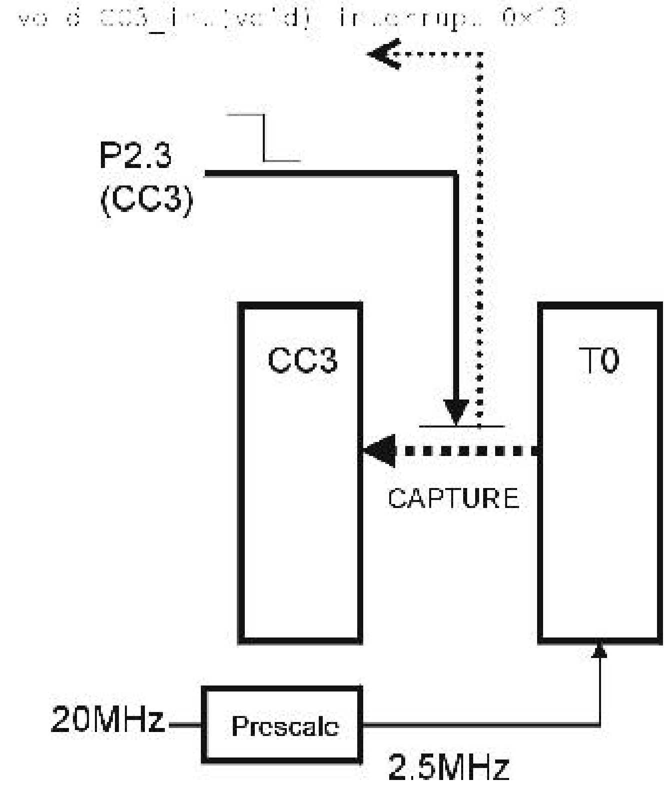
Set the priority of the CC8 input captures interrupt to 01:

```
void init_CC8_int(void) {
   CCM2 = 0x0002  ; // Capture interrupt on P2.8, negative edge triggered
   Set_Priority_01(CC8IC) ; // Higher priority than
                            // T3 overflow interrupt
   }
```

EXERCISE 16: EX16

Objective:

Use CAPCOM unit and interrupts to measure frequency of square wave on P2.3.



Procedure:

The CAPCOM channel on port P2.3 must be configured to capture the value of a free running 16-bit timer, Timer0 every time that a falling edge appears on the pin. A small interrupt routine must be called to calculate the number of timer counts between successive edges, using:

```
time_between_edges = CC3 - time_last_edge ; // Find time since last edge
```

Provided that not more than one timer0 overflow occurs between edges, the result will always be a positive number that represents the time between edges. Make T0 run at 0.4us/count.

Each port 2 pin has a CAPCOM channel associated with it. Channel CC0 is attached to P2.0. Here, channel CC3 is connected to P2.3.

(i) The CCM0 (CAPCOM mode register zero) register contains four 4-bit fields that allow the modes of CAPCOM channel 0,1,2 & 3 to be individually set. CAPCOM channel 3 (port P2.3) occupies the upper nibble of CCM0. The ACCx bit in each case assigns the CAPCOM channel to either Timer 0 or Timer 1. Here, you must use Timer 0.

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(ii) The CC3IC interrupt control register must be configured to:
- Allow an interrupt to occur when the negative edge on P2.3 occurs
- Assign interrupt priority level 2, group level 1 to the CC3 channel

(iii) An interrupt service routine is required to which the CPU will jump when the negative edge occurs. The argument to the interrupt keyword is the TRAP number, obtained from the interrupt vector table in section 5 of the C167CR manual. This routine will contain the subtraction calculation.

(iv) The frequency of the input signal is found by taking the reciprocal of the measured time. For convenience, this should be a floating point calculation. The result is printed to the LCD display.

Put the C515C DIL switch to position '00000010' to start the square wave generator.

02

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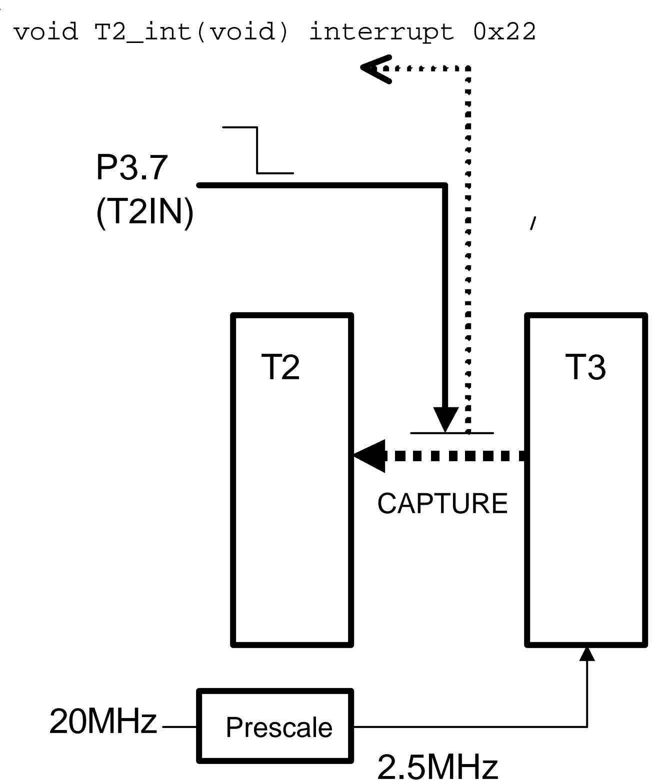
EXERCISE 16 (FOR C165: EX16 .165)

Objective:

Use GPT1 timer2 and timer 3 and an interrupt to measure frequency of waveform on P3.7 (T2IN). Note that this exercise is located in C:\166train\ex16\work.165.



Procedure:

The T2IN pin on port 3.7 must be configured to capture the value of a free running 16-bit timer, Timer3 every time that a falling edge appears on the pin. A small interrupt routine must be called to calculate the number of timer counts between successive edges, using:

```
time_between_edges = T2 - time_last_edge ; // Find time since last edge
```

Provided that not more than one timer3 overflow occurs between edges, the result will always be a positive number that represents the time between edges. Make T3 run at 0.4us/count.

Each GPT timer has an input pin associated with it that can trigger its timer to do something, here it will be capture. Timer2's input pin, T2IN, is attached to P3.7.

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(i) Set the T2CON register to make T2IN (P3.7) negative edge triggered, capture mode.

(ii) The T2IC interrupt control register must be configured to:
- Allow an interrupt to occur when the negative edge on P3.7 occurs
- Assign interrupt priority level 2, group level 1 to the T2 interrupt

(ii) The CC3IC interrupt control register must be configured to:
- Allow an interrupt to occur when the negative edge on P2.3 occurs
- Assign interrupt priority level 2, group level 1 to the CC3 channel

(iii) An interrupt service routine is required to which the CPU will jump when the negative edge occurs. The argument to the interrupt keyword is the TRAP number, obtained from the interrupt vector table in section 5 of the C167CR manual. This routine will contain the subtraction calculation.

(iv) The frequency of the input signal is found by taking the reciprocal of the measured time. For convenience, this should be a floating point calculation. The result is printed to the LCD display.

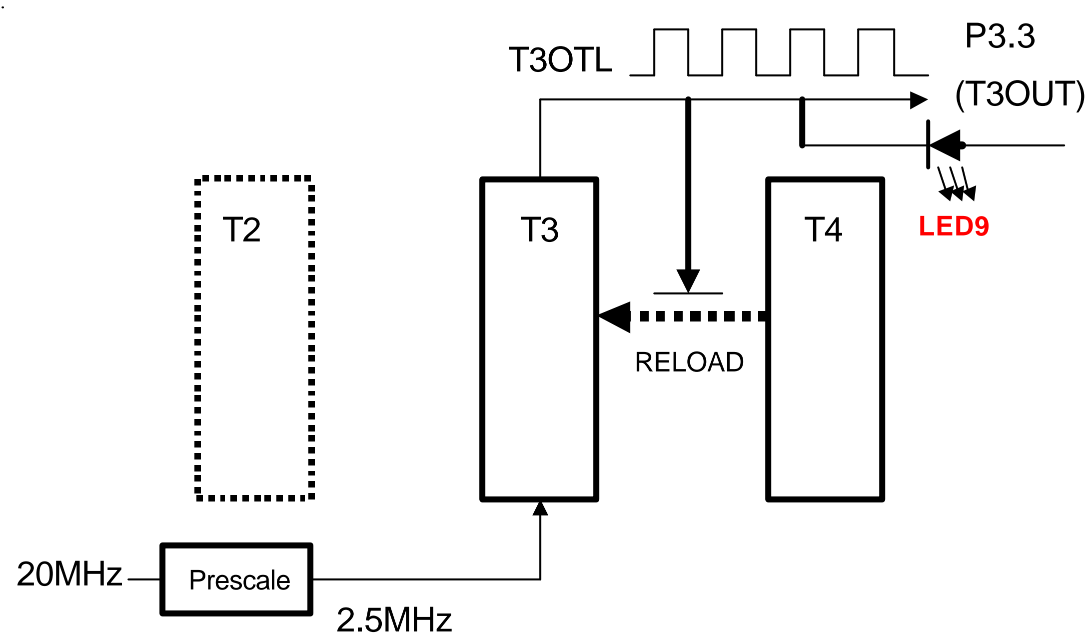
Put the C515C DIL switch to position '00000010' to start the square wave generator.

02

EXERCISE 16A (FOR C165: EX16A.165)

Objective:

Use GTP1 timer4 & 3 to generate a regular 1Hz interrupt via the T3 output toggle latch (T3OTL) and T3OUT pin (P3.3). Make the timer3 interrupt flash the first LED in the array, LED0 (P2.6) by conventional pin-toggling in the service routine. Use the T3OUT function to drive LED9 in the LED array. **Note:** LED9 has been wired to T3OUT and is the 10th LED (leftmost). Note that this exercise is located in C:\166train\ex16a\work.165.



Procedure:

(i) Use Timer 3 as a free running timer. Set the Timer 3 prescaler to the same value as used in EX3 so that the overflow rate is 1.68 seconds. Make T3 count up and enable the T3OE function.

(ii) Initialise LED0 and T3OUT (P3.3) as output pins so that the LEDs in the 10-way array on the training board can be driven.

(iii) Configure T4COM to reload T3 on any transition of the T3OTL, itself toggled by a T3 overflow. The T4 timer register should contain the same value used for T7REL in EX3 to give a 1 second period.

(iv) Use interrupt level 2, group level 0 for the T3 interrupt service routine. Toggle LED0 using an exclusive OR function in the service routine..

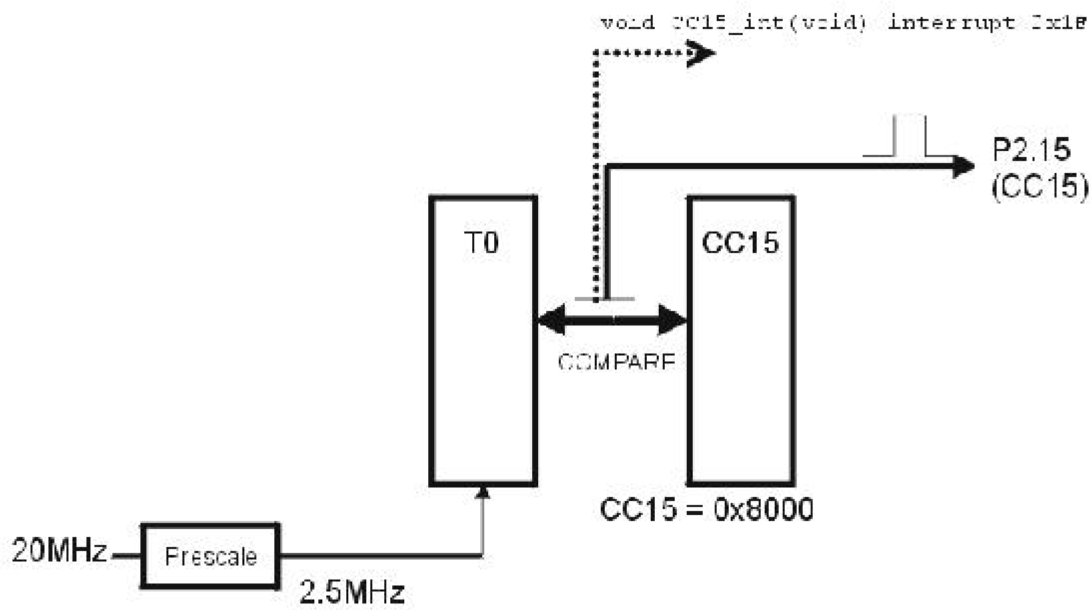
(v) Load the progam into HiTOP and run it. If you force new values into T4 via the SFR window you should see that the flash rate alters accordingly.

