
Implementing a Bootloader for the PIC16F87X

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INTRODUCTION

The PIC16F87X family of microcontrollers has the ability to write to their own program memory. This feature allows a small bootloader program to receive and write new firmware into memory. This application note explains how this can be implemented and discusses the features that may be desirable.

In its most simple form, the bootloader starts the user code running, unless it finds that new firmware should be downloaded. If there is new firmware to be downloaded, it gets the data and writes it into program memory. There are many variations and additional features that can be added to improve reliability and simplify the use of the bootloader, some of which are discussed in this application note.

The general operation of a bootloader is discussed in the OPERATION section. Appendix A contains assembly code for a bootloader developed for the PIC16F877 and key aspects of this bootloader are described in the IMPLEMENTATION section.

For the purpose of this application note, the term “boot code” refers to the bootloader code that remains permanently in the microcontroller and the term “user code” refers to the user’s firmware written into FLASH memory by the boot code.

FEATURES

The more common features a bootloader may have are listed below:

- Code at the Reset location.
- Code elsewhere in a small area of memory.
- Checks to see if the user wants new user code to be loaded.
- Starts execution of the user code if no new user code is to be loaded.
- Receives new user code via a communication channel if code is to be loaded.
- Programs the new user code into memory.

OPERATION

The boot code begins by checking to see if there is new user code to be downloaded. If not, it starts running the existing user code. If there is new user code to be downloaded, the boot code receives and writes the data into program memory. There are many ways that this can be done, as well as many ways to ensure reliability and ease of use.

Integrating User Code and Boot Code

The boot code almost always uses the Reset location and some additional program memory. It is a simple piece of code that does not need to use interrupts; therefore, the user code can use the normal interrupt vector at 0x0004. The boot code must avoid using the interrupt vector, so it should have a program branch in the address range 0x0000 to 0x0003.

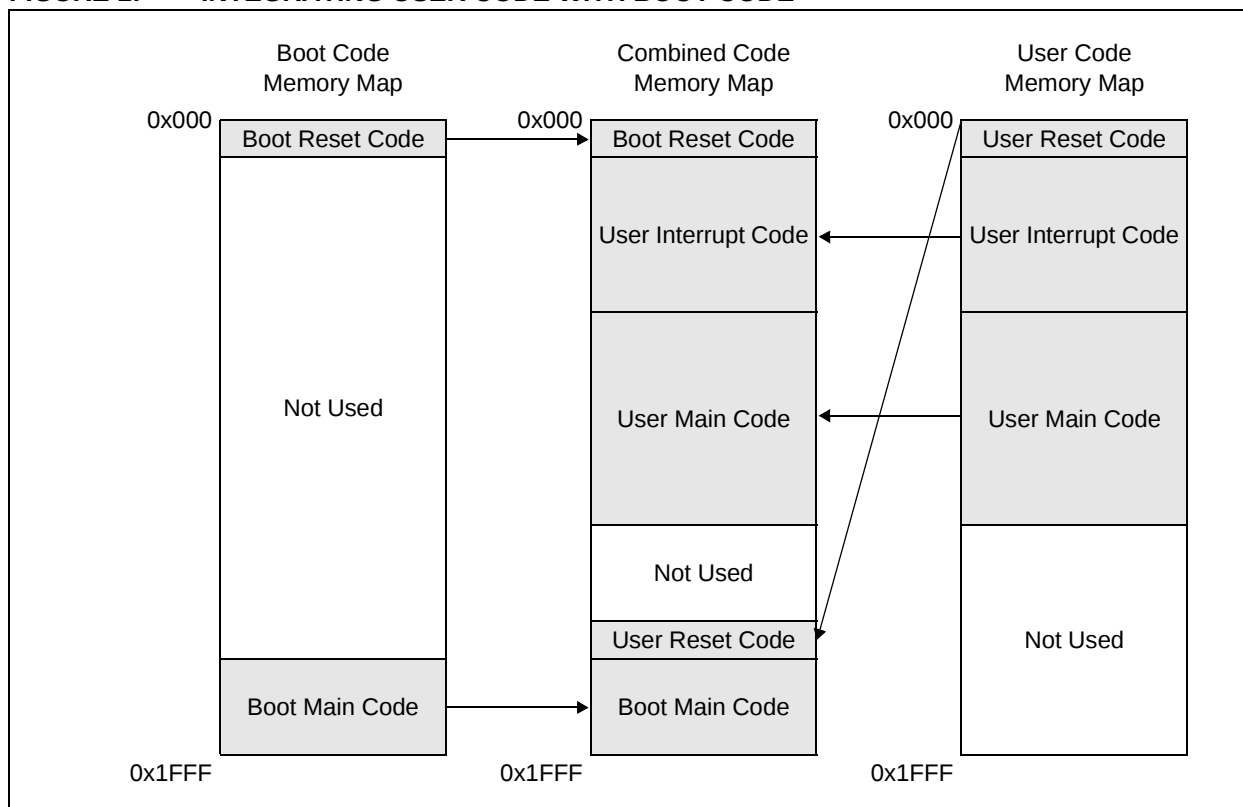
The boot code must be programmed into memory using conventional programming techniques, and the configuration bits must be programmed at this time. The boot code is unable to access the configuration bits, since they are not mapped into the program memory space. Setting the configuration bits is discussed in the next section.

In order for the boot code to begin executing the user code, it must know where the code starts. Since the boot code starts at the Reset vector, the user code cannot start at this location. There are two methods for placing the starting point of the user code.

One method is to use an `ORG` directive to force the user code to start at a known location, other than the Reset vector. To start executing the user code, the boot code must branch to this fixed location, and the user code must always use this same location as its start address.

An alternative method is to start the user code at the normal Reset vector and require that the user code has a `goto` instruction in the first four instructions to avoid the interrupt vector. These four instructions can then be relocated by the boot code and programmed into the area of program memory used by the boot code. This simplifies the development of code for use with the bootloader, since the user code will run when programmed directly into the chip without the boot code present. The boot code must take care of paging and banking so the normal Reset conditions apply before executing the relocated code.

FIGURE 1: INTEGRATING USER CODE WITH BOOT CODE



Configuration Bits

The configuration bits cannot be changed by the boot code since they are not mapped into the program memory space. This means that the following configuration options must be set at the time that the boot code is programmed into the device and cannot be changed:

CPx	Program Memory Code Protection Enable
DEBUG	In-Circuit Debugger Mode Enable
WRT	Program Memory Write Enable
CPD	Data EEPROM Code Protection Enable
LVP	Low Voltage In-Circuit Programming Enable
BODEN	Brown-out Reset Enable
PWRTE	Power-up Timer Enable
WDTE	Watchdog Timer Enable
FOSCx	Oscillator Selection

Most of these configuration options are hardware or design-dependent, and being unable to change them when the user code changes is of no consequence.

The various PIC16F87X devices have different code protection implementations. Please consult the appropriate data sheet for details.

Some devices (such as the PIC16F877), can code protect part of the program memory and prevent internal

writes to this protected section of memory. This can be used to protect the boot code from being overwritten, but also prevents the user code from being code protected, however.

On some devices, code protecting all the program memory still allows internal program memory write cycles. This provides security against the user code being read out of the chip, but does not allow the boot code to be protected from being overwritten.

Data EEPROM Code Protection Enable would normally not need to be set, unless data is programmed into the data EEPROM when the boot code is originally programmed and this data needs to be protected from being overwritten by the user code.

