

A Simple CAN Node Using the MCP2515 and PIC12C672

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INTRODUCTION

This application note describes the design, development and implementation of a smart, low-cost, stand-alone Controller Area Network (CAN) node. It combines the Microchip 8-pin PIC12C672 microcontroller and the Microchip 18-pin MCP2515 Stand-Alone CAN controller. This creates a fully autonomous CAN node, which supports both “time-based” and “event driven” message transmission.

The node is interrupt driven, capable of monitoring five external inputs (two analog and three digital) and automatically generating messages based upon their value. The node also controls two digital outputs, responding to message requests via the CAN network and generating a repeating, time-based message.

The system supports a maximum CAN bus speed of 125 Kbits per second and both standard or extended frames. The system is presented using standard frames and some code changes would be required to implement extended frames.

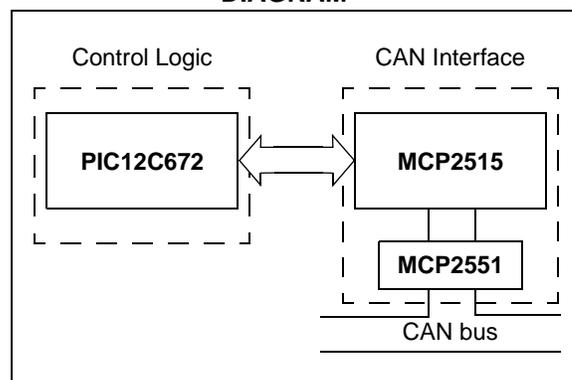
This application note focuses on the design and development of the node from the system level. No discussion of the nature of the analog signals is presented and the digital inputs are simply switch contacts, whose purpose is left for the reader to define. This application note concentrates on the unique requirements of implementing the CAN node functions using an I/O limited microcontroller and a Stand-Alone CAN protocol controller.

SYSTEM DESCRIPTION

Overview

Figure 1 shows the block diagram of the overall system. There are two functional blocks. The first is the Control Logic block. This function is performed by the PIC12C672 microcontroller. The PIC12C672 was chosen because of the low pin count and powerful feature set, including an internal oscillator, on-board, multi-channel, 8-bit Analog-to-Digital Converter (ADC), multiple interrupt sources and low-power Sleep mode. The second is the CAN interface block. This block is comprised of the MCP2515 CAN controller and the MCP2551 transceiver. The MCP2515 provides a full CAN 2.0 implementation with message filtering, which relieves the host microcontroller from having to perform any CAN bus related overhead. This is a key feature given the limited available code space of the PIC12C672.

FIGURE 1: CAN NODE BLOCK DIAGRAM



Communication between the Control Logic block and the CAN interface block makes use of the MCP2515 device's built-in support for the SPI protocol. The PIC12C672 does not have a hardware SPI interface, so the necessary functions are implemented in firmware.

Two external analog signals are tied directly to the analog input pins of the PIC12C672. An A/D conversion is performed automatically for the Analog Channel 0 (AN0), based upon the internal timer setup, and the value is automatically transmitted over the CAN bus when the conversion is completed.

The node also utilizes the MCP2515 device's multiple filters to respond to four additional CAN Message Identifiers received via the CAN bus. The masks and filters are set to accept messages into Receive Buffer 1 only. The identifiers are interpreted as one of the following, depending upon which filter is matched:

- Read Analog Channel 1
 - Perform A/D conversion for Analog Channel 1 (AN1) and initiate transmission of the value, back to the requesting node.
- Read Digital Inputs
 - Read the value of the MCP2515 input pins and transmit the value back to the requesting node.
- Update Digital Output 1
 - Write the received value to the MCP2515 Digital Output 1.
- Update Digital Output 2
 - Write the received value to the MCP2515 Digital Output 2.

Since only Receive Buffer 1 is to be used, in order to take advantage of the greater number of filters associated with that receive buffer, the Mask registers for Receive Buffer 0 must all be set to a '1'. The filter bits must then be set to match an unused message identifier (typically all '0' or all '1').

Message Identifier Format

As presented, the system requires that the messages intended for the node have a standard identifier, which has a value of 0x3F0 to 0x3F3, with each of the four filters configured to accept one of these messages. For the messages that the node transmits back, it uses the same identifier as the received message, with the exception that the ID3 bit is set to a '1'. Therefore, when the 'Read Analog Channel 1' message is received (ID = 0x3F0), the node transmits the data back using a message ID of 0x3F8. The time-based message for the value of Analog Channel 0 is transmitted with an identifier of 0x3FE. In the event of a system error being detected, the system error message uses the identifier, 0x3FF. [Table 1](#) summarizes the various transmit and receive message identifiers used. All transmitted messages use data byte 1 of the CAN message to hold the data to be sent.