Note: The training board's CPU is not used in this example.

EXERCISE 16A: EX16A

Objective:

Use CAPCOM unit to generate a regular 1Hz interrupt via the output compare mode. Make the CAPCOM flash LED0 (P2.6) by conventional pin-toggling in the service routine but use the pin-toggling compare mode for LED9 (P2.15).



Procedure:

(i) Use Timer 0 as the timebase for CAPCOM channel CC15 (P2.15). Set the Timer 0 prescaler to the same value as used in EX3 so that the overflow rate is 1.68 seconds.

(ii) Initialise LED0 and LED9 as output pins so that the LEDs in the 10-way array on the training board can be driven.

(iii) Configure CC15 to use a compare mode that gives an interrupt and the automatic toggling of port 2.15. In a manner similar to that used in EX16, set the four bits that control channel CC15 via the _bfld_() intrinsic function.

(iv) Use interrupt level 2, group level 0 for the interrupt service routine. In the service routine, add an increment "interrupt_period" to the existing CC15 value to create the next interrupt. Toggle LED0 using an exclusive OR function.

(v) Load the progam into ***HiTOP*** and run it. If you force new values into "interrupt_period" via the Watch window you should see that the flash rate alters accordingly.

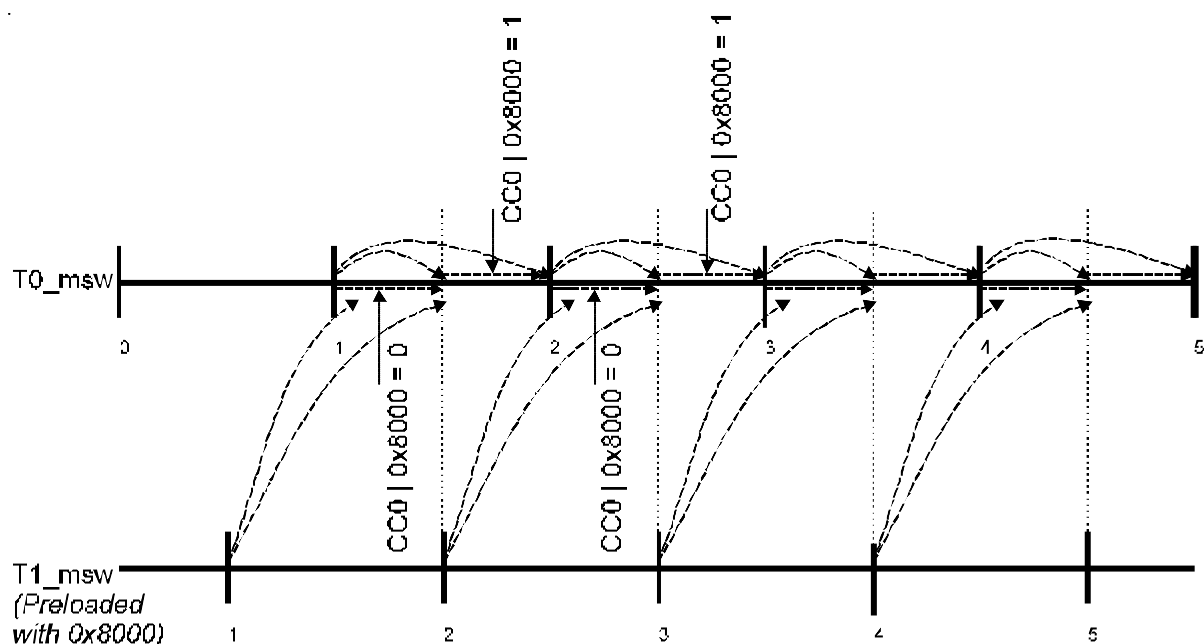
Note: The training board's CPU is not used in this example.

14.4.1 Application Example - 32-Bit Captures

The limitation of the method used in the last exercise is that if the period of the input is greater than or equal to twice the period of the 16-bit timer, result will be incorrect. By using both timer 1 and timer 2 as a reference, period measurements of very low frequency signals can be made accurately. The need to measure periods from very low to very high frequencies is often required in engine management systems, where crankshaft speeds can be nearly zero under cold starting conditions but very high at maximum power.

Here is how it is done:

Timer T1 is preloaded with 0x8000 while T0 remains at zero. Both timers have overflow interrupts at (for example) priority level 12. Each overflow interrupt simply increments the appropriate overflow counter and exits. The timers are started together by writing to the T01CON register. As T1 was preloaded with 0x8000, the T1 overflow counter will always be one count ahead of that for T0. The input waveform is applied to a capture pin, assigned to timer T0. The capture interrupt service routine at priority level 13, checks whether the captured value was in the upper half of T0. If it was, then it can be guaranteed that the overflow word for T0 is stable and will not change. This value is then used to calculate the 32-bit period value since the last edge. If the captured value is in the lower half of T0, then the overflow count from T1 is used as it can be guaranteed that it is stable. The fact that the overflow interrupts cannot interrupt the capture routine ensures that the chosen timer overflow counter is stable.



An example of this technique can be found in \EX16A\SOLUTION.

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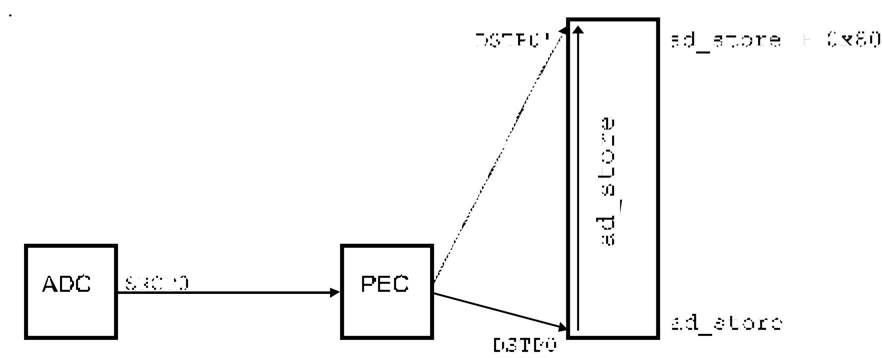
14.5 The Interrupt-Driven PEC System

The peripheral event controller (PEC) is an excellent way of moving data to and from C166 peripherals and RAM. It is essentially an extension to the interrupt system. Commonly, the PEC transfers are made between peripherals and the on-chip RAM, using just one CPU cycle (100ns). The transfer is triggered by any active interrupt source producing an interrupt request. Rather than result in a normal service routine call, the PEC system just moves data from the address indicated by the source pointer (SRCPx) to that indicated by the destination pointer (DSTPx). If either of the two pointers is incremented by the PEC, as would be required if an array was the destination or source, a conventional interrupt service routine will be required after up to 255 transfers to reset the pointers back to the base of the array. The source and destination addresses are indicated by source and destination pointers. These are situated at 0xFDE0 - 0xFDFF on the C166 and 0xFCE0- 0xFCFF on the C167/5, with PEC channel zero's pointers being at the lower address limit in each case.

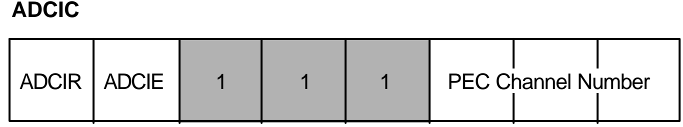
Note: The design of the C166 restricts the PEC destination and source addresses to being in the first 64kb.



P.E.C. Overview

14.5.1 Setting The PEC Channel Number

The interrupt control registers must be set as follows:


ADCIC

ADCIR	ADCIE	1	1	1	PEC Channel Number

Where the lower three bits set the channel number to be used.

14.5.2 Setting Up The PEC System

The C166 language features necessary to use the PECs are:

```
#pragma PECDEF(x,y,...),_sof_(addr) , SRCPx, DSTPx
```

The necessary steps are:

(i) Reserve space in on-chip RAM for PEC pointers with #pragma PECDEF(x,y,....).
(ii) Set source pointer, SRCPx to address of register or location that will generate data

```
SRCP0 = (unsigned int)&ADDAT    ;  // Set up source pointer 0
```

(iii) Set destination pointer, DSTPx, to address of location into which data is to be placed.

```
DSTP0 = _sof_(ad_store) ;  // Setup store pointer 0
```

(iv) Configure PEC control registers to set the number of transfers, whether they are byte or word and whether the source or the destination pointers are to be incremented or decremented.

```
PECC0 = 0x80 ;     // Transfer 0x80 values via PEC
 PECC0 |= 0x0200 ;  // Inc dest pointer for store in array, word transfer
```

(v) Set up PEC channel to be used.

```
ADCIC |= 0x38 ;    // Interrupt 14 priority, group level 0 => PEC channel 0
```

(vi) If number of transfers != 0xff, create an interrupt service routine to reset pointers and count register

```
 DSTP0 = _sof_(ad_store) ;  // Set destination pointer back to base of buffer
 PECC0 |= 0x80 ;            // Reset PEC channel counter to store 80 values
```

14.5.3 Special C166 Language PEC Features Explained

```
#pragma PECDEF(0) // Reserve space for PEC pointers at 0FCEO
```

Causes L166 to reserve 4 bytes for source and destination pointers

```
DSTP0 = (unsigned short) _sof_(ad_store) ; // Set destination pointer to buffer base
```

Sets PEC channel 0 destination pointer to the base of the results buffer by using the intrinsic function which returns a 16 value corresponding to the offset of the buffer from the base of segment 0. The _sof_() function has to be used as ad_buffer exists in the near data area which must be addressed via DPP2. If the C "address of operator", '&' was used, only the offset from the base of the near data area would be returned.

```
SRCP0 = (unsigned short) &ADDAT ; // Set up source pointer 0
```

Sets PEC channel source pointer to A/D convertor results register by using & operator. As the ADDAT register exists in the sdata area, DPP3 is used implicitly and so the apparent address of the register is its actual address as DPP3 = 3.

The SRCPx and DSTPx pointers are not real pointers in the normal sense. They are created as a result of a special cast from a constant value to an address.

Extract From reg167.h

The special casts used to convert RAM locations between 0xfce0 and 0xfcff into PEC pointers.

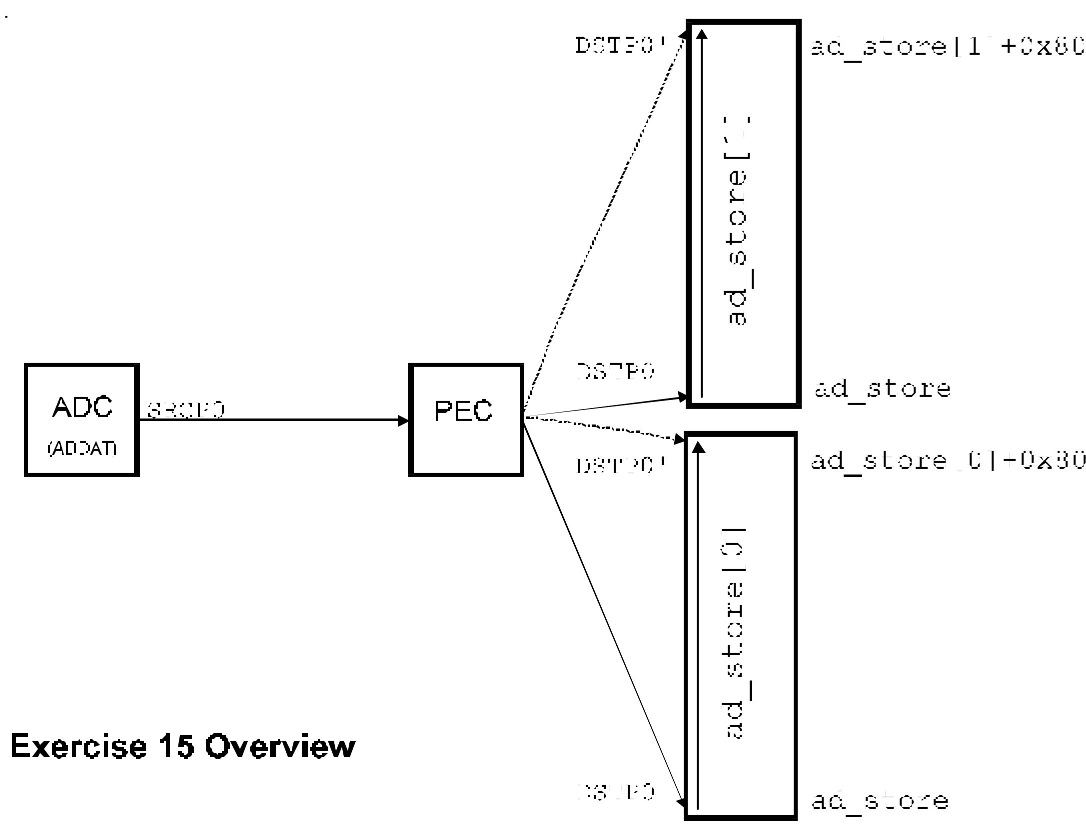
```
#define  SRCP0 (*((unsigned int volatile sdata *) 0xFCE0))
#define  DSTP0 (*((unsigned int volatile sdata *) 0xFCE2))
#define  SRCP1 (*((unsigned int volatile sdata *) 0xFCE4))
#define  DSTP1 (*((unsigned int volatile sdata*) 0xFCE6))
.
.
```

EXERCISE 17: EX17

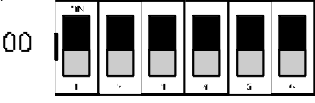
Objective: Use PEC to reduce CPU load in buffering continuous conversion results into dual arrays.