Program Memory Write Enable must be enabled for the boot code to work, since it writes to program memory. Low Voltage In-Circuit Serial Programming (ICSP™) enable only needs to be set if the user wishes to program the PICmicro MCU in-circuit, using logic level signals on the RB3, RB6 and RB7 pins. Since the purpose of the boot code is to program user code into the PICmicro MCU, in most cases, it would be redundant to have facilities for low voltage ICSP.

If the Watchdog Timer is enabled, then the boot code must be written to support the Watchdog Timer and all user code will have to support the Watchdog Timer.

Determining Whether to Load New Code or to Execute User Code

After a Reset, the boot code must determine whether to download new user code. If no download is required, the bootcode must start execution of existing user code, if available.

There are many ways to indicate whether or not new user code should be downloaded. For example, by testing a jumper or switch on a port pin, polling the serial port for a particular character sequence, or reading an address on the I²C™ bus. The particular method chosen depends on the way that user code is transferred into the microcontroller. For example, if the new user code is stored on an I²C EEPROM that is placed in a socket on the board, then an address in the EEPROM could be read to determine whether a new EEPROM is present.

If an error occurred while downloading new user code, or the bootloader is being used for the first time, there might not be valid user code programmed into the microcontroller. The boot code should not allow faulty user code to start executing, because unpredictable results could occur.

Receiving New User Code to Load into Program Memory

There are many ways that the microcontroller can receive the new firmware to be written into program memory. A few examples are from a PC over a serial port, from a serial EEPROM over an I²C or SPI™ bus, or from another microcontroller through the parallel slave port.

The boot code must be able to control the reception of data, since it cannot process any data sent to it while it is writing to its own program memory. In the case of data being received via RS-232, there must be some form of flow control to avoid data loss.

The data received by the boot code will usually contain more than just program memory data. It will normally contain the address to which the data is to be written and perhaps a checksum to detect errors. The boot code must decode, verify and store the data, before writing it into program memory. The available RAM (GPR registers) of the device limits the amount of data that can be received before writing it to program memory.

Programming the FLASH Program Memory

The PIC16F87X devices have special function registers that are used to write data to program memory. There is a specific sequence of writes to these registers that must be followed to reduce the chances of an unintended program memory write cycle occurring. Because code cannot be executed from the FLASH program memory while it is being written, program execution halts for the duration of the write cycle. Program memory is written one word at a time.

Error Handling

There are several things that can go wrong during execution of the boot code or user code. The bootloader should handle the following error conditions:

- No valid user code written into the chip.
- Error in incoming data.
- Received user code does not have any code at its Reset vector.
- Received user code overlaps boot code.
- User code causes execution into the boot code area.

If the bootloader is being used for the first time, or if the user code is partially programmed because of a previous error, there might not be valid user code programmed into the microcontroller. The boot code should not allow potentially faulty user code to start executing.

The transfer of data can be interrupted, which will cause the boot code to stop receiving data. There are several ways to handle this depending on how the data is being received. For example, the boot code may be able to time-out and request the data to be sent again. The simplest method is to wait, trying to receive more data with no time-out, until the user intervenes and resets the device. Since the boot code needs to leave the most possible program memory space for the user code and also be reliable, the smallest, simplest implementation is often the best.

Incoming data may be corrupted by noise or some other temporary interruption, and this should be detected, otherwise, incorrect data could be programmed. A checksum or other error detection method can be used.

Incorrect use of flow control can result in data being sent to the PICmicro MCU while it is not ready to receive data. This can cause overrun errors that should be handled by the boot code. Once an overrun has occurred, the data is lost and this is essentially the same as a data transfer interruption, discussed above.

In some cases, data could be sent to the microcontroller before the boot code is running, causing part of the data to be lost. If this type of error is possible, then it should be detected. This error may manifest itself as user code that does not seem to have any code at the Reset location and can be detected by checking the addresses being programmed. An alternative is to generate a checksum on all the code that is written into program memory and transmit this to the user for verification, after programming has been completed.

The code developer should take care that the user code does not use the same program memory space that the boot code uses. The exception is the user code at the Reset location that can be relocated, as explained earlier. If the user code does try to use program memory that contains boot code, the boot code should detect the conflicting address and not overwrite itself. In some devices, part of the program memory can be code protected to prevent internal writes to the part of the memory that contains the main boot code. Note that this does not apply to all PIC16F87X devices.

Faulty user code, or a brown-out condition that corrupts the program counter, can cause execution to jump to an unprogrammed memory location and possibly run into the start of the boot code. If the user code at the Reset location is being relocated, as explained earlier, then execution can enter the boot code area if a program branch does not occur in these four relocated instructions. The boot code should trap the program execution to avoid these errors from causing any unintended operation.

When an error is detected, it is useful to indicate this in some way. This can be as simple as turning on an LED, or sending a byte out the serial port. If the system includes a display and the display drivers are incorporated into the boot code, then more sophisticated error messages can be used.