TABLE 1: MESSAGE IDENTIFIERS

ID	Tx/Rx	
3F0	Rx	Read Analog Channel 1
3F1	Rx	Read Digital Inputs
3F2	Rx	Change Digital Output 1
3F3	Rx	Change Digital Output 2
3F8	Tx	Analog Channel 1 Value
3F9	Tx	Current Values of Digital Inputs
3FA	Tx	3F2 Command Acknowledgement
3FB	Tx	3F3 Command Acknowledgement
3FE	Tx	Analog Channel 0 Value
3FF	Tx	System Error

HARDWARE DESCRIPTION

Design/Performance Considerations

When designing a system, there are a number of design considerations/trade-offs/limitations that must be taken into account. Proper selection allows the system to achieve optimal performance from the available resources, and to determine if the desired performance can be achieved. The overall performance of the system is a function of several things:

- The system clock rate
- The throughput of the SPI bus
- Interrupt latency
- External interrupt request frequency

System Clock

The PIC12C672 has only six available I/O pins, and all of these are used, two for analog inputs and four (three SPIs and one INT) to interface to the MCP2515. This requires the system to take advantage of the internal RC oscillator of the PIC12C672. The internal RC oscillator provides a 4 MHz system clock to the microcontroller, which translates to a 1 μ s instruction cycle.

The instruction cycle time directly affects the achievable speed of the SPI bus. This, in turn, determines the interrupt latency time as the SPI communication makes up the majority of the time required for the Interrupt Service Routine (ISR).

SPI Bus

The standard SPI interface has been modified in this application to use a common signal line for both Serial In (SI) and Serial Out (SO) lines, isolated from each other via a resistor. This method requires only three I/O pins to implement the SPI interface, instead of the usual four. Using this configuration does not support the Full-Duplex mode of SPI communications, which is not an issue in this application.

The system achieves an overall SPI bus rate of slightly more than 80 kbps. The raw SPI clock rate averages 95 kbps. The clock low time is a fixed 5 μ s, and the clock high time is either 5 μ s or 6 μ s, depending upon whether a '0' or a '1' is being sent/received, which gives a worst case (sending the value 0xFF) of 90.9 kbps raw clock rate. The overall effective speed achieved includes the additional software overhead of 'bit-banging' the SPI protocol.

Interrupts

There are two interrupt sources in the system. The first is the PIC12C672 Timer0 interrupt. This interrupt occurs every 10.16 ms. The second interrupt source is the $\overline{\text{INT}}$ pin of the PIC12C672. This pin is connected to the $\overline{\text{INT}}$ output of the MCP2515. This interrupt occurs any time a valid message is received or if the MCP2515 detects a CAN bus related error. This external interrupt is completely asynchronous with respect to the rest of the system.

Interrupt Latency

It is necessary to carefully consider the interrupt latency requirements during the system design/development phase. This system has two interrupt sources: the internal timer interrupt, which occurs approximately every 10 ms, and the external $\overline{\text{INT}}$ pin interrupt, which is generated by the MCP2515 CAN controller and may occur at any time. The latency time for the timer ISR is essentially fixed. This parameter is a function of the time it takes for the ADC to perform a conversion on both channels, write the values to the transmit buffer, and issue a Request to Send (RTS) command to the MCP2515, via the SPI interface. This takes approximately 428 μ s to complete.

Digital Inputs and Outputs

The MCP2515 has three pins that can be configured as general purpose inputs and two pins that can be configured as digital outputs. Both of these are implemented in this design. These are treated at their simplest level within the scope of this application note. The inputs as shown are connected to switch contacts and the outputs to LED indicators. The MCP2515 inputs have internal pull-up resistors and will read high when the attached switch is open and low when it is closed.

The MCP2515 has two I/O pins ($\overline{\text{RX0BF}}$ and $\overline{\text{RX1BF}}$) that can be configured as general purpose outputs. These pins are configured as outputs, and are connected to LEDs to function as some type of indicator lights, that are controlled via the CAN bus.

CAN Bus

The CAN bus is configured to run at 125 kbps. The clock source for the MCP2515 is a standard, 8 MHz crystal connected to the OSC1 and OSC2 inputs. The CAN physical layer has been implemented using an industry standard CAN transceiver chip (e.g., Microchip MCP2551). This device supports CAN bus rates of up to 1 Mbps and is more than adequate for the application presented here.