Procedure:

Write a program to continuously read AD channel 0 using "fixed channel continuous conversion" mode. Use the PEC to transfer 128 samples into two buffers alternately. Create a two-dimensional array such as `"unsigned short ad_store[2][0x80]"`. On successive ADC interrupt service routines, set the destination pointer to firstly `"&ad_store[0][0]"` and then to `"&ad_store[1][0]"`.



NOTE: Put the C515C DIL switch to position '00000000' to stop the square wave generator.



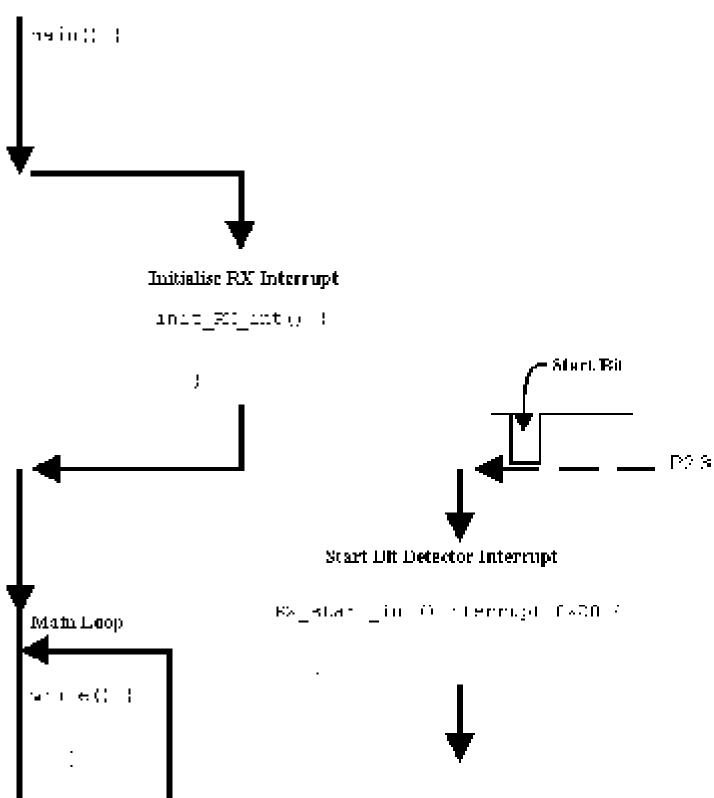
EXERCISE 18: EX18

To illustrate how interrupts are used in C166, we will try to write a 4800 baud software UART, or at least the receiver, the difficult part! This is a real-time program which requires two peripherals to be used in tandem, namely GPT1 and CAPCOM1.

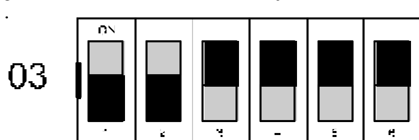
(i) Set up an interrupt function that triggers when a negative edge occurs on the input capture pin, P2.3. This will eventually be used to detect the falling edge of the start bit. Put the initialisation code in a function called "init_RX_int()". Name the interrupt service routine "RX_int_start(). Use the capture mode of the CAPCOM unit and use the Set_Priority_0X(xxIC) macros to set priority level 2, group level 0.

The input capture mode of the CAPCOM unit can be used to create an interrupt only in response to an edge on one of the port 2 pins. In this mode, it is set up to perform an input capture with interrupt service routine but in this example, the captured value is simply ignored.

There is a serial bit stream being applied to P2.3 so you should be able to generate an interrupt from it. Check that you can repeatably get to the interrupt function in ***HiTOP.***



NOTE: Put the C515C DIL switch to position '00000011' to start the character transmitter. It is sending just one character every 100ms. Initially, aim to get your program to detect the falling edge of the start bit.



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14.6 Switching Registerbanks In C

14.6.1 The USING Control

By including the USING <regbankname> control in an interrupt function definition, a new registerbank can be made available for the function and no stacking of general purpose registers will be required.

Here is an example:

```
; /***  Interrupt Service For Timer 0  ***/
;

                REGDEF   R0 - R15
      T0REGBANK  REGBANK  R0 - R15  <———————— Create new register bank

          ?PR?T  SECTION  CODE WORD 'NCODE'

     timer0_int  PROC  INTERRUPT = 16 USING T0REGBANK
     GLOBAL  timer0_int
; FUNCTION timer0_int (BEGIN  RMASK = @0x0012)
;    void timer0_int(void) interrupt 0x10 using T0REGBANK {
                                          ; SOURCE LINE # 13
     SCXT DPP3,#3
     NOP
     MOV  T0REGBANK,R0    <————————— Switch context to new register bank; old CP PUSHed onto
stack.
     SCXT CP,#T0REGBANK
     NOP
?C0006:
?C0007:
     POP  CP  <———————— Original CP restored from stack.
     POP  DPP3
     RETI
; FUNCTION timer0_int (END    RMASK = @0x0012)
     timer0_int  ENDP
          ?PR?T  ENDS
```

Here, a new set of registers is made available and the time for pushing has been eliminated. The decision of when to use the using control should be made after examining the actual code produced by the compiler. If up to three registers are pushed, there is no real advantage in “using”.

14.6.2 Sharing Register Banks

Interrupts of the same priority can share a register bank as they can never interrupt one another and hence no register-bound data be lost.

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EXERCISE 19: EX19

This builds directly on the last exercise to complete the UART receiver.

(i) Write a function called “timer3_init()” to set up timer3 to produce an overflow interrupt every 208us, the basic bit period at 4800 baud - call the interrupt “timer3_int()”. Run it in auto-reload mode with timer2 as the reload register. Use the Set_Priority_0X(n) macros to set priority level 3, group level 0.

Put a USING <regbankname> on both interrupt functions that you have written. Check that you can repeatably get to the interrupt in ***HiTOP***.

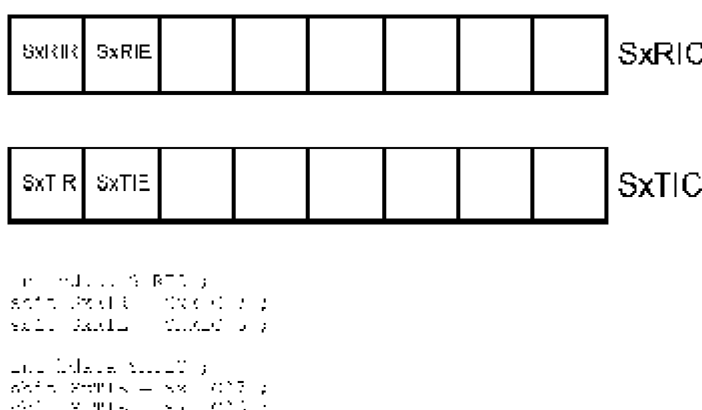
(ii) On each timer3 interrupt, capture the value of P2.3 into bit 9 of an unsigned int bdata variable (`rx_shift_reg`) which will be used as a shift register. You will also need a incoming bit counter called rx_bit_count. On each interrupt, you will need to shift `rx_shift_reg` one place to the right.

(iii) Modify the P2.3 input capture interrupt to enable the timer3 overflow interrupt. Make sure that the timeout from this point to the first timer3 interrupt is one and a half the 208us bit period used in the timer3_init() function. This will make sure that you are sampling each subsequent incoming bit in the centre! A good trick is just to force T3 to a one and a half bit-period count in the capture interrupt so that you get one longer timeout period to start with. This makes the first timer 3 interrupt occur in the middle of the first bit - the start bit contains no information!

(iv) After 9 interrupts (i.e. 10-bits per frame) the timer 3 interrupt must disable itself.

(v) On the last interrupt, move the byte in the lower half of `rx_shift_reg` into a global variable called “SxRBUF”. Create a global bit flag called SxRIR and set it at this point to tell the background that a character has been received.

(vi) Stop timer 3, clear the interrupt request flag for CC3 and set its interrupt enable, ready for the next start bit.



NOTE: Once you can reliably receive the transmitted character, put the C515C DIL switch to position '00000100' to make the character transmitter send an ASCII message string.

Collect the received characters into a buffer in the main() loop:

```
while(1) {
      while(!SxRIR) { ; }
      SxRIR = 0 ;
      rx_buffer[i++] = SxRBUF ;
       }
```

14.6.3 Application Note - Using just the CAPCOM unit to realise the UART receiver

A more elegant solution is to use the CC3 CAPCOM channel to both detect the start bit and generate the bit clock to capture the incoming bits in the serial stream. The initial configuration of CC3 is identical to that already used. However, in the CC3 interrupt, the mode set by CCM0 is changed to compare mode. The CC3 register is then incremented by the number of timer counts that corresponds to one bit time. After all the bits have been captured, the CCM0 mode is set back to capture mode, so that the next start bit falling edge can be detected.

EXERCISE 20: EX20

Objective:

Implement the CAPCOM-based UART receiver.

Procedure:

(i) Edit MULTUART.C and locate a function called uartA_init(). Modify this function to do the following:

- Set a variable called SABRG to equal the parameter "baudrate". SABRG is a global variable and will be
used later in the CC3 interrupt.
- Set a variable called uartA_bit_count to 9
- Use the _bfld_() intrinsic function to set CAPCOM channel 3 to negative edge triggering to detect the falling edge of the start bit. You will need to use CCM0 to do this.
- Set the CC3 interrupt to priority level 12, group level 0
- Set the start_bit_detect_mode bit variable to 0

This completes the initial configuration of CAPCOM channel 3.

(ii) Modify the uartA_rx_interrupt() function to do the following:
- If start_bit_detect_mode is one, as it will be while CC3 is in negative edge-triggered mode, add a umber of counts corresponding to one and a half bit periods (SABRG + SABRG/2) to CC3 itself.
- Set the CC3 mode to compare mode to create another interrupt one and a half bit periods later.
- Clear the start_bit_detect_mode bit flag.

- If start_bit_detect_mode bit flag is zero, capture the bit on port 2.3 into "rxA_shift_reg". We have provided a sbit named "rxA_shift_reg_input" that is the bit 9 of rxA_shift_reg. Likewise, uartA_input_pin is an sbit representing port 2, bit3. The C statement "rxA_shift_reg_input = uartA_input_pin ;" will perform the bit capture into rxA_shift_reg.
- Shift the word variable "rxA_shift_reg" one place to the right.
- Decrement the bit counter "uartA_bit_count".
- When uartA_bit_count reaches zero, set start_bit_detect_mode to 1 and transfer the lower 8 bits of rxA_shift_reg to a variable called "SARBUF". Set uartA_bit_count back to 9 and change the compare mode of CC3 back to capture on negative edge, ready for the next start bit. Finally, set a bit called "SARIR" to tell the code in MAIN.C that a new character has been received.

(iii) MAIN.C need not be changed. It will capture the received characters into a buffer which may be examined via ***HITOP***.