FIGURE 2: FLOWCHART FOR BOOTLOADER

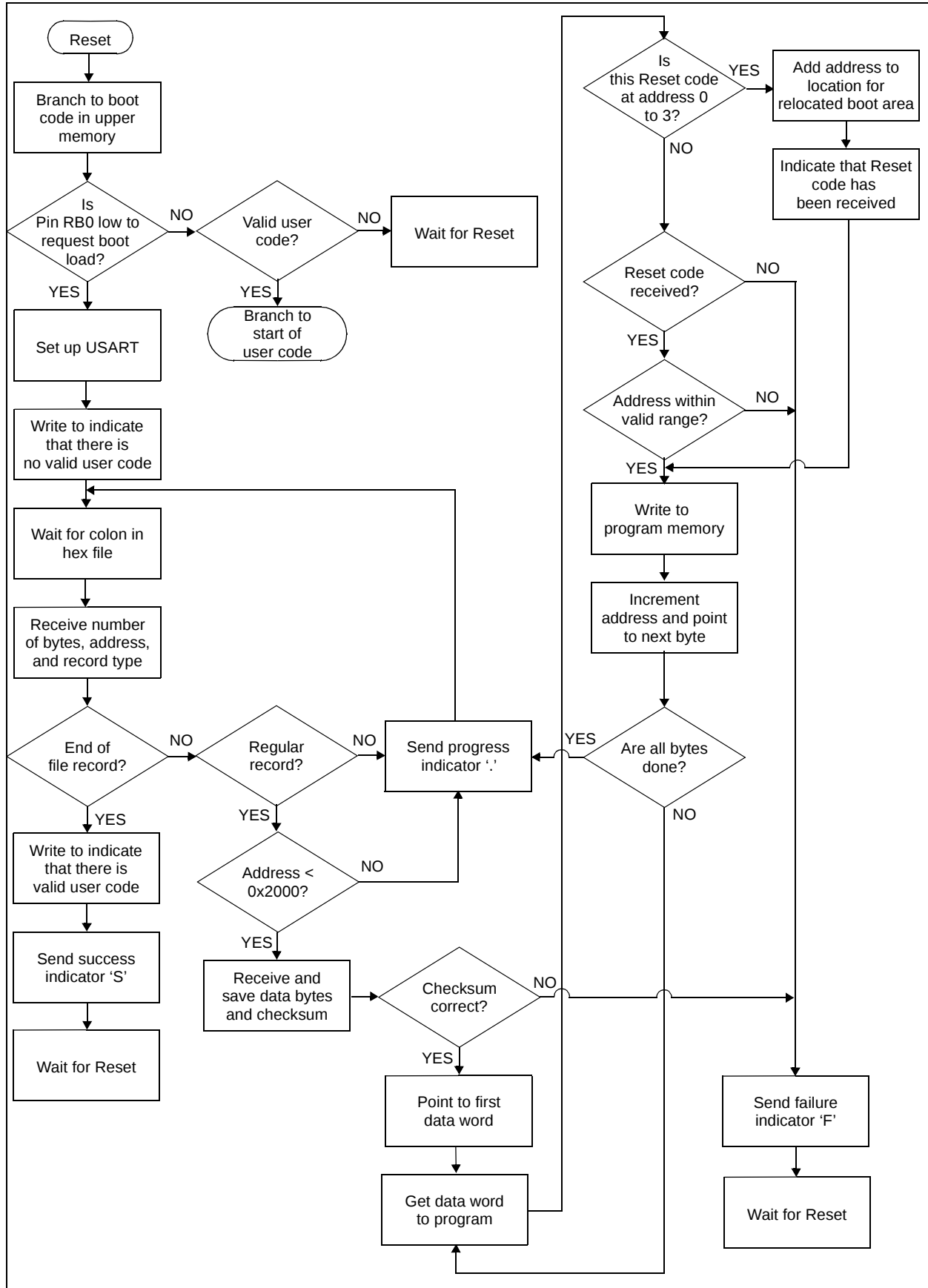
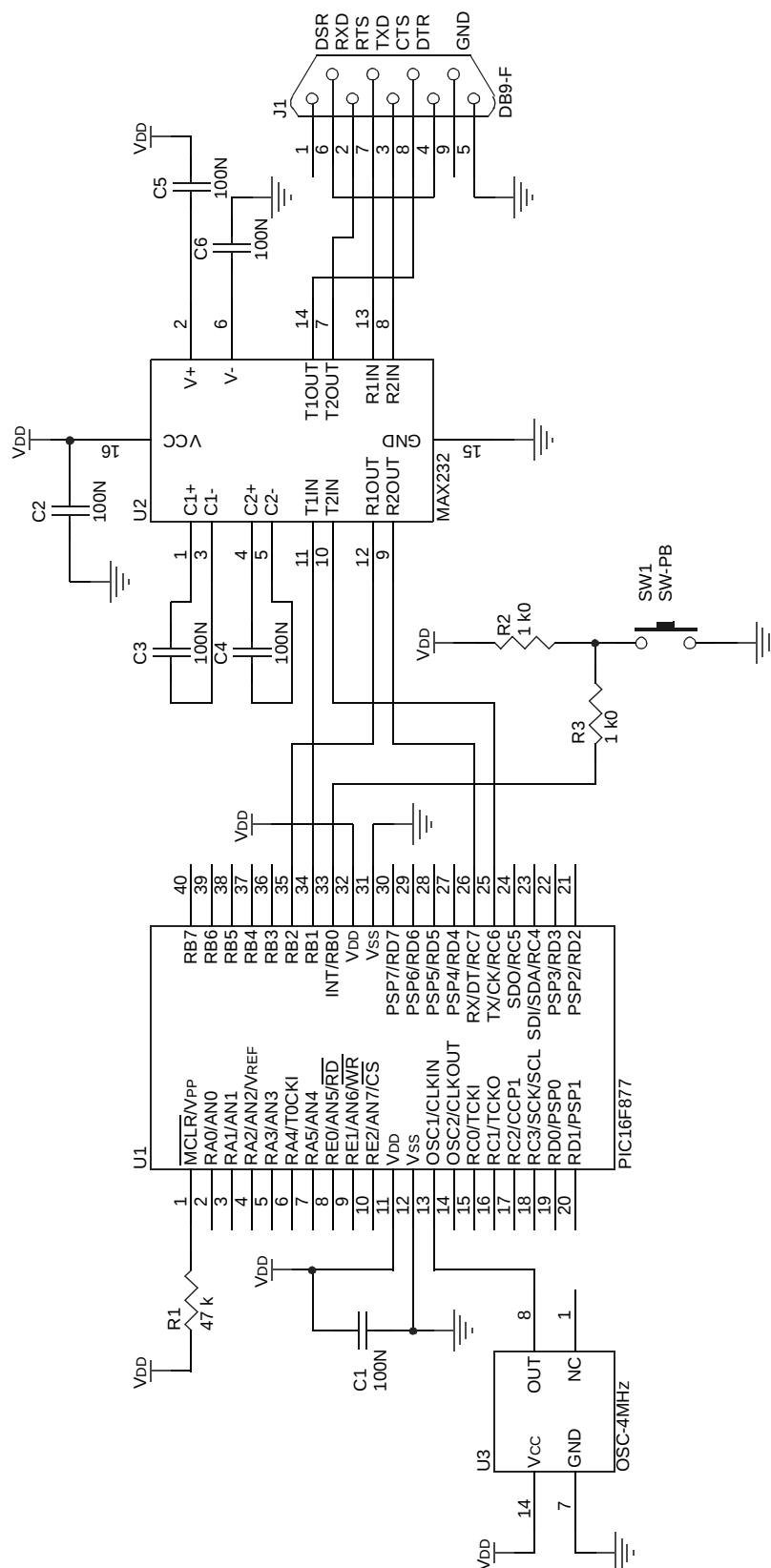


FIGURE 3: SCHEMATIC SHOWING SERIAL PORT AND TEST PIN



IMPLEMENTATION

How this Bootloader Works

The boot code in Appendix A implements a bootloader in a PIC16F877 device. It uses the USART to receive data with hardware handshaking, tests a pin to decide if new user code should be received and includes many of the features discussed in this application note.

Integrating User Code and Boot Code

The code at the Reset location (`ResetVector`) writes to `PCLATH`. To set the page bits, it then jumps to the rest of the boot code in upper memory. The main code is in the upper 224 bytes of memory starting at address `0x1F20` (`StartOfBoot`). The first instructions at this location trap accidental entry into the boot code. The main bootloader routine starts at the address labeled `Main`.

The boot code requires that the user code includes a `goto` instruction in the first four locations after the Reset vector and relocates these four instructions into the boot code section (`StartUserCode`). This simplifies the development of code for use with the bootloader, since the same user code will also run when programmed directly into the chip, without the boot code present. The boot code changes to bank 0 and clears `PCLATH` before executing the relocated code, so that the normal Reset conditions apply. If a program branch does not occur in the four relocated instructions, then program execution is trapped in an endless loop to avoid any unintended operation.

The boot code must be programmed into the PIC16F877 using conventional programming techniques and the configuration bits are programmed at the same time. The configuration bits are defined with a `__CONFIG` directive and cannot be accessed by the boot code, because they are not mapped into the program memory space. The boot code does not use a Watchdog Timer.

Determining Whether to Load new Code or to Execute User Code

The boot code tests port pin RB0 to determine whether new user code should be downloaded. If a download is required, then the boot code branches to the `Loader` routine that receives the data and writes it into program memory.

If pin RB0 does not indicate that new user code should be loaded, then a program memory location (labeled `CodeStatus`) is read with routine `FlashRead` to determine whether there is valid user code in the device. If there is valid user code, the boot code transfers execution to the user code by branching to location `StartUserCode`. Otherwise, execution is trapped in an endless loop to avoid this error from causing any unintended operation.