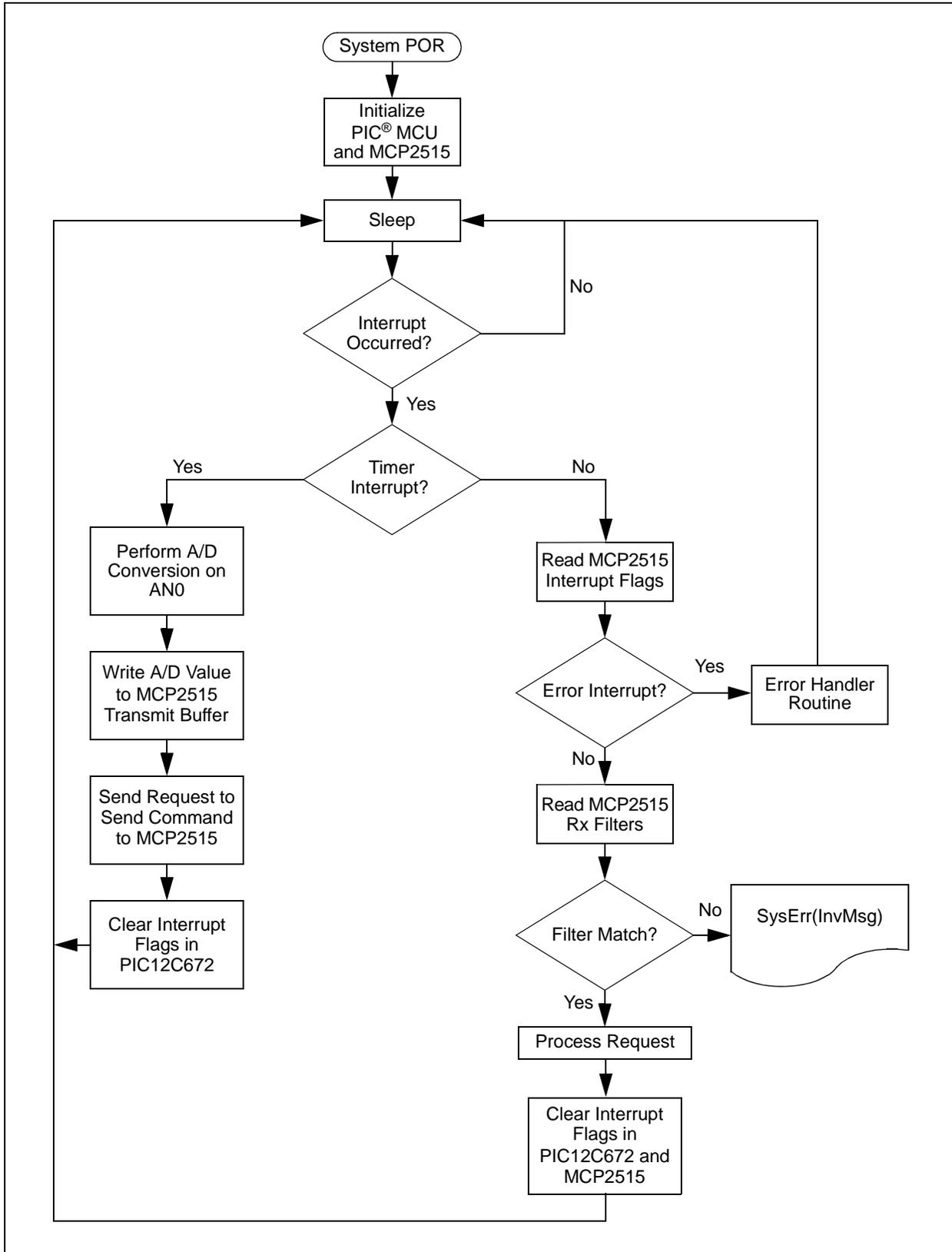
FIRMWARE DESCRIPTION

The firmware is written in PIC[®] microcontroller (MCU) assembly code. The relative simplicity and small size of this application makes the assembly language more than a suitable choice.

Figure 2 shows the top level flowchart for the overall system operation. The PIC MCU, after going through self initialization and initializing the MCP2515, goes to Sleep and waits for an interrupt to occur. The following sections provide more detailed discussion of the operation of each of the major blocks in the firmware.

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FIGURE 2: NODE OPERATION



PIC[®] MCU Initialization

Initialization of the PIC12C672 is straightforward. There are three major functions that need to be properly configured within the PIC12C672:

- General Purpose I/O (GPIO) pins
- Timer0 module
- A/D Converter module

In addition, the Configuration Word must also be programmed to enable/disable code protection and select the oscillator type.