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14.7 When Your C166 CPU Keeps Flying Off Into Space...

Filling The 80C166's Trap Area With Dummy Interrupts

Good practice says that any unused interrupt vectors should be filled with a jump to a defined address, usually RESET. This prevents a system from crashing should an unexpected interrupt occur. However, during debugging, it is more useful to be able to find out what the erroneous trap was, rather than to just go back to reset.

14.7.1 The Trap.C File

To allow the source of traps to be easily found, we have created a file containing dummy interrupt functions for all 80C166 interrupt sources. Each function contains an endless while(1) loop. Thus, if the CPU vectors off to some unexpected interrupt, it will come to rest safely in a loop which will allow the source to be identified. If a debugger is being used, set breakpoints on each of the dummy interrupt routines so that you can look back though the trace buffer to find out where the error or false interrupt occurred.

Here is an extract from the file:

```
/*** CAPCOM Unit Interrupt Traps ***/
void CAPCOM0_int(void) interrupt 0x10 {
while(1){;} }
void CAPCOM1_int(void) interrupt 0x11 {
while(1){;} }
void CAPCOM14_int(void) interrupt 0x1e  { while(1)  { ; } }
void CAPCOM15_int(void) interrupt 0x1f  { while(1)  { ; } }
void timer0_int(void) interrupt 0x20  {
while(1) { ; } }

/*** General Purpose Timer Unit Traps ***/
void GPT_timer2_int(void) interrupt 0x22  {
while(1)  { ; }
void GPT_timer6_int(void) interrupt 0x26  { while(1)  { ; } }
void GPT_CAPREL_int(void) interrupt 0x27  { while(1)  { ; } } }
void serial0_tx_int(void) interrupt 0x2a { while(1)  { ;} }
void serial0_rx_int(void) interrupt 0x2b { while(1)  { ; } }
void serial0_error_int(void) interrupt 0x2c { while(1)  { ; }
void serial1_tx_int(void) interrupt 0x2d { while(1)  { ; } }
void serial1_rx_int(void) interrupt 0x2e { while(1)  { ;} }
 void serial1_error_int(void) interrupt 0x2f{
while(1) { ; } }

/*** Hardware Traps ***/
void NMI_Trap(void) interrupt 0x02 {
while(1)  {; }
} void STKOF_Trap(void) interrupt 0x04 {
while(1)  { ; }
} void ClassB_Trap(void) interrupt 0x0a { while(1)  { ; } }

/*** Software Traps ***/
void software_trap_49(void) interrupt  49 { while(1) { ; }
} void software_trap_50(void) interrupt  50 { while(1) { ;} }
} void software_trap_127(void) interrupt  127 { while(1) { ; } }
```

This file is compiled and linked as normal. As the vector area is now filled with JMPSs, the normal reserve statement can be removed. Note that any interrupt sources used by your application must be commented out

of the source file otherwise when you link, "duplicate interrupt number errors" will be flagged. If you are using a ***HiTOP166*** monitor debugger, you will need to comment out the serial port0 traps.

In the final application, it would be more useful to call a diagnostics function which could perhaps send an error message to a terminal. Of course, the error message should be suitably cryptic so that your end user will not know that your released code has encountered a system stack overflow and hence not start asking awkward questions....

14.7.2 Common Reasons For Getting To Unexpected Traps

(i) If you end up at the "word access to odd address" trap, check that you have not externally referenced a char quantity as an unsigned int! Using the suggested intelligent include files method, this problem can be eliminated.

(ii) If you end up at an interrupt vector which was completely unexpected, check that you have not got two interrupt sources set with the same priority *and* group level. Using the Set_Priority() macros will help avoid this. Also check that you have not got an incorrect or missing interrupt number.

(iii) If your program seems to end up at main() again rather than going to an interrupt routine, check that you have got the interrupt number right. The CPU could vector off, find no JMPS and just plough on until it sees ?C_STARTUP again!

14.7.3 New Control for Interrupt Functions

NOT_SAVE_DPP3

New C167 Libraries which do not alter DPP0 and DPP3 registers. All accesses to far/huge/xhuge variables are done with EXTS/EXTP instruction sequences which means that DPP3 and DPP0 are never changed. PUSHes and POPs of DPP3 and DPP0 in interrupt functinoc are eliminated. Only safe with MOD167.

14.8 Advanced Technique - Simulating Static Register Variables

The C166 core was designed to allow automatic variables to be allocated to registers so that no intermediate data needs to be moved off chip and hence only 100ns register instructions are used. The C166 compiler will automatically try to allocate locals to registers. It is often that case though that an interrupt function will need to operate on some static data, which will normally have to be in ordinary data RAM that requires extra time to access. The USING directive is useful for allowing a fast context switch but it can also provide what are effectively static register variables: provided that no other interrupt function uses a particular register bank, the data left behind after a previous run of the interrupt function will still be there. Thus, any automatics created in an interrupt function which has an USING will in practice be static locals, whose values will be preserved between function calls. Making use of this trick can drastically reduce the run time of large interrupt functions. There are unfortunately two drawbacks in the current v3.0x C166 compiler:

(i) The static data in the interrupt cannot easily be accessed by background loop functions, as with any local.

(ii) The normal compiler memory initialisation cannot be relied upon to clear the register bank and no initial values can be given.

However, the zeroing phase can be performed by creating a special function which has the same USING register bank, as shown in the function “void clear_regs(void) using T0REGS”. Note the sdata pointer “context pointer” created to the base of the register bank by casting the CPU’s context pointer (CP) to a unsigned int pointer.

```
#include <reg166.h>
extern unsigned int rptr ;
unsigned int * sdata regs ;
unsigned int basereg ;
int const i = 0xaaaa ;

/*** Interrupt Function Using A Registerbank ***/
void timer0(void) interrupt 0x20 using T0REGS {
    unsigned int var1, var2 ;  // These are in practice statics

   var1 = CC0 - var2 ;  // Find time between interrupts
   var2 = CC0 ;   // Remember CC0 value for next time...
   }

/*** Clear Out Register Bank Used By Interrupt Function ***/

void clear_regs(void) using T0REGS {

   static unsigned char i ;
   static unsigned int sdata *context_ptr ; // Create pointer to base of regbank

   context_ptr = (unsigned int sdata *) CP ;

   for(i = 1 ; i < T0REGS_Size ; i++) {  // Never touch R0

      context_ptr[i] = 0 ;
      }
   }

/*** Main Background Loop ***/

void main(void) {

   clear_regs() ;

   basereg = (*((unsigned int sdata *) rptr)) ;
   regs = (unsigned int *) rptr ;
   *regs = 0xaaaa ;
   regs[1] = 0x5555 ;
   }
```

14.9 Fixing Register Banks At Absolute Addresses

Registerbanks created by the USING statement can be fixed at specific addresses using the REGBANK control. This is sometimes necessary when on-chip RAM is in short supply and precise control of where things end up is required. C166's default register bank, used by background loop functions, goes by the name of ?C_MAINREGISTERS and will sit at 0xfc00 unless told otherwise. Any new register banks created by the USING statement can also be placed, for example:

```
void timer0_int(void) interrupt 0x20 USING T0REGS {
   }

main.obj,&
moda.obj &
to exec.abs &
CLASSES(FDATA(0x8000),
        FDATA0(0x8000)) &
SECTIONS(?MAIN?FD0%FDATA0(0xA000))
REGBANK(T0REGS(0xfd20))
```

14.10 Controlling the CP directly -Some Tricks With Registerbanks

A registerbank is really just 16 contiguous words of on-chip RAM. Thus is it entirely possible to create your own registerbanks from int arrays. The context pointer can then be set to point at the base of the array to perform a manual context switch.

```
int idata NEWREGBANK[0x10] ;  // Create a word array of 16bytes
.
.
CP = &NEWREGBANK[0] ;  // Perform a manual context switch
```

Why would you want to this? In very time-critical code, the ideal situation would be that any subsequent functions from an interrupt function would have their own dedicated registerbank. Thus both the interrupt function and the called function could use up to 15 registers each for locals. Unfortunately, C166 does not really allow you to do this, although the register mask concept can help.

```
interrupt_func() using INTREGS {
  otherfunc() ;
  }
```

In a real project, it was necessary to employ the "Simulating Static Register Variables" trick outlined earlier on to permit an interrupt function to use registers to best effect. Unfortunately some time later in the development, a call to a function with many local variables had to be added. The use of registers in the interrupt function was thus largely inhibited, with a great loss of performance.

Adding the registermask @0x8000 to the called function's prototype restored the use registers in the caller to the original state - this mask value says effectively that "this function uses no registers". Unfortunately though, the two functions were now using the same registerbank with the result that the local data from the caller was being destroyed by the second function. The solution was to use the @0x8000 registermasks with a manual context pointer switch to a 16 word array. This allowed both caller and called functions to have their own registerbanks.

Example Of Allocating One Registerbank Per Function

```
/*** Define a new register bank manually ***/

#define INTERPREGS_SIZE 0x10
unsigned int idata INTERPREGS[INTERPREGS_SIZE] ;

/*** Crankshaft TDC Interrupt ***/

void tdc_int(void) interrupt 0x1f using TDCREGS {

   unsigned int temp, time_for_60 ;  // Make this a register variable
   unsigned int time_last_60 ; // These are really static but dedicated
   unsigned int tooth_count ; // regbank TDCREGS makes them like static
                                // register variables
    unsigned int CP_temp ; // Store for current context pointer during interpolator call
.
.
.
    CP_temp = CP ; // Make copy of the current context pointer TDCREGS
    CP = &INTERPREGS[0] ;  /// Set context pointer to special regbank
    master_inj_PW = map_interp((ADDAT & 0x3ff),engine_speed,default_map2) ;
// Call function in new regbank
   CP = CP_temp ;        // Restore original regbank (TDCREGS)
    time_last_60 = CC15 ;  // Store current CC15 for next time...
    }
```

External function's prototype:

```
#ifdef _INTERP_

#else

/***  External  References ***/

    extern unsigned int map_interp(unsigned int,
                                   unsigned int,
                                    unsigned int near *) @0x8000 ;

#endif
```

Note: As the context pointer had to be switched before the function was called, none of the parameters passed to it could be register variables - by switching the registerbank base, they would be inaccessible. Here, the parameters were a CPU sfr and a global variable so no problem arose.

The end result was that both functions could freely use registers and hence the run time was reduced by 40%!

14.11 Special Note On idata (classes IDATA0, IDATA) For C165/7

The C167/5 have an internal RAM which starts at 0xf600 rather than the 0xfa00 of the C166. Unless you tell it otherwise, the program data declared as idata will go into the IDATA0 class and be placed by C166 at 0xfc20, above the 20 bytes required by the background loop registerbank, ?C_MAINREGISTERS.

L166 will not use the region below 0xfa00 unless you tell it via the classes control. This is simply done with the following linker invocation file:

```
main.obj,&
moda.obj &
```

```
to exec.abs &
CLASSES(IDATA0(0xF600),
         FDATA(0x8000),
         FDATA0(0x8000)) &
SECTIONS(?MAIN?FD0%FDATA0(0xA000))
```

It is usually only necessary to specify IDATA0 as any compiler-generated idata classes will be of this type.

14.12 Bit Addressable Data

A major frustration for assembler programmers coming to C used to be the inability of ANSI C to handle bits in the bit addressable area directly. However in the C166, it is possible to force data into the bit addressable area where the 80C166's bit instructions can be used directly.

The simplest bit type is the "bit". Bit variables are declared in the same way as ints and chars:

```
bit flag_bit = 0 ;
```

14.12.1 Special Function Bits

It is also possible to name the bits in a word located in the bdata bit-addressable on-chip RAM area. This allows related bit flags to be grouped together in a single unsigned int object.

First an object is declared as bdata

```
unsigned int bdata test ;
```

Now individual bits may be enabled for bit addressing

```
sbit mybit0 = test^0 ;
```

The symbol mybit0 may now be used for all future bit operations on bit 0 of test.

14.12.2 Note on declaring an sbit as external

To reference an sbit defined in another module, simply use:

```
extern bit mybit0 ;
```

The fact that it was originally defined as a sbit is irrelevant - C166 simply regards it as an ordinary bit data type.

15. Assembler Interfacing - In-line Assembler

C166 allows small sections of assembly code to be embedded directly within C functions. It is however best avoided and it is always better to call assembler code via a normal function call, as described in the next section.