Receiving New User Code to Load into Program Memory

The boot code receives the new firmware as a standard Intel® hex file (`INHX8M` format), using the USART in Asynchronous Receiver mode (hex format defined in Appendix B). It is assumed that a PC will be used to send this file via an RS-232 cable, connected to a COM port. Hardware handshaking allows the boot code to stop the PC from transmitting data while FLASH program memory is being written. Since the PICmicro device halts program execution while the FLASH write occurs, it cannot read data from the USART during this time.

Hardware handshaking (described in Appendix C) is implemented using port pin RB1 as the RTS output and RB2 as the CTS input. The USART is set to 8-bit Asynchronous mode at 9600 baud in the `SerialSetup` routine. The `SerialReceive` routine enables transmission with the RTS output and waits until a data byte has been received by the USART, before returning with the data. The `SerialTransmit` routine checks the CTS input until a transmission is allowed and then sends a byte out the USART. This is used for transmitting progress indication data back to the PC.

The boot code receives the hex file, one line at a time and stops transmission after receiving each line, while received data is programmed into program memory.

Decoding the Hex File

The boot code remains in a loop, waiting until a colon is received. This is the first character of a line of the hex file. The following four pairs of characters are received and converted into bytes, by calling the `GetHexByte` routine. The number of bytes (divided by two to get the number of words) and the address (divided by two to get a word address) are saved, and the record type is checked for a data record, or end of file record.

If the record type shows that the line contains program memory data, then this data is received, two pairs of characters at a time (using the `GetHexByte` routine), and is stored in an array. The checksum at the end of the line is received and checked, to verify that there were not any errors in the line.

Once the hex file line has been received, hardware handshaking is used to stop further transmission, while the data is written into the program memory. The `<CR>` and `<LF>` characters that are sent at the end of the line are ignored. This gives the handshaking time to take effect by ignoring the byte being transmitted, when the handshaking signal is asserted. Once the data from the line has been programmed, the following lines are received and programmed in the same way, until the line indicating the end of the file has been received. A success indication 'S' is then transmitted out the USART (by the `FileEnd` routine) and the boot code waits for a Reset.

Programming the FLASH Program Memory

Data is written to the FLASH program memory using special function registers. The address is written to the EEADR and EEADRH registers and the first two bytes of data are written to EEDATA and EEDATH. The `FlashWrite` routine is then executed, which writes the data into program memory. The address is then incremented and the next two data bytes are written. This is repeated until all the data from the line of the hex file has been programmed into the FLASH program memory.

Error Handling

There are several things that can go wrong during execution of the boot code or user code, and a number of these error conditions are handled by the boot code. If an error occurs, the boot code traps it by executing an infinite loop, until the user intervenes and resets the device. If an error is detected in the incoming data, then a failure indication 'F' is transmitted. This does not occur in the case of an overflow error, or if the data transmission is halted.

If the bootloader is being used for the first time, or if the user code is partially programmed because of a previous error, there might not be valid user code programmed into the microcontroller. The boot code handles this by writing a status word (`0x3fff`) at a location labeled `CodeStatus`, before programming the FLASH device, and then writing a different status word (`0x0000`) to this same location, when programming of the user code has been completed. The boot code tests this location and only starts execution of the user code, if it sees that the user code was successfully programmed. When the boot code is originally programmed into the PICmicro MCU, the status word indicates that there is not valid user code in the device.

The transfer of data can be interrupted. In this case, the boot code waits, trying to receive more data with no time-out, until the user intervenes and resets the device. Noise, or a temporary interruption, may corrupt incoming data. The Intel hex file includes a checksum on each line and the boot code checks the validity of each line by verifying the checksum.

Incorrect use of flow control can result in data being sent to the PIC16F877, while it is not ready to receive data. This can cause an overrun error in the USART. Once an overrun has occurred, the USART will not move any new data into the receive FIFO and the boot code will be stuck in a loop waiting for more data. This effectively traps the error until the user intervenes by resetting the device.

If the user starts transmitting a hex file before the boot code is running, the boot code may miss the first lines of the file. Since all the lines of a hex file have the same format, it is not normally possible to determine whether the line being received is the first line of the hex file. However, since MPASM generates hex files with addresses in ascending order, the first valid line of the

hex file should contain the code for the Reset vector which is checked by the boot code.

The user code may try to use program memory locations that contain boot code. This is detected by checking the address being programmed and detecting conflicting addresses. The boot code will not overwrite itself and is not code protected.

Faulty user code, or noise that corrupts the program counter, can cause execution to jump to an unprogrammed memory location and possibly run into the start of the boot code. The first instructions in the boot code are an infinite loop that traps execution into the boot code area.

Because the first four instructions in program memory are relocated in the boot code implementation, there must be a program branch within these four instructions. If there is no program branch, then execution is trapped by the boot code.

Using the Bootloader

The procedure for using the bootloader is as follows:

- On the PC, set up the serial port baud rate and flow control (hardware handshaking).
- Connect the serial port of the PIC16F87X device to the serial port of the PC.
- Press the switch to pull pin RB0 low.
- Power up the board to start the boot code running.
- The switch on RB0 can be released if desired.
- From the PC, send the hex file to the serial port.
- A period '.' will be received from the serial port for each line of the hex file that is sent.
- An 'S' or 'F' will be received to indicate success or failure.
- The user must handle a failure by resetting the board and starting over.
- Release the switch to set pin RB0 high.
- Power-down the board and power it up to start the user code running.

On the PC, there are several ways to set up the serial port and to transfer data. This also differs between operating systems.

A terminal program allows the user to set up and send data to a serial port. In most terminal programs, an ASCII or text file can be sent and this option should be used to send the hex file. A terminal program will also show data received on the serial port and this allows the user to see the progress '.' indicators and the success 'S' or failure 'F' indicators. There are many terminal programs available, some of which are available free on the Internet. This boot code was tested using Tera Term Pro, Version 2.3. The user should be aware that some popular terminal programs contain bugs.

A serial port can be set up in a DOS window, using the MODE command and a file can be copied to a serial port, using the COPY command. When using Windows® 95/98, the MODE command does not allow the handshaking signals to be configured. This makes it difficult to use the COM port in DOS. When using Windows NT® or Windows 2000®, the following commands can be used to send a hex file named filename.hex to serial port COM1:

```
MODE COM1: BAUD=9600 PARITY=N DATA=8
STOP=1 to=off xon=off odsr=off
octs=on dtr=off rts=on idsr=off

COPY filename.hex COM1:
```

Resources Used

The boot code coexists with the user code on the PIC16F877 and many of the resources used by the boot code can also be used by the user code. The boot code uses the resources listed in Table 1.

TABLE 1: RESOURCES USED BY THE BOOT CODE

Resource	Amount
Program memory	224 words
Data memory	72 bytes
I/O pins	5 pins
Peripherals	USART

The program memory used by the boot code cannot be used for user code, although it is possible to call some of the subroutines implemented in the boot code to save space. The user code can use all the data memory.

The USART can be used by the user code with the two I/O pins for the USART and the I/O pins used for handshaking. The I/O pin used to indicate that the boot code should load new user code, is connected to a switch or jumper. This can be isolated with a resistor and used as an output, so that it is possible to use all the I/O pins used by the bootloader.

In summary, all resources used by the boot code, except program memory, can also be used by the user code.

CONCLUSION

Using a bootloader is an efficient way to allow firmware upgrades in the field. Less than 3% of the total program memory is used by the boot code and the entire program memory available on a PIC16F877 can be programmed in less than one minute at 19,200 baud.