Any module containing in-line assembler must be compiled with the SRC switch to generate a valid assembler file. This file has original C lines simply as comments. Examining the .src file is also useful way of understanding how the compiler works!

EXAMPLE 1:

Compile with:

```
C166 main.c SRC
```

and then assembler with:

```
A166 main.src

void main(void) {

   char x,y,z ;

   x = 1 ;

#pragma  asm

   MOV   R10,#010H ; Assembler

#pragma  endasm

   /* Further C Code */

   }
```

With C166's good code efficiency and intrinsic functions, there are very few occasions when in-line assembler is really required.

Note! You are strongly advised not to use this C166 feature! In almost every case, proper use of the compiler will produce code with near-assembler efficiency. If you absolutely have to use assembler, call it as a function.

15.1 Calling Assembler Functions From C166

15.1.1 Coping With Start Addresses And Parameters

It is entirely possible to call assembler functions from C166. The most fundamental requirements are:

(i) Ensure that the start address label is accessible to C166 i.e. make sure that L166 can tie up the call in C166 with the target label in the assembler file.

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Any label declared as PUBLIC in A166 is accessible from C166:

A166 Module

```
           PUBLIC  ASM_START

ASM_START: MOV    R1,#100H
           MOV    R2,[R1+]
```

C166 Module

```
extern void asm_start(void) ;

.
.
.
   asm_start() ;    // Call function written in assembler
.
.
```

(ii) Make sure that any parameters required by the assembler function are placed in the correct registers by C166.

The simplest way to acheive this is to write the C module which contains the call to the assembler function and compile it with the SRC option. The resulting .SRC file will show in which the placement of each parameter will be shown.

Example

```
asm_func(0x1000,0x80000000, (char huge *) 0x104000) ;  // Call asm function

     MOV   R11,#16384              ; huge pointer (SOF offset)
     MOV   R12,#16                 ; huge pointer (SEG number)
     MOV   R9,#0                   ; long data lower word
     MOV   R10,#-32768             ; long data upper word
     MOV   R8,#4096                ; int data word
     CALLA cc_UC,asm_func
;
```

15.1.2 Pointer Passing To Assembler Functions

The components of a pointer are passed to functions by C166, according to the following rules:

near pointers
The pointer consists of a single 16-bit value which is able to address a 0x4000 range, passed in a single register.

```
MOV  R4,[R8]
```

far pointers
The far pointer is page based and consists of two words (32-bit) value which are able to address a 0x4000 range, passed in two registers:

Rx+1 - page number
Rx - page offset

```
EXTP R9,#1
MOV  R4,[R8]
```

huge and xhuge pointers
The huge pointer is segment based and consists of two words (32-bit) value which is able to address a 0x10000 range, passed in two registers. The xhuge pointer is identical in format but able to address an unlimited range.

Rx+1 - segment number
Rx - segment offset

```
EXTS R9,#1
MOV  R4,[R8]
```

15.2 Using C166 To Write Assembler Functions

The simplest way to produce assembler modules is to use C166 as the starting point. Here is what to do;

(i) Create a C module which contains a function with the required name.

(ii) Declare the major local and global data required by the embryonic assembler function.

(iii) Compile the C module with the SRC option.

(iv) Use the resulting .SRC file as a template on which to base your own further assembler work.

(v) Assemble .SRC file with A166

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Example

```
$NOMACRO
$SEGMENTED CASE MOD167
;
; 'S.SRC' GENERATED FROM INPUT FILE 'S.C'
; COMPILER INVOKED BY:
;       C:\C166V2\BIN\C166.EXE S.C SRC
;
           NCODE  CGROUP  ?PR?S
         NCONST  DGROUP  ?NC?S
         NDATA  DGROUP  ?ND0?S
         SDATA  DGROUP  ?ID0?S,SYSTEM

                ASSUME  DPP1 : NCONST
                ASSUME  DPP2 : NDATA
                ASSUME  DPP3 : SDATA
         ?NC?S  SECTION  DATA WORD 'NCONST'
        string  DB  'H','E','L','L','O',00H
        PUBLIC  string
         ?NC?S  ENDS

        ?ND0?S  SECTION  DATA BYTE 'NDATA0'
   asm_global1  DSB  1
        PUBLIC  asm_global1
        ?ND0?S  ENDS

        ?ID0?S  SECTION  DATA WORD 'IDATA0'
   asm_global2  DSW  1
        PUBLIC  asm_global2
   asm_global0  DSW  1
        PUBLIC  asm_global0
        ?ID0?S  ENDS

; #pragma MOD167
; #include <reg167.h>
;
; char const near string[] = "HELLO" ;
; int idata asm_global0 ;
; char near asm_global1 ;
; int idata * idata asm_global2 ;
;
        REGDEF   R0 - R15
    TIMER_REGS  REGBANK  R0 - R15

         ?PR?S  SECTION  CODE WORD 'NCODE'

        asm_timer_int  PROC  INTERRUPT = 16 USING TIMER_REGS
        GLOBAL asm_timer_int
; FUNCTION asm_timer_int (BEGIN  RMASK = @0x0010)
; void asm_timer_int(void) interrupt 0x10 using TIMER_REGS {
                                           ; SOURCE LINE # 10
        SCXT    DPP3,#3
        NOP
        MOV     TIMER_REGS,R0
        SCXT    CP,#TIMER_REGS
        NOP
?C0003:
        SUB     R0,#2
;
;    int a, b ;
;
;    a = CC1 ;
                                           ; SOURCE LINE # 14
        MOV     R4,CC1
;—— Variable 'a?01' assigned to Register 'R4' ——
;
;    }
                                           ; SOURCE LINE # 16
        ADD     R0,#2
?C0004:
        POP     CP
        POP     DPP3
        RETI
; FUNCTION asm_timer_int (END   RMASK = @0x0010)
        asm_timer_int ENDP
         ?PR?S  ENDS
        END
```

16. The Part 2.0B CAN Module

The CAN module on the C167CR microcontroller has the following features;

- Transfer rates up to 1Mbaud.
- Standard 11-bit and Extended 29-bit protocols.
- Message object architecture.
- Minimal CPU management overhead.

The CAN module is derived from standalone CAN components like the 82C257 so anybody having written CAN software before should find the procedures very familiar. The first job is to understand what the CAN module's control registers do and how they are addressed.

16.1 CAN Registers

The CAN module is a C167 XBUS peripheral which is accessed via an area of memory-mapped registers, starting at address 0xEF00. These registers are made up of 6 General Control Registers (GCR) and 15 Message Object Buffers (MOB). Their arrangement is shown in the diagram below.

Control/Status Register

Address	Register
0xEF00	General Registers
0xEF10	Message Object 1
0xEF20	Message Object 2
0xEF30	Message Object 3
0xEF40	Message Object 4
0xEF50	Message Object 5
0xEF60	Message Object 6
0xEF70	Message Object 7
0xEF80	Message Object 8
0xEF90	Message Object 9
0xEFA0	Message Object 10
0xEFB0	Message Object 11
0xEFC0	Message Object 12
0xEFD0	Message Object 13
0xEFE0	Message Object 14
0xEFF0	Message Object 15

General Register	Address
Control/Status Register	0xEF00
Interrupt Register	0xEF02
Bit Timing Register	0xEF04
Global Mask Register	0xEF06
Global Mask Long	0xEF08
Mask of Last Message	0xEF0C

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These bits control and indicate the status of the CAN module.

BOFF	EWRN	_	RXOK	TXOK	LEC	LEC	LEC	0	CCE	0	0	EIE	SIE	IE	INIT
r	r	r	rw	rw		rw		r	rw	r	r	rw	rw	rw	rw

LSByte is control part of register;-

INIT **-** Start initialisation
Write 1 to start the software initialisation of the CAN module.
Write 0 to activate CAN module after initialisation.

IE **-** Interrupt enable of CAN module
Write 1 to enable CAN objects to generate TX/RX interrupts.
Write 0 to stop them.

SIE **-** Status interrupt enable
Write 1 to enable interrupts when TXOK, RXOK are set or LEC is updated.
Write 0 to stop them.

EIE **-** Error interrupt enable
Write 1 to enable interrupts when EWRN or BOFF change.
Write 0 to stop them.

CCE **-** Configuration change enable
Write 1 to enable access to Bit Timing Register.
Write 0 to prevent/protect access.

MSByte is the status part of the register:

LEC - Last Error Code

0	NO ERROR
1	STUFF ERROR
2	FORMAT ERROR
3	ACKNOWLEDGE ERROR
4	BIT 1 ERROR
5	BIT 0 ERROR
6	CRC ERROR

TXOK - Transmitted message successfully
RXOK **-** Received message successfully
EWRN **-** Indicates warning level has reached 96
BOFF **-** Busoff state error level >= 255

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Interrupt Register

The CAN interrupt register indicates the source of the different interrupts that the module can generate:

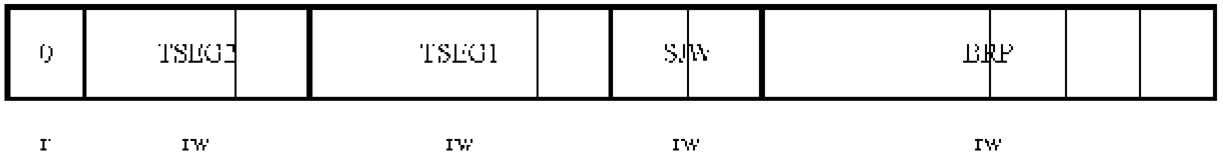
RESERVED	INTID
	r r r r r r r r

INTID - 00 interrupt idle
- 01 status change interrupt
  - if **SIE** set, update of LEC or set of RXOK or TXOK
  - if **EIE** set, change of BOFF or EWRN.
- 2 Message Object 15 (Receive only) interrupt, highest priority
- (2+N) Message Object N interrupt (N=1..14)

Unlike other peripherals in the C167, all the possible interrupt sources in the CAN module share the same vector. Therefore in the single CAN service routine, the user must check the flags in the CAN interrupt register to see what event actually caused the interrupt. In the interrupt routine, the interrupt source must be serviced and then INTID checked again to see if there are any other interrupt sources pending until INTID = 0. This process is covered in more detail later.

Bit Timing Register

This register contains the fields which define the bit times used on the network.



Its probably a good idea to read a document which explains the definitions and theory of calculation behind the CAN bit timing before you get too stuck here! Fortunately, there are some "rules of thumb" that can safely be used in most applications. However, as the timings are largely dependent on the electrical characteristics of physical layer, you should take special care if you have an unusual or very long transmission line.

BRP - Baud Rate Prescaler, defines time quanta.
SJW - (Re)Synchronization Jump Width, allow bit time resync up to (SJW+1) quanta.
TSEG1 - Time Segment before sample point, sample after (TSEG1+1) quanta.
TSEG2 - Time Segment after sample point, (TSEG2+1) quanta after sample.

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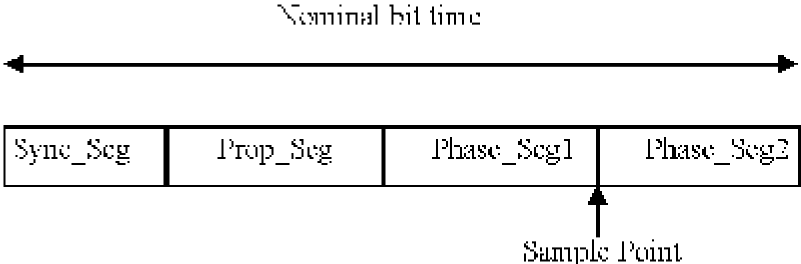
16.1.1 Bit Time calculation

Here is a diagram of a single CAN bit time, which is divided up into 4 separate time segments.



SYNC_SEG - Synchronization segment
PROP_SEG - Propagation segment
PHASE_SEG1 - Phase segment 1
PHASE_SEG2 - Phase segment 2

The fields in the Bit Timing Register relate as follows;

```
TimeSeg1 = PROP_SEG + PHASE_SEG1
TimeSeg2 = PHASE_SEG2

BIT time = SYNC_SEG + TimeSeg1 + TimeSeg2

SYNC_SEG   =  1 quanta (This time is not adjustable)
TimeSeg1   =  (TSEG1+1) quanta
TimeSeg2   =  (TSEG2+1) quanta
1 quanta   =  (BRP+1) * 2 * t
t          =  1 / XCLK FREQUENCY
```

The general rule on defining the sample point is that is should be about 60% of the total BIT time, as recommended in the CAN specification. This corresponds to the capacitive-type loading on the bus, particularly over long distances.