The cost of fixing code bugs can be reduced with a bootloader. Products can be upgraded with new features in the field, adding value and flexibility to the products. The ability to upgrade in the field is an added feature and can enhance the value of a product.

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APPENDIX A: SOURCE CODE – FILE BOOT877.ASM

MPASM 02.40 Released BOOT877.ASM 6-26-2000 14:58:44 PAGE 1

LOC	OBJECT CODE	LINE	SOURCE TEXT
VALUE			
00001			=====
00002			00001 ; Software License Agreement
00003			00002 ;
00004			00003 ; The software supplied herewith by Microchip Technology Incorporated
00005			00004 ; (the "Company") for its PICmicro® Microcontroller is intended and
00006			00005 ; supplied to you, the Company's customer, for use solely and
00007			00006 ; exclusively on Microchip PICmicro Microcontroller products. The
00008			00007 ; software is owned by the Company and/or its supplier, and is
00009			00008 ; protected under applicable copyright laws. All rights are reserved.
00010			00009 ; Any use in violation of the foregoing restrictions may subject the
00011			00010 ; user to criminal sanctions under applicable laws, as well as to
00012			00011 ; civil liability for the breach of the terms and conditions of this
00013			00012 ; license.
00014			00013 ;
00015			00014 ; THIS SOFTWARE IS PROVIDED IN AN "AS IS" CONDITION. NO WARRANTIES,
00016			00015 ; WHETHER EXPRESS, IMPLIED OR STATUTORY, INCLUDING, BUT NOT LIMITED
00017			00016 ; TO, IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A
00018			00017 ; PARTICULAR PURPOSE APPLY TO THIS SOFTWARE. THE COMPANY SHALL NOT,
00019			00018 ; IN ANY CIRCUMSTANCES, BE LIABLE FOR SPECIAL, INCIDENTAL OR
00020			00019 ; CONSEQUENTIAL DAMAGES, FOR ANY REASON WHATSOEVER.
00021			00020 ;
00022			00021 ;=====

```

00023 ;      Filename:      boot877.asm
00024 ;=====
00025 ;      Author:      Mike Garbutt
00026 ;      Company:      Microchip Technology Inc.
00027 ;      Revision:      1.00
00028 ;      Date:      26 June 2000
00029 ;      Assembled using MPASM V2.40
00030 ;=====
00031 ;      Include Files:  pl16f877.inc    V1.00
00032 ;=====
00033 ;      Boot code to receive a hex file containing user code from a
00034 ;      serial port and write it to program memory. Tests a pin to see
00035 ;      if code should be downloaded. Receives hex file using USART and
00036 ;      hardware handshaking. Does error checking on data and writes to
00037 ;      program memory. Waits for reset and then starts user code running.
00038 ;=====
00039
00040      list p=16f877, st=OFF, x=OFF, n=0
00041      errorlevel -302
00042      #include <pl16f877.inc>
00043
00044      list
00045      ; P16F877.INC Standard Header File, Version 1.00      Microchip Technology, Inc.
00046
00047      list
00048
00049      CPD_OFF & _LVP_OFF
00050      _CONFIG_BODEN_OFF & _CP_OFF & _PWRTE_ON & _WDT_OFF & _WRT_ENABLE_ON & _XT_OSC & _DEBUG_OFF & _
00051      ;-----
00052      ;Constants
00053
00054      TEST_INPUT      EQU      0      ;Port B Pin 0 input indicates download
00055      RTS_OUTPUT      EQU      1      ;Port B Pin 1 output for flow control
00056      CTS_INPUT      EQU      2      ;Port B Pin 2 input for flow control
00057
00058      BAUD_CONSTANT    EQU      0x19      ;Constant for baud generator for 9600 baud
00059      BAUD_CONSTANT    EQU      0x0c      ;Constant for baud generator for 19200 baud
00060      ;Fosc is 4MHz
00061
00062      ;-----
00063      ;Variables in bank0
00064
00065      CBLOCK 0x20
00066      AddressH:      1      ;flash program memory address high byte
00067      AddressL:      1      ;flash program memory address low byte
00068      NumWords:      1      ;number of words in line of hex file
00069      Checksum:      1      ;byte to hold checksum of incoming data
00070      Counter:      1      ;to count words being saved or programmed

```

```

00000025      TestByte:      1      ;byte to show reset vector code received
00000026      HexByte:      1      ;byte from 2 incoming ascii characters
00000027      DataPointer:  1      ;pointer to data in buffer
00000028      DataArray:    0x40   ;buffer for storing incoming data
                                ENDC
00070
00071
00072 ;-----
00073 ;Macros to select the register bank
00074 ;Many bank changes can be optimised when only one STATUS bit changes
00075
00076 Bank0      MACRO
00077      bcf      STATUS,RP0
00078      bcf      STATUS,RP1
00079      ENDM
00080
00081 Bank1      MACRO
00082      bsf      STATUS,RP0
00083      bcf      STATUS,RP1
00084      ENDM
00085
00086 Bank2      MACRO
00087      bcf      STATUS,RP0
00088      bsf      STATUS,RP1
00089      ENDM
00090
00091 Bank3      MACRO
00092      bsf      STATUS,RP0
00093      bsf      STATUS,RP1
00094      ENDM
00095
00096 ;=====
00097 ;Reset vector code
00098
00099      ORG      0x0000
00100
00101 ResetVector:  movlw   high Main
00102      movwf    PCLATH      ;set page bits for page3
Message[306]: Crossing page boundary -- ensure page bits are set.
00103      goto     Main      ;go to boot loader
00104
00105 ;=====
00106 ;Start of boot code in upper memory traps accidental entry into boot code area
00107
00108      ORG      0x1f20      ;Use last part of page3 for PIC16F876/7
00109      ORG      0x0f20      ;Use last part of page1 for PIC16F873/4
00110      ORG      0x0720      ;Use last part of page0 for PIC16F870/1
00111

```

```

1F20 301F 00112 StartOfBoot:    movlw    high TrapError    ;trap if execution runs into boot code
1F21 008A 00113             movwf    PCLATH              ;set correct page
1F22 2F22 00114 TrapError:    goto     TrapError          ;trap error and wait for reset
                                00115
                                00116 ;-----
00117 ;Relocated user reset code to jump to start of user code
00118 ;Must be in bank0 before jumping to this routine
00119
00120 StartUserCode:    clrf     PCLATH              ;set correct page for reset condition
00121                 nop                          ;relocated user code replaces this nop
00122                 nop                          ;relocated user code replaces this nop
00123                 nop                          ;relocated user code replaces this nop
00124                 nop                          ;relocated user code replaces this nop
00125 00125 movlw    high TrapError1 ;trap if no goto in user reset code
00126 008A 00126 movwf    PCLATH              ;set correct page
00127 2F2A 00127 TrapError1:    goto     TrapError1      ;trap error and wait for reset
00128
00129 ;-----
00130 ;Program memory location to show whether valid code has been programmed
00131
00132 CodeStatus:    DA      0x3fff                ;0 for valid code, 0x3fff for no code
00133
00134 ;-----
00135 ;Main boot code routine
00136 ;Tests to see if a load should occur and if valid user code exists
00137
00138 Main:
00139 1C06          Bank0          PORTB,TEST_INPUT    ;change to bank0 in case of soft reset
00140 2F3A          btfs          Loader              ;if low then do bootload
00141 27B5          call          LoadStatusAddr      ;load address of CodeStatus word
00142 27F6          call          FlashRead          ;read data at CodeStatus location
00143           Bank2          ;change from bank3 to bank2
00144 088C          movf          EEDATA,F            ;set Z flag if data is zero
00145           Bank0          ;change from bank2 to bank0
00146 1D03          btfs          STATUS,Z           ;test Z flag
00147 2F38          goto         TrapError2          ;if not zero then is no valid code
00148 2F23          goto         StartUserCode       ;if zero then run user code
00149
00150 ;-----
00151 ;Start of routine to load and program new code
00152
00153 Loader:
00154 01A5          clrf          TestByte            ;indicate no reset vector code yet
00155 27B5          call          LoadStatusAddr      ;load address of CodeStatus word
00156 303F          movlw        0x3f                ;load data to indicate no program
00157 008E          movwf        EEDATH              ;load data to indicate no program
00158 30FF          movlw        0xff

```

1F3F	008C	00159	movwf	EEDATA	
1F40	27EA	00160	call	FlashWrite	;write new CodeStatus word
		00161			
1F41	27CC	00162	call	SerialSetup	;set up serial port
		00163			
		00164			-----
		00165			;Get new line of hex file starting with ':'
		00166			;Get first 8 bytes after ':' and extract address and number of bytes
		00167			
1F42	27DB	00168	call	SerialReceive	;get new byte from serial port
1F43	3A3A	00169	xorlw	','	;check if ':' received
1F44	1D03	00170	btfss	STATUS,Z	
1F45	2F42	00171	goto	GetNewLine	;if not then wait for next byte
		00172			
1F46	01A3	00173	clrf	Checksum	;start with checksum zero
		00174			
1F47	27BC	00175	call	GetHexByte	;get number of program data bytes in line
1F48	391F	00176	andlw	0x1F	;limit number in case of error in file
1F49	00A2	00177	movwf	NumWords	
1F4A	1003	00178	bcf	STATUS,C	
1F4B	0CA2	00179	rrf	NumWords,F	;divide by 2 to get number of words
		00180			
1F4C	27BC	00181	call	GetHexByte	;get upper half of program start address
1F4D	00A0	00182	movwf	AddressH	
		00183			
1F4E	27BC	00184	call	GetHexByte	;get lower half of program start address
1F4F	00A1	00185	movwf	AddressL	
		00186			
1F50	1003	00187	bcf	STATUS,C	
1F51	0CA0	00188	rrf	AddressH,F	;divide address by 2 to get word address
1F52	0CA1	00189	rrf	AddressL,F	
		00190			
1F53	27BC	00191	call	GetHexByte	;get record type
1F54	3A01	00192	xorlw	0x01	
1F55	1903	00193	btfsc	STATUS,Z	;check if end of file record (0x01)
1F56	2FAB	00194	goto	FileDone	;if end of file then all done
		00195			
1F57	0826	00196	movf	HexByte,W	;check if regular line record (0x00)
1F58	3A00	00197	xorlw	0x00	;if not then ignore line and send ','
1F59	1D03	00198	btfss	STATUS,Z	
1F5A	2FA8	00199	goto	LineDone	
		00200			
1F5B	30E0	00201	movlw	0xe0	;check if address < 0x2000
1F5C	0720	00202	addwf	AddressH,W	;which is ID locations and config bits
1F5D	1803	00203	btfsc	STATUS,C	
1F5E	2FA8	00204	goto	LineDone	;if so then ignore line and send ','
		00205			

```

00206 ;-----
00207 ;Get data bytes and checksum from line of hex file
00208
00209          movlw   dataArray
00210          movwf   FSR
00211          movf    NumWords,W
00212          movwf   Counter
00213
00214 GetData:  call    GetHexByte
00215          movwf   INDF
00216          incf    FSR,F
00217
00218          call    GetHexByte
00219          movwf   INDF
00220          incf    FSR,F
00221          ;point to next low byte
00222
00223          decfsz   Counter,F
00224          goto     GetData
00225
00226          call    GetHexByte
00227          movf    Checksum,W
00228          btfs    STATUS,Z
00229          goto     ErrorMessage
00230
00231          bsf      PORTB,RTS_OUTPUT ;set RTS off to stop data being received
00232 ;-----
00233 ;Get saved data one word at a time to program into flash
00234
00235          movlw   dataArray
00236          movwf   FSR
00237          movf    NumWords,W
00238          movwf   Counter
00239
00240          ;set counter to half number of bytes
00241 ;-----
00242 ;Check if address is in reset code area
00243
00244 CheckAddress:  movf   AddressH,W
00245               btfs   STATUS,Z
00246               goto   CheckAddress1
00247
00248               movlw   0xfc
00249               addwf   AddressL,W
00250               btfs   STATUS,C
00251               goto   CheckAddress1
00252
00253               bsf     TestByte,0
00254               ;show that reset vector code received

```

```

1F7C 0821      movf    AddressL,W      ;relocate addresses 0-3 to new location
1F7D 3E24      addlw   low (StartUserCode + 1) ;add low address to new location
                                ;change from bank0 to bank2
1F80 008D      movwf   EEADR        ;load new low address
1F81 301F      movlw   high (StartUserCode + 1) ;get new location high address
1F82 008F      movwf   EEADRH       ;load high address
1F83 2F9A      goto    LoadData     ;go get data byte and program into flash
00260
00261 ;-----
00262 ;Check if reset code has been received
00263 ;Check if address is too high and conflicts with boot loader
00264
00265 CheckAddress1: btfss   TestByte,0      ;check if reset vector code received first
00266                goto    ErrorMessage   ;if not then error
00267
00268                movlw   high StartOfBoot ;get high byte of address
00269                subwf   AddressH,W
00270                btfss   STATUS,C        ;test if less than boot code address
00271                goto    LoadAddress     ;yes so continue with write
00272                btfss   STATUS,Z        ;test if equal to boot code address
00273                goto    ErrorMessage     ;no so error in high byte of address
00274
00275                movlw   low StartOfBoot ;get low byte of address
00276                subwf   AddressL,W
00277                btfsc   STATUS,C        ;test if less than boot code address
00278                goto    ErrorMessage     ;no so error in address
00279
00280 ;-----
00281 ;Load address and data and write data into flash
00282
00283 LoadAddress:   movf    AddressH,W      ;get high address
00284                Bank2   ;change from bank0 to bank2
00285                movwf   EEADRH         ;load high address
00286                Bank0   ;change from bank2 to bank0
00287                movf    AddressL,W      ;get low address
00288                Bank2   ;change from bank0 to bank2
00289                movwf   EEADR          ;load low address
00290
00291 LoadData:      movf    INDF,W          ;get low byte from array
00292                movwf   EEDATA         ;load low byte
00293                incf    FSR,F           ;point to high data byte
00294                movf    INDF,W          ;get high byte from array
00295                movwf   EEDATH         ;load high byte
00296                incf    FSR,F           ;point to next low data byte
00297
00298                call    FlashWrite     ;write data to program memory
00299