Example

Calculation to generate BIT time to give 100Kbaud with a sampling point of 60% of the nominal BIT time.

```
XCLK = 20Mhz
t = 1/20Mhz

Choose 1 time quanta = 500ns = (BRP + 1) * 2 * t
BRP = 4
```

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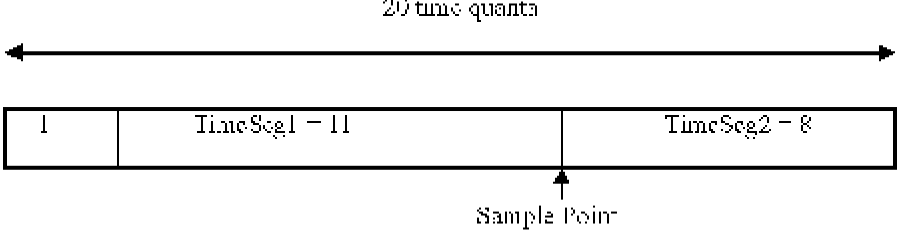
Total time quanta in 100Kbaud = 20

So sample point at 60% = 12 quanta into BIT time



Therefore:

```
TSEG1 = (TimeSeg1 - 1) quanta = 10
TSEG2 = (TimeSeg2 - 1) quanta = 7
```

Choose SJW = 3 (see next paragraph)

```
BTR = (TSEG2 << 12) | (TSEG2 << 8) | (SJW << 6) | BRP = 0x7AC4
```

16.1.2 Resynchronization

Resynchronization occurs when a recessive to dominant bit state change occurs outside an expected SYNC_SEG. If the bit change is earlier than the SYNC_SEG, then PHASE_SEG1 is shortened to compensate. If the bit change is latter than the SYNC_SEG then PHASE_SEG2 is lengthened.

This adds the following constraints on the timings;

```
TimeSeg1   >= Tsjw + PROP_SEG
TimeSeg2   >= Tsjw
```

The maximum number of time quanta that can be added or subtracted is defined by

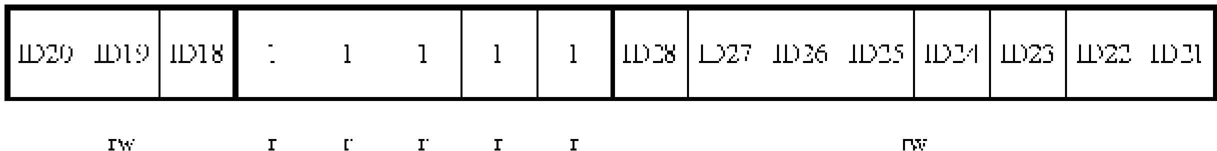
```
Tsjw       =  (SJW+1) quanta
```

So the SJW field allows compensation for phase shift between clocks on different nodes.

Mask Registers

These tell the CAN module which bits of the incoming message ID to compare against the ID's in the RX message object's buffers.

Global Mask Short



ID28..18 **-** standard CAN 11-bit mask

If a bit is set to 1 in the mask it means that the corresponding bit of any message seen on the bus will be compared with the corresponding ID bit in any receive type message objects to see if there is a match. If set to 0, this bit is “don’t care” so it will not be compared against.

Quick example;

```
CAN_Global_Mask = 0xE001;        /* Mask ID = 0x00f */
```

Here, the CAN module only checks the bottom nibble of the 11-bit ID against the RX message object buffers to find a match then captures CAN message.

Upper Global Mask Long / Lower Global Mask Long

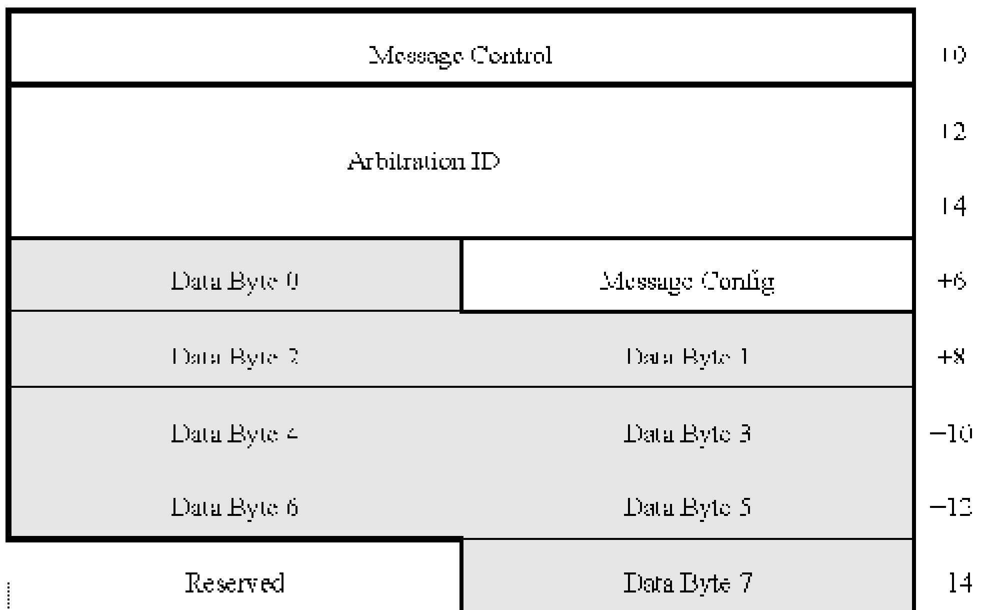
These are two 16-bits registers which contain the 29-bit masks when using extended CAN.

Upper Mask of Last Message / Lower Mask of Last Message

Message object 15 is a receive only object, which can be used for different and infrequently sent messages. It has its own independent mask registers, containing either a 11-bit or a 29-bit mask, depending on type of CAN used.

16.2 Message Objects

The CAN module has a total of 14 identical message objects and a message object 15, which is receive only, having its own masks and double buffering. Each object consists of 15 objects of 15 consecutive bytes, at an address multiple of 16 bytes. The objects represent packets of information of which 8 bytes are real data and the remainder are part of the CAN protocol. A diagram follows:



Message Control Register

This register contains 8 fields which are each made up of 2 complementary bits. This allows a selective set or reset of specific bits without requiring read-modify-write operations. It can also give the software engineer many hours of fun interpreting hex numbers.... The interpretation of the 2-bit fields is given below;

Value	Function on Write	Meaning on Read
00	Reserved	Reserved
01	Reset element	Element is reset
10	Set element	Element is set
11	Unchanged	Reserved

RMTPND	TXRQ	MSGLST CPUUPD	NEWDAT	MSGVAL	TXIE	RXIE	INTPND

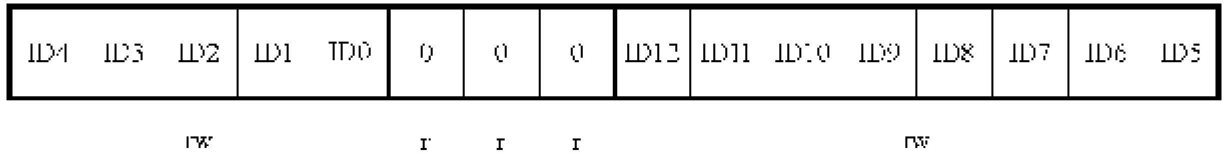
INTPND - Indicates this object generated an interrupt request
Read this to find out if object has interrupted.
RXIE - Interrupt when object successfully receives a message
Set this field if you want interrupts generated when message RXed
TXIE- Interrupt when object successfully transmits message
Set this field if you want interrupts generated when message TXed
MSGVAL - Indicates if object valid. CAN module only operates on valid objects
Clear this to stop CAN module messing with object while your updating it.
NEWDAT - Indicates if data has been written by CPU or CAN module since last cleared
Read this to find out if object has been written too.
MSGLST - RX objects only. Indicates CAN module stored new data while NEWDAT = 1
Read this to find out if previous message was overwritten.
CPUUPD - TX objects only. Stops TX of object while CPU is updating the object.
Set this to stop CAN module Txing this object will your updating it.
TXRQ - Indicates TX of object as been requested by CPU or remote frame
Set this to request TX of this message.
RMTPND - TX objects only. Indicates TX has been requested by remote node.
Read this to find out if the TX of this object has been Remotely Requested.

Upper Arbitration Register

ID20 ID19 ID18	ID17 ID16 ID15	ID14	ID13	ID28	ID27 ID26 ID25	ID24	ID23	ID22 ID21

rw rw

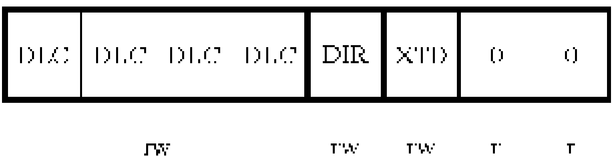
Lower Arbitration Register



Arbitration registers for 11- or 29-bit IDs. Set the RX ID to be captured off the bus for RX type objects or the ID to be TXed for TX type objects.

ID28..0 - 29-bit extended CAN id
ID28..ID18 - 11-bit standard CAN id (ID17..0 Don't care)

Message Configuration Register



XTD - Set if object is set up for 29-bit CAN else standard 11-bit CAN
DIR - Message Direction

DIR = 1 TX Object. When TXRQ set message is transmitted.
On RX of remote frame with matching ID the TXRQ + RMTPND are set

DIR = 0 RX Object. When TXRQ set remote frame with its ID is TXed
On RX of data frame with matching ID message data is stored in object

DLC - Data Length Code values 0..8

Data Fields

DATA BYTE 0	
DATA BYTE 2	DATA BYTE 1
DATA BYTE 4	DATA BYTE 3
DATA BYTE 6	DATA BYTE 5
RESERVED	DATA BYTE 7

DATA BYTE 0..7 - Storage for up to 8 bytes in each message object.

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16.2.1 Using The SECTIONS Control To Access The C167CR CAN Peripheral

It has ben widely commented upon that the CAN module's registers do not appear in REG167.H, along with all the other SFRs. The reason for this is that as an XBUS peripheral, the SFR data type is not appropriate as really the module is just a memory-mapped region with a special significance. Keil suggest that you use casts to a pointer of constant addresses in the CAN peripheral but this is a little dangerous as the linker has no knowledge of the registers and may drop something else on top of them.

It is better to address it via appropriately-named C variables situated over the real control and data registers. This can be acheived with the following souce file, used in conjunction with the given linker input file. The advantage of this approach is that unlike the pointer-based method, L166 physically places these data objects at 0xEF00, so preventing anything else accidentally end up there and causing problems.

Some special controls to note are:

- The ORDER which ensures that the linker places the data in memory in the order in which it appears in the source file.
- The NOINIT control which stops the CAN peripheral being zeroed before the program gets to main().
- The RENAMECLASS control which makes the compiler emit a distinctively named section which the linker's SECTIONS control can use to fix the data at 0xEF00.

File: CAN_REGS.C

```
#pragma ORDER
#pragma  NOINIT
#pragma  RENAMECLASS(SDATA = CAN_REGS)

#include  "can_regs.h"

unsigned  short  volatile  sdata  CAN_Control_Status;
unsigned  char  sdata  CAN_Interrupt;
static  unsigned  char  sdata  reserved;
unsigned  short  sdata  CAN_Bit_Timing;
unsigned  short  sdata  CAN_Global_Mask;
unsigned  short  sdata  CAN_Upper_Global_Mask;
unsigned  short  sdata  CAN_Lower_Global_Mask;
unsigned  short  sdata  CAN_Upper_Last_Mask;
unsigned  short  sdata  CAN_Lower_Last_Mask;

struct  MESSAGE_OBJECT  sdata  CAN_Object[15];
```

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File: CAN_REGS.H

```
struct MESSAGE_OBJECT {
      unsigned short volatile control;
      unsigned short upper_arb;
      unsigned short lower_arb;
      unsigned char config;
      unsigned char volatile data[8];
      unsigned char reserved; };

extern unsigned short volatile sdata CAN_Control_Status;
extern unsigned char sdata CAN_Interrupt;
extern unsigned short sdata CAN_Bit_Timing;
extern unsigned short sdata CAN_Global_Mask;
extern unsigned short sdata CAN_Upper_Global_Mask;
extern unsigned short sdata CAN_Lower_Global_Mask;
extern unsigned short sdata CAN_Upper_Last_Mask;
extern unsigned short sdata CAN_Lower_Last_Mask;
extern struct MESSAGE_OBJECT sdata CAN_Object[];
```

File: EXEC.LIN Linker Control File

```
CLASSES(ICODE(0x200),
         NCODE(0x1000),
         NCONST(0x2000),
              SDATA(0xE000),
              SDATA0(0xE000),
              NDATA(0x40000),
              NDATA0(0x40000))

SECTIONS(?SD?CAN_REGS%CAN_REGS(0xEF00))
```

16.3 Setting Up The CAN Module Baudrate And Sampling Point

EXERCISE 30: EX30

Directory: \166TRAIN.WIN\EX30\WORK

Object: Set up basic CAN module parameters of:

- Baud rate
- (Re)synchronisation Jump Width
- Sampling point

The specification calls for the following settings:

```
CPU clock frequency                    = 20MHz
Baudrate                               = 100kbit/s
(Re)synchronization Jump Width (SJW) = TSEG2 – 1 quanta (SJW <=3)
Synchronisation  Segment               = 1
Sampling point                          = 75%
```

You must calculate the values of the TSEG1, TSEG2, SJW and BRP fields in the CAN_Control_Status and Bit_Timing registers to complete the task. All the other exercises depend on you getting these basic settings right!