```

```

1FA3 0FA1      Bank0      ;change from bank3 to bank0
1FA4 2FA6      incfsz     AddressL,F ;increment low address byte
1FA5 0AA0      goto      CheckLineDone ;check for rollover
                                incf     AddressH,F ;if so then increment high address byte
1FA6 0BA4      CheckLineDone: decfsz     Counter,F ;check if all words have been programmed
1FA7 2F74      goto      CheckAddress ;if not then go program next word
                                00307
00308 ;-----
00309 ;Done programming line of file
00310
00311 LineDone:  movlw     '.' ;line has been programmed so
00312            call      SerialTransmit ;transmit progress indicator back
00313            goto      GetNewLine ;go get next line hex file
00314
00315 ;-----
00316 ;Done programming file so send success indicator and trap execution until reset
00317
00318 FileDone:  movlw     'S' ;programming complete so
00319            call      SerialTransmit ;transmit success indicator back
00320
00321            call      LoadStatusAddr ;load address of CodeStatus word
00322            clrf      EEDATH ;load data to indicate program exists
00323            clrf      EEDATA ;load data to indicate program exists
00324            call      FlashWrite
00325 TrapFileDone: goto      TrapFileDone ;all done so wait for reset
00326
00327 ;-----
00328 ;Error in hex file so send failure indicator and trap error
00329
00330 ErrorMessage: movlw     'F' ;error occurred so
00331            call      SerialTransmit ;transmit failure indicator back
00332 TrapError3:  goto      TrapError3 ;trap error and wait for reset
00333
00334 ;-----
00335 ;Load address of CodeStatus word into flash memory address registers
00336 ;This routine returns in bank2
00337
00338 LoadStatusAddr: Bank2
00339            movlw     high CodeStatus ;load high addr of CodeStatus location
00340            movwf     EEADRH
00341            movlw     low CodeStatus ;load low addr of CodeStatus location
00342            movwf     EEADR
00343            return
00344
00345 ;-----
00346 ;Receive two ascii digits and convert into one hex byte

```

```

00347 ;This routine returns in bank0
00348
1FBD 27DB      00349 GetHexByte:      call    SerialReceive      ;get new byte from serial port
1FBE 3EBF      00350      addlw    0xbf          ;add -'A' to Ascii high byte
1FC0 1C03      00351      btfss   STATUS,C      ;check if positive
1FBF 3E07      00352      addlw    0x07          ;if not, add 17 ('0' to '9')
1FC0 3E0A      00353      addlw    0x0a          ;else add 10 ('A' to 'F')
1FC1 00A6      00354      movwf    HexByte      ;save nibble
1FC2 0EA6      00355      swapf    HexByte,F      ;move nibble to high position
00356
1FC3 27DB      00357      call    SerialReceive      ;get new byte from serial port
1FC4 3EBF      00358      addlw    0xbf          ;add -'A' to Ascii low byte
1FC5 1C03      00359      btfss   STATUS,C      ;check if positive
1FC6 3E07      00360      addlw    0x07          ;if not, add 17 ('0' to '9')
1FC7 3E0A      00361      addlw    0x0a          ;else add 10 ('A' to 'F')
1FC8 04A6      00362      iorwf    HexByte,F      ;add low nibble to high nibble
1FC9 0826      00363      movf     HexByte,W      ;put result in W reg
1FCA 07A3      00364      addwf    Checksum,F      ;add to cumulative checksum
1FCB 0008      00365      return
00366
00367 ;-----
00368 ;Set up USART for asynchronous comms
00369 ;Routine is only called once and can be placed in-line saving a call and return
00370 ;This routine returns in bank0
00371
1FCE 1486      00372 SerialSetup:      Bank0      ;change from bank3 to bank0
00373      bsf     PORTB,RTS_OUTPUT ;set RTS off before setting as output
00374      Bank1   ;change from bank0 to bank1
00375      bcf     TRISB,RTS_OUTPUT ;enable RTS pin as output
00376      movlw   BAUD_CONSTANT   ;set baud rate 9600 for 4Mhz clock
00377      movwf   SPBRG
00378      bsf     TXSTA,BRGH      ;baud rate high speed option
00379      bsf     TXSTA,TXEN      ;enable transmission
00380      Bank0   ;change from bank1 to bank0
00381      bsf     RCSTA,CREN      ;enable reception
00382      bsf     RCSTA,SPEN      ;enable serial port
00383      return
00384
00385 ;-----
00386 ;Wait for byte to be received in USART and return with byte in W
00387 ;This routine returns in bank0
00388
1FDD 1086      00389 SerialReceive:      Bank0      ;change from unknown bank to bank0
1FDE 1E8C      00390      bcf     PORTB,RTS_OUTPUT ;set RTS on for data to be received
1FDF 2FDE      00391      btfss   PIR1,RCIF      ;check if data received
1FDE 2FDE      00392      goto     $-1          ;wait until new data
1FDE 081A      00393      movf    RCREG,W      ;get received data into W

```

```

1FE1 0008
00394      return
00395
00396 ;-----
00397 ;Transmit byte in W register from USART
00398 ;This routine returns in bank0
00399
00400 SerialTransmit: Bank0      ;change from unknown bank to bank0
00401      btfsc PORTB,CTS_INPUT  ;check CTS to see if data can be sent
00402      goto $-1
00403      btfss PIR1,TXIF        ;check that buffer is empty
00404      goto $-1
00405      movwf TXREG            ;transmit byte
00406      return
00407
00408 ;-----
00409 ;Write to a location in the flash program memory
00410 ;Address in EEADRH and EEADR, data in EEDATH and EEDATA
00411 ;This routine returns in bank3
00412
00413 FlashWrite: Bank3
00414      movlw 0x84
00415      movwf EECON1
00416
00417      movlw 0x55
00418      movwf EECON2
00419      movlw 0xaa
00420      movwf EECON2
00421      bsf EECON1,WR          ;begin writing to flash
00422
00423      nop
00424      nop
00425      return
00426
00427 ;-----
00428 ;Read from a location in the flash program memory
00429 ;Address is in EEADRH and EEADR, data returned in EEDATH and EEDATA
00430 ;Routine is only called once and can be placed in-line saving a call and return
00431 ;This routine returns in bank3 and is called when in bank2
00432
00433 FlashRead: movlw 0x1f
00434      andwf EEADRH,F
00435
00436      Bank3
00437      movlw 0x80
00438      movwf EECON1
00439
00440      bsf EECON1,RD          ;read from flash

```

```

00441
1FFD 0000
1FFE 0000
1FFF 0008
00441 nop
00442 nop
00443 nop
00444 return
00445
00446 ;-----
00447
00448 END

MEMORY USAGE MAP ('X' = Used, '-' = Unused)

0000 : XXX-----
1F00 : -----
1F40 : XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX
1F80 : XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX
1FC0 : XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX
2000 : -----X-----

All other memory blocks unused.

Program Memory Words Used: 227
Program Memory Words Free: 7965

Errors : 0
Warnings : 0 reported, 0 suppressed
Messages : 1 reported, 24 suppressed
;processor waits while reading
```

APPENDIX B: HEX FILE FORMAT

MPASM generates an 8-bit Intel hex file (INHX8M) by default. The lines of this hex file all have the following format:

:BBAAAATTTHHH...HHCC

A colon precedes each line and is followed by hexadecimal digits in ASCII format.

BB is a 2-digit hexadecimal byte count representing the number of data bytes that will appear on the line. This is a number from 0x00 to 0x10 and is always even because the PIC16F87X parts have a 14-bit wide memory and use two bytes for every program memory word.

AAAA is a 4-digit hexadecimal address representing the starting byte address of the data bytes that follow. To get the actual program memory word address, the byte address must be divided by two.

TT is a 2-digit hexadecimal record type that indicates the meaning of the data on the line. It is 0x00 for a regular data record and 0x01 for an end of file record. The boot code ignores all other record types.

HH are 2-digit hexadecimal data bytes that correspond to addresses, incrementing sequentially from the starting address earlier in the line. These bytes come in low byte, high byte pairs, corresponding to each 14-bit program memory word.

CC is a 2-digit hexadecimal checksum byte, such that the sum of all bytes in the line including the checksum, is a multiple of 256. The initial colon is ignored.

The code in Example B-1 will generate a line in a hex file as shown in Figure B-1.

EXAMPLE B-1: CODE TO GENERATE A HEX FILE

```

ORG          0x17A

movlw        0xFF
movwf        PORTB
bsf          STATUS,RP0
movwf        TRISA
clrf         TRISB
bcf          STATUS,RP0
    
```

FIGURE B-1: LINE OF HEX FILE

:0C02F400FF30860083168500860183120F

Checksum is 0x0F

$$\begin{aligned}
 &0x0C + 0x02 + 0xF4 + 0x00 + 0xFF + 0x30 + \\
 &0x86 + 0x00 + 0x83 + 0x16 + 0x85 + 0x00 + \\
 &0x86 + 0x01 + 0x83 + 0x12 + 0x0F = 0x0500
 \end{aligned}$$

Result of addition⁽¹⁾ mod 256 is zero

Second program memory word is 0x0086

This corresponds to an instruction MOVWF 0x06⁽²⁾

First program memory word is 0x30FF

This corresponds to an instruction MOVLW 0xFF

Record type is 0x00 indicating a regular data record

Address of first program memory word is $0x02F4 \div 2 = 0x017A$

Number of data bytes is 0x0C

Number of program memory words is $0x0C \div 2 = 0x06$

Note 1: The calculation to test the checksum adds every byte (pair of digits) in the line of the hex file, including the checksum itself.

2: The label PORTB is defined as 0x06 in the standard include file for the PIC16F877.

APPENDIX C: RS-232 HARDWARE HANDSHAKING SIGNALS

Understanding hardware flow control can be confusing, because of the terminology used and the slightly different way that handshaking is now implemented, compared to the original specification.

RS-232 hardware handshaking was specified in terms of communication between Data Terminal Equipment (DTE) and Data Communications Equipment (DCE). The DTE (e.g., computer terminal) was always faster than the DCE (e.g., modem) and could receive data without interruption. The hardware handshaking protocol required that the DTE would request to send data to the DCE (with the request to send RTS signal) and that the DCE would then indicate to the DTE that it was cleared to send data (with the clear to send CTS signal). Both RTS and CTS were, therefore, used to control data flow from the DTE to the DCE.

The Data Terminal Ready (DTR) signal was defined so that the DTE could indicate to the DCE that it was attached and ready to communicate. The Data Set Ready (DSR) signal was defined to enable the DCE to indicate to the DTE that it was attached and ready to communicate. These are higher level signals not generally used for byte by byte control of data flow, although they can be used for this purpose.

Most RS-232 connections use 9-pin DSUB connectors. A DTE uses a male connector and a DCE uses a female connector. The signal names are always in terms of the DTE, so the RTS pin on the female connector of the DCE is an input and is the RTS signal from the DTE.

Over time, the clear distinction between the DTE and DCE has been lost. In many instances, two DTE devices are connected together. In other cases, the DCE device is able to send data at a rate that is too high for the DTE to receive continuously. In practice, the DTR output of the DTE has come to be used to control the flow of data to the DTE and now indicates that the DCE (or other DTE) may send data. It no longer indicates a request to send data to the DCE.

It is common for a DTE to be connected to another DTE (e.g., two computers), and in this case, they will both have male connectors and the cable between them will have two female connectors. This is known as a null modem cable. The cable is usually wired in such a way that each DTE looks like a DCE to the other DTE. To achieve this, the RTS output of one DTE is connected to the CTS input of the other DTE and vice versa. Each DTE device will use its RTS output to allow the other DTE device to transmit data and will check its CTS input to determine whether it is allowed to transmit data.

FIGURE C-1: DTE TO DCE CONNECTION

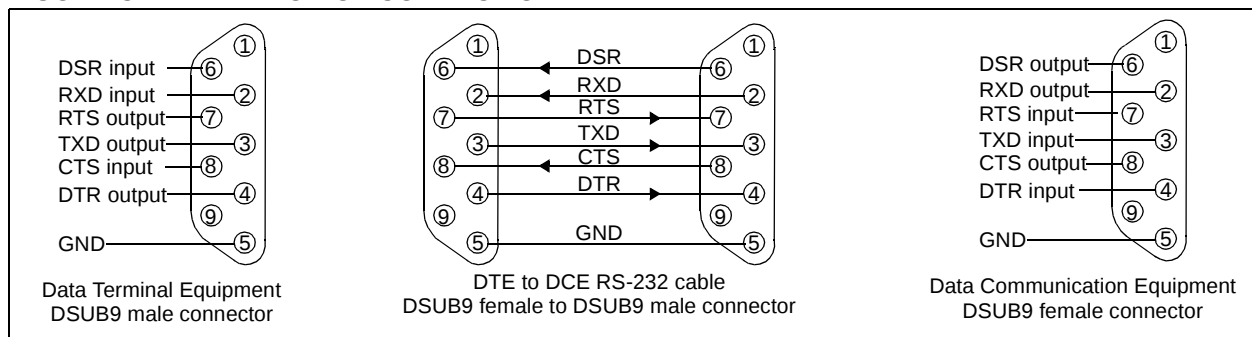
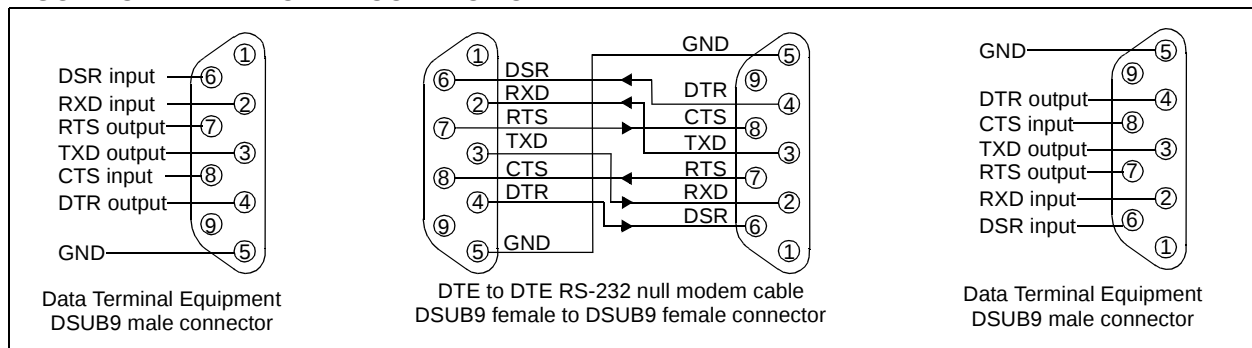


FIGURE C-2: DTE TO DTE CONNECTION



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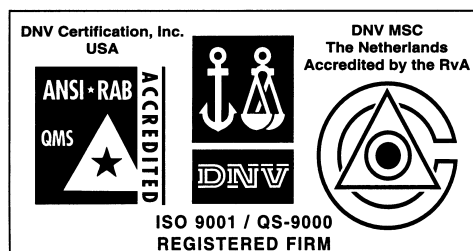
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