Procedure:

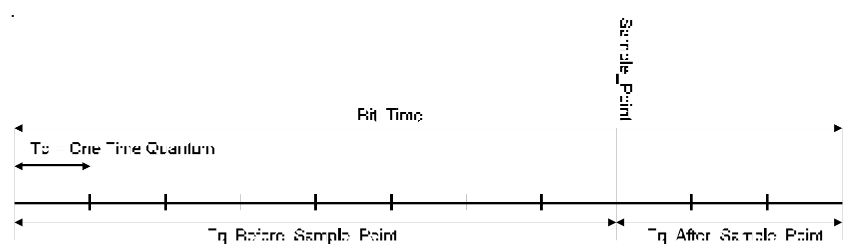
Open the project \166TRAIN.WIN\EX30\WORK and edit the C source file “CAN.C”.

(i) Set the INIT bit in the CAN_Control_Status register to ‘1’ to put the CAN module into initialisation mode. Refer to page 23-6 in the C167CR CAN module description for details of this register.

(ii) Set the CCE bit to remove the write protection on the Bit Timing register. Refer to page 23-10 in the C167CR CAN module description for details of this register.

(iii) Work out the value for the Baud Rate Prescaler (BRP), TSEG1 and TSEG2 fields in the Bit_Timing_Register. The size of the time quanta "Tq" in microseconds must be found first of all. You will also have to find the number of time quanta per bit period plus the TSEG1 and TSEG2 to do this. You can use the following method:

(a) Calculate the bit time at the required baudrate (1/Baudrate). Use microseconds and MHz throughout.
(b) Draw a diagram of the time before the sample point and the time after it:



(c) Write down the equation for this, using units of :

```
Tq_Before_Sample_Point * Tq + Tq_After_Sample_Point * Tq = Bit_Time
```

Substitute: Tq_Before_Sample_Point = (0.75/(1-0.75) * Tq_After_Sample_Point

```
=> (0.75/(1-0.75) * Tq_After_Sample_Point *Tq) + Tq_After_Sample_Point * Tq = Bit_Time

=> 3*Tq_After_Sample_Point * Tq + Tq_After_Sample_Point * Tq = Bit_Time

=> 4*Tq_After_Sample_Point = Bit_Time/Tq

Tq_After_Sample_Point = Bit_Time/(4 * Tq)

=> Tq_After_Sample_Point = 10us/(4 * Tq)
```

To give finally:

```
Tq_After_Sample_Point = 2.5/Tq
```

(d) By inspection of the above equation, a number of values of Tq are possible that give integer values of Tq_After_Sample_Point:

```
Tq = 0.1us,  Tq_After_Sample_Point = 25 time quanta, => Tq_Before_Sample_Point = 75
Tq = 0.5us,  Tq_After_Sample_Point = 5 time quanta, => Tq_Before_Sample_Point = 15
Tq = 2.5us,  Tq_After_Sample_Point = 1  time quanta, => Tq_Before_Sample_Point = 3
```

(e) From the 167 data book:

```
TSEG2 = Tq_After_Sample_Point - 1
TSEG1 = Tq_Before_Sample_Point - Sync_Seg - 1
```

where (2 <= TSEG1 <= 15) and (1 <= TSEG2 <= 7). In simple terms, the number of Tq per bit must be between 8 and 25 inclusive.

These limits should allow you to choose one of the three values of Tq and thence the values of TSEG1 and TSEG2.

Alternatively, you can refer to the supplied table of all possible values of Tq. (Table produced by EXCEL spreadsheet that is available as a handout)

Note on SJW: The biggest possible synchronization jump width will occur when the time quantum size, Tq, is large. This implies that the BRP chosen must therefore be the highest value consistent with meeting the TSEG1 and TSEG2 criteria. A large SJW will therefore make the network more robust.

(iv) You are now able to calculate the value for the Baud Rate Prescaler field in the bit timing register, using the formula:

```
BRP = (Tq*Fosc/2)-1   (using units of microseconds for Tq and MHz for Fosc)
```

(v) Put the value for BRP into the lower 6 bits of the Bit_Timing register.

(vi) Put the resulting value TSEG1 into CAN_Control_Status bits 8-11

(vii) Put the resulting value TSEG2 into CAN_Control_Status bits 12-14

(viii) Set the resynchronization jump width (SJW) to the value TSEG2-1 by writing to CAN_Control_Status bits 6-7.

(ix) Complete the CAN module setup by clearing the bits in the CAN_Control_Status register

(x) Rebuild the project using Project-Build.

(xi) Load the program into the ***HiTOP*** debugger, click the Target Reset button (TR) and run the program. The LCD display should confirm whether you have got the settings correct!

16.4 Configuring The CAN Module For Transmit

EXERCISE 31: EX31

Directory: \166TRAIN.WIN\EX31\WORK

Object: Transmit the digital value of potentiometer zero on the IO board to the CAN monitor program on the OHP screen

This exercise builds on exercise EX30.

CAN message object 1 will be used to send the value to the CAN monitor program that is driving the OHP screen. If you successfully complete the exercise, you will be able to use your potentiometer zero to control the length of a bar on the OHP screen corresponding to your node number!

The means of periodically reading the value of the potentiometer (pot.) is performed in an interrupt routine on timer 3, which is provided.

To transmit, you must decide what message ID to use to transmit your pot value across the network. All the message numbers being used are based on 0x70F. If you are team zero, your transmit message number will be 0x70F. If you are team A, you must use 0x71F. Team B must use 0x72F, team 3 0x73F and so on. You will be given the correct identifier at the start of the session.

Note that in the examples, the number of the CAN object will be denoted by “ONE”, “TWO”, “THREE”, “FOUR” and FIVE”. For example, ”CAN_Object[ONE].control” is the control register for CAN object 1 and “CAN_Object[TWO].upper_arb” is the upper arbitration register for CAN object two and so on.

Open the project \166TRAIN.WIN\EX31\WORK\exec.prj and edit CAN.C.

Procedure:

(i) Before trying to use the CAN module, you must reset all the flags in the Message Control Register for each of the 15 message objects. As these flags consist of *two* bits each, ‘01’ must be written to each two bit field to clear it. Over the total of 8 flags, the pattern 0x5555 will do this.

Special note on the CAN object control registers: This register is unusual in that each flag in it has two bits. To set a flag, ‘10’ must be written and to clear it, ‘01’. If ‘11’ is written, the flag is unaltered. This arrangement is required to allow changes to be made to flags without a READ-MODIFY-WRITE.

Examples:

· To set the MSGVAL flag:

```
Message Control = 0xFFBF ;
```

· To clear the MSGVAL flag:

```
Message Control = 0xFF7F ;
```

CAN_REGS.H file contains ready-made definitions that you can use to set and clear the various flags in the control register during the exercises:

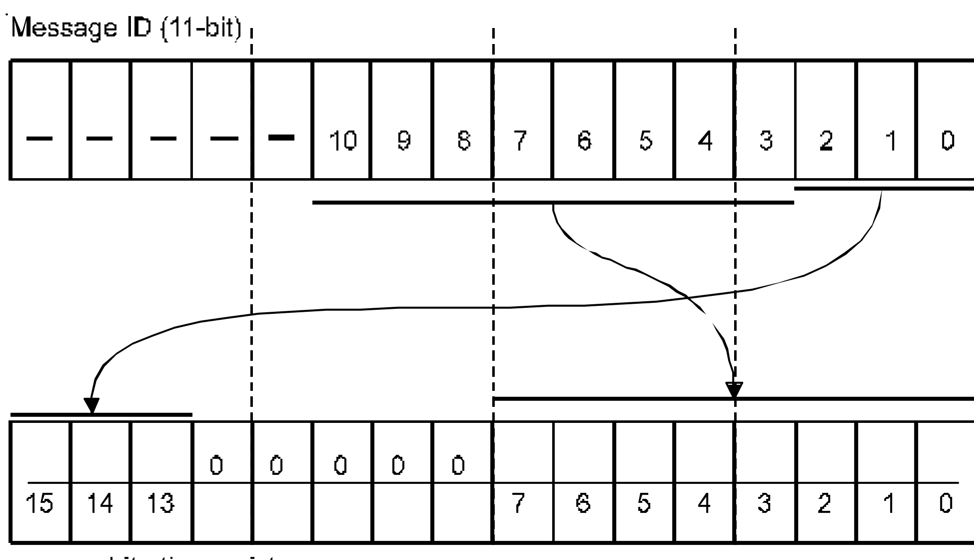
```
#define  SET_RMTPND                    0xbfff
#define  CLR_RMTPND                    0x7fff
#define  RMTPND                        0x8000
#define  SET_TXRQ                      0xefff
#define  CLR_TXRQ                      0xdfff
#define  TXRQ                          0x2000
#define  SET_CPUUPD                    0xfbff
#define  CLR_CPUUPD                    0xf7ff
#define  CPUUPD                        0x0800
#define  SET_MSGLST                    0xfbff
#define  CLR_MSGLST                    0xf7ff
#define  MSGLST                        0x0800
#define  SET_NEWDAT                    0xfeff
#define  CLR_NEWDAT                    0xfdff
#define  NEWDAT                        0x0200
#define  SET_MSGVAL                    0xffbf
#define  CLR_MSGVAL                    0xff7f
#define  MSGVAL                        0x0080
#define  SET_TXIE                      0xffef
#define  CLR_TXIE                      0xffdf
#define  TXIE                          0x0020
#define  SET_RXIE                      0xfffb
#define  CLR_RXIE                      0xfff7
#define  RXIE                          0x0008
#define  SET_INTPND                    0xfffe
#define  CLR_INTPND                    0xfffd
#define  INTPND                        0x0002

/* Bit Patterns for Message Configuration Registers */

#define  EIGHT_DATA_BYTES              0x80
#define  SEVEN_DATA_BYTES              0x70
#define  SIX_DATA_BYTES                     0x60
#define  FIVE_DATA_BYTES               0x50
#define  FOUR_DATA_BYTES               0x40
#define  THREE_DATA_BYTES              0x30
#define  TWO_DATA_BYTES                     0x20
#define  ONE_DATA_BYTE                      0x10
#define  ZERO_DATA_BYTES               0x00
#define  FOR_TX                        0x08
#define  FOR_RX                   0x00
#define  STANDARD_FRAME                     0x00
#define  EXTENDED_FRAME                     0x04

#define  CHECK_ALL_ID_BITS             0xffff

#define  BOFF                          0x8000
#define  EWRN                          0x4000
#define  RXOK                          0x1000
#define  TXOK                          0x0800
#define  CCE                           0x0040
#define  EIE                           0x0008
#define  SIE                           0x0004
#define  IE                       0x0002
#define INIT                           0x0001
```

(ii) Each structure in the array of structures "CAN_Object[ ].control" must have 0x5555 written to it.

(iii) You must set the message ID for the potentiometer value you are going to send to the screen. Set message object 1 to use your transmit message number by writing a pattern to CAN object 1 upper arbitration register "CAN_Object[ONE].upper_arb" . The pattern is found by taking the message ID and rearranging its bits according to:

Message ID upper_arbitration register - see C167 manual page 23-16

Bits 0-2 Bits 13-15
Bits 3-10 Bits 0-7



(iv) 11-bit IDs are being used here so the lower_arbitration register is set to zero. In a 29-bit system, these would be set by rearranging the remaining bits of the ID to cover both the lower and upper arbitration registers.

(v) The configuration, i.e. the operating mode for message object must be set. In the CAN object 1 configuration register "CAN_Object[ONE].config" , you must set:

· Message is a transmit object, i.e. data is to be sent across network
  `- Set the DIR (direction) bit`
· One byte of the eight possible bytes is to be sent
  `- Put a '1' in the DLC (data length code) field`
· 11-bit identifier is to be used.
  `- Make sure the XTD (extend) bit is '0'`

(vi) Finally, in the CAN object 1 message control register "CAN_Object[ONE].control" set the "MSGVAL" field to make the message valid. This will allow the CAN module to transmit data, once the CAN object 1 data register has be written with data. Note that this has two bits per flag so that you will have to write '10' to the MSGVAL field to make the message valid.

(vii) The timer 3 interrupt service routine has some code which will make the 167's ADC take a reading of the voltage on potentiometer zero every 100ms. Take the value from the ADC results register (ADDAT) and write it into CAN message object 1, data byte zero "CAN_Object[ONE].data[0]". To make the CAN module put the data onto the network, set the transmit request bit in the CAN object 1 control register "CAN_Object[ONE].control". Again this is a two bit field so you will have to write '10' to the TXRQ field. This completes the setup.

ADVANCED FEATURE: *In real applications, messages transmitted across network may consist of more than one byte. It is possible that transmission of the message may begin before all bytes have been updated so that the receiver will get some new bytes and some old ones, resulting in a data "coherency" problem. This is mainly a problem with the remote request mode, covered in detail in exercise EX4.*

The CPUUPD flag will cause transmission to be suspended while the 167 updates the bytes in the message. Once the update has completed, the CPUUPD flag is cleared. As this example only sends one byte at a time, coherency is not a problem. In this and future exercises, you must remember to set the CPUUPD flag during any write to a message data object.

(vii) Build the project with the Project-Build button.

(viii) Load the program into ***HiTOP***, perform a target reset with the TR button. Run the program and if you have got it right, you should be able to control the length of the bar corresponding to your node number on the OHP screen.

C Programmer's Note:

The CAN peripheral is simply memory-mapped into the C167CR's memory space at 0xEF00 – 0xEFFF. As the C166 compiler has no specific support for this, an array of structures containing appropriately named elements is created and placed over the CAN module at 0xEF00. Each structure represents all the registers that pertain to one of the 15 CAN message objects. The programmer simply has to use the following type of statement to access the message objects:

```
CAN_Object[ONE].control = MSGVAL ;
```

One peculiarity of this approach is that while the C167CR data book numbers the message objects from 1 to 15, in C, the objects are represented by structures 0 to 14. Thus object 1 is accessed via "CAN_Object[0].control…", object 2 reference through CAN_Object[1].control and so-on.

```
struct MESSAGE_OBJECT     // Structure template representing CAN peripheral's registers
{
     unsigned short volatile control;     // Control register
     unsigned short upper_arb;            // Upper arbitration register
     unsigned short lower_arb;            // Lower arbitration register
     unsigned char config;                // Configuration register
     unsigned char volatile data[8];      // 8 bytes of data
     unsigned char reserved;              // Unused byte
};

struct MESSAGE_OBJECT CAN_Object[15]; // Create array of 15 structures representing
                                      // CAN module
```

Note: The data bytes in the message objects are represented by the 8 byte array, "data[]" in the structures.

16.5 Configuring The CAN Module For Receive

EXERCISE 32: EX32

Directory: \166TRAIN.WIN\EX32\WORK

Object: Receive the value of the neighbouring team's potentiometer zero

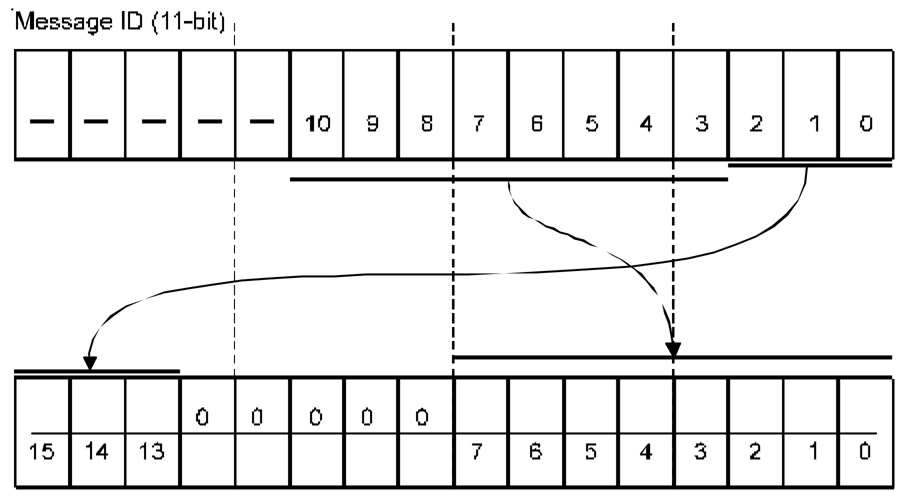
This exercise builds on the last exercise. Now you must configure CAN message objects 2,3 and 4 to receive messages about the values on the potentiometers of three neighbouring teams. Some pre-written software will allow you to put these values into the 167's PWM unit to that the brightness of three LEDs can be controlled remotely from pots on neighbouring nodes.

The message IDs of the neighbouring pots. that you must receive will generally be 0x10, 0x20 and 0x30 greater than your transmit object, established in exercise 1. However, you will be given the exact message IDs that you must receive.

Open the project in \166TRAIN.WIN\EX32\WORK and edit CAN.C.

Procedure:

(i) Set the CAN object 1 upper arbitration register ("CAN_Object[TWO].upper_arb") to the message ID of the first neighbouring pot. Remember to rearrange the bits in the message ID, as you did in exercise EX1, plus you must set the lower_arbitration register to zero.



(ii) Set the upper arbitration register for CAN objects 3 and 4. You can use the simple C function "standard_id()" to convert the message ID into the required format, rather than manually rearranging the bits.

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(iii) Write to the message configuration register to set the mode for each CAN message object so that they will do the following:

· Receive one byte of data per occurance of the message ID on the network.
  `DLC field = 1`
· Use a standard 11-bit ID
  `XTD field = 0`

In the Message control register for each object, make sure objects 2,3 and 4 are receive:

· Enable receive
  `TXRQ = 0`

(iv) Make objects 2,3 and 4 valid, i.e. ready to receive by writing to the MSGVAL two-bit field in "CAN_Object[X].control". Remember that this field requires you to write '10' to set the MSGVAL flag and make the object valid.

(v) The CAN peripheral allows a simple filtering to be done so that only certain messages can be received. It can be programmed to ignore certain bits in the ID. This is simply done by writing a pattern to the CAN global 11-bit mask register "CAN_Global_11Bit_Mask". In this exercise, we want all messages on the network to be able to enter the CAN peripheral so all the bits must be set to '1'. That completes the set up.

(vi) In the timer 3 interrupt service routine, we have provided a means of using the neighbouring pots to drive three LEDs. Take the data received in the CAN object 2 data byte zero "CAN_Object[TWO].data[0]" , negate it and put it into the CC4 PWM register. Data from object 3 must be put into CC5 in a similar manner. Finally, take the data from object 4 and put it straight into the PW2 register.

(vii) Make sure that you edit the part carried over from the last exercise at the top of the function which sets the transmit message for your pot…

```
/* Set Message ID */

CAN_Object[ONE].upper_arb = 0x____ ; // This is your transmit pot message ID
CAN_Object[ONE].lower_arb = 0x____ ;  // always = 0 for standard 11-bit CAN ID
```

(viii) Build the project by clicking on the build button.

(ix) Load the program into ***HiTOP*** and hit the TR button. Now run the program by clicking the green traffic light. Get a neighbouring team to alter the position of their pot. – you should see one of the LEDs on your IO board change in brightness!

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16.6 Configuring The CAN Module For Remote Request

EXERCISE 33: EX33

Directory: \166TRAIN.WIN\EX33\WORK

Object: Use remote request mode to request an 8-byte text string from the tutor's CAN node

As in EX3, configure a message object (use number 5) to 0x70E and make it a receive object for the maximum 8 data bytes possible in a CAN message. Now by setting CAN object 5's TXRQ bit in the message control register, the CAN node which is able to send message 0x70E will send it automatically. This is the remote "request mode".

The message ID you should use is 0x01 less than that which you used for your CAN object 1 (the potentiometer value transmit object). Thus if your object 1 is message ID 0x70F, the remote request object will be 0x70E, for example.

In the exercise, you will receive a 8-byte text string which can be printed to the LCD display. The strings will say something useful!

Open the project in \166TRAIN.WIN\EX33\WORK and edit CAN.C.

Procedure:

(i) Configure CAN object 5 to be a receive object for 8 data bytes, using a message ID of one less than that used for CAN object 1. Remember that the message ID is set via
CAN_Object[FIVE].upper_arb,
the number of data bytes, 11-bit ID and receive mode are configured via CAN_Object[FIVE].config.

(ii) Make CAN object 5 valid by setting the MSGVAL two-bit field to '10'.

(iii) At the bottom of the timer 3 interrupt service routine, check whether the NEWDAT flag in CAN_Object[FIVE].control is set. If it is, clear it and print the 8 data bytes in
CAN_Object[FIVE].data
to the LCD display. Note that NEWDAT is a two bit field so you will be checking for '10' in bits 8 and 9 of the message control register for object 5. To clear the NEWDAT field, you will need to write '01' to it.

(iv) Now set the TXRQ bits in CAN_Object[FIVE].control to '10' so that the tutor's node will send the message to your object 5 again.

(v) Make sure that you edit the part carried over from exercise EX2 at the top of the function which sets the transmit message for your pot…

```
/* Set Message ID */

CAN_Object[ONE].upper_arb = 0x____ ; // This is your transmit pot message ID
CAN_Object[ONE].lower_arb = 0x____ ;  // always = 0 for standard 11-bit CAN ID
```

(v) Build the project by clicking on the Build button.

(vi) Load the program into ***HiTOP*** and perform a target reset. Run the program with the green traffic light.

(vii) Check the message on the LCD – if you are the first team to complete the exercise, you will get a special message…

16.7 CAN Module Bit Timing Calculation Spreadsheet

Sample	0.75	**Sync_Seg**	1	**Quantum**	
Baud	100000	**Bit Time**	10	**uS**	
Fosc	20	**MHz**			
BRP	**Tq**				
n	uS	Tq_before	Tq_after	TSEG1	TSEG2
0	0.1	75.0	25.0	73.0	24.0
1	0.2	37.5	12.5	35.5	11.5
2	0.3	25.0	8.3	23.0	7.3
3	0.4	18.8	6.3	16.8	5.3
4	0.5	15.0	5.0	13.0	4.0
5	0.6	12.5	4.2	10.5	3.2
6	0.7	10.7	3.6	8.7	2.6
7	0.8	9.4	3.1	7.4	2.1
8	0.9	8.3	2.8	6.3	1.8
9	1	7.5	2.5	5.5	1.5
10	1.1	6.8	2.3	4.8	1.3
11	1.2	6.3	2.1	4.3	1.1
12	1.3	5.8	1.9	3.8	0.9
13	1.4	5.4	1.8	3.4	0.8
14	1.5	5.0	1.7	3.0	0.7
15	1.6	4.7	1.6	2.7	0.6
16	1.7	4.4	1.5	2.4	0.5
17	1.8	4.2	1.4	2.2	0.4
18	1.9	3.9	1.3	1.9	0.3
19	2	3.8	1.3	1.8	0.3
20	2.1	3.6	1.2	1.6	0.2
21	2.2	3.4	1.1	1.4	0.1
22	2.3	3.3	1.1	1.3	0.1
23	2.4	3.1	1.0	1.1	0.0
24	2.5	3.0	1.0	1.0	0.0
25	2.6	2.9	1.0	0.9	0.0
26	2.7	2.8	0.9	0.8	-0.1
27	2.8	2.7	0.9	0.7	-0.1
28	2.9	2.6	0.9	0.6	-0.1
29	3	2.5	0.8	0.5	-0.2
30	3.1	2.4	0.8	0.4	-0.2
31	3.2	2.3	0.8	0.3	-0.2

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