GENERAL PURPOSE I/O PINS

The GPIO pins are the six I/O pins that are used to interface the PIC12C672 to the MCP2515 and sample the analog signals. The PIC MCU OPTION, TRIS and INTCON registers are used to control the setup of the GPIO pins. In this case, the OPTION register is programmed to disable the internal pull-up resistors on GP0/GP1/GP3. It also configures GP2 to generate an interrupt on the negative going edge (to match the MCP2515 device's active low INT output). The TRIS register, which controls whether each I/O pin is configured as an input or an output, is configured to set GP0/GP1/GP3 as inputs, and GP2 and GP5 as outputs. With the exception of GP4, all of the GPIO pins will remain in their initially configured state. GP4 will be changed between Input and Output mode, depending upon whether an SPI read or write operation is being performed by the PIC12C672. The final step of configuring the port pins is to program the INTCON register to enable the interrupt-on-change feature for GP2. This allows the MCP2515 to generate an interrupt to the PIC12C672.

TIMER0 MODULE

The Timer0 module operation is controlled by the OPTION register and the TMR0 register. The OPTION register contains the control bits for the Timer0 prescaler, which is set to divide-by-256. The TMR0 register is the counting register for Timer0 and generates an interrupt when it rolls over from 0xFF to 0x00. This register must be reloaded as part of the ISR in order to correctly control the time period between Timer0 interrupts. The target time period between Timer0 messages was 10 ms. In order to approach that target, it is necessary to determine the amount of time required to complete the Timer0 ISR, since the time between messages will be the sum of the Timer0 value and the ISR execution time. The A/D conversion takes approximately 19 μ s for the SPI communication to write the A/D result to the MCP2515 transmit buffer. Then, the conversion sends the RTS command, which requires approximately 409 μ s to complete, for a total of approximately 428 μ s for the ISR to execute. Subtracting the ISR execution time from the 10 ms target, yields 9.572 ms. Given that the prescaler is configured in Divide-by-256 mode, the closest value is

9.728 ms (256 μ s * 38). Adding the 428 μ s for the ISR execution gives a total time between messages of 10.156 ms, which is within 2% of the target.

ANALOG-TO-DIGITAL CONVERTER MODULE

The Timer0 module is configured to use the FOSC/8 option for the conversion clock, which gives a TAD value of 2 μ s and an overall conversion time of 19 μ s (TAD * 9.5). This is more than fast enough compared to the amount of time spent on SPI communications during the ISR.

MCP2515 Initialization

Before the system can communicate on the CAN bus, the MCP2515 must be properly configured. The configuration of the MCP2515 is accomplished by loading the various control registers with the desired values. The firmware is written to take advantage of the table read functionality of the PIC MCU. The values for each register are stored at the top of the PIC ROM memory. During the MCP2515 initialization, the values are sequentially read by the table read function and then written to the MCP2515, via the SPI interface.

CAN BUS TIMING

The CAN bit rate configuration is controlled by the CNF1, CNF2 and CNF3 registers. The details behind determining what is the 'best' configuration of these registers, for a given CAN bus system, is beyond the scope of this application note. The MCP2515 is configured to operate at a CAN bus rate of 125 kbps using the following parameters:

- 8 MHz Oscillator
- Baud rate prescaler equivalent to divide-by-4
- 8 TQ per bit Time
- Sync Segment: 1 TQ
- Prop Segment: 1 TQ
- Phase Segment 1: 3 TQ
- Phase Segment 2: 3 TQ
- Sync Jump Width: 1 TQ

Refer to the "MCP2515 Stand-Alone CAN Controller with SPI Interface Data Sheet" (DS21291) for more detailed information regarding the setting of these parameters.

In order to make use of the MCP2515 device's general purpose input and output pins, it is necessary to configure the TXRTSCTRL and BFPCTRL registers, respectively.

TXRTSCTRL

To enable the use of the TXnRTS pins as general purpose inputs, the mode control bit, <BnRTSM>, is cleared. This register also holds the current state of each of the input pins in bits 3:5, which can be read by the microcontroller at any time via the SPI interface.

BFPCTRL

To use the RXnBF pins of the MCP2515 as output pins, it is necessary to functionally enable the pin by setting the BnBFE bits and then to select the general purpose output mode of operation by clearing the BnBFM bits. Once the register has been configured, it is also used to control the state of the output pins by toggling the BnBFS bits. This is accomplished via the MCP2515 device's built-in Bit Modify Command which allows only the desired bit to be modified.

CANINTE

The MCP2515 device's CANINTE register controls the individual interrupt source enables. For this application only, the error interrupt (ERRIE) and Receive Buffer 1 interrupts (RX1IE) are enabled. In this configuration, the MCP2515 will generate an interrupt when a valid message is accepted into the receive buffer, or any of the various error conditions in the EFLG register occur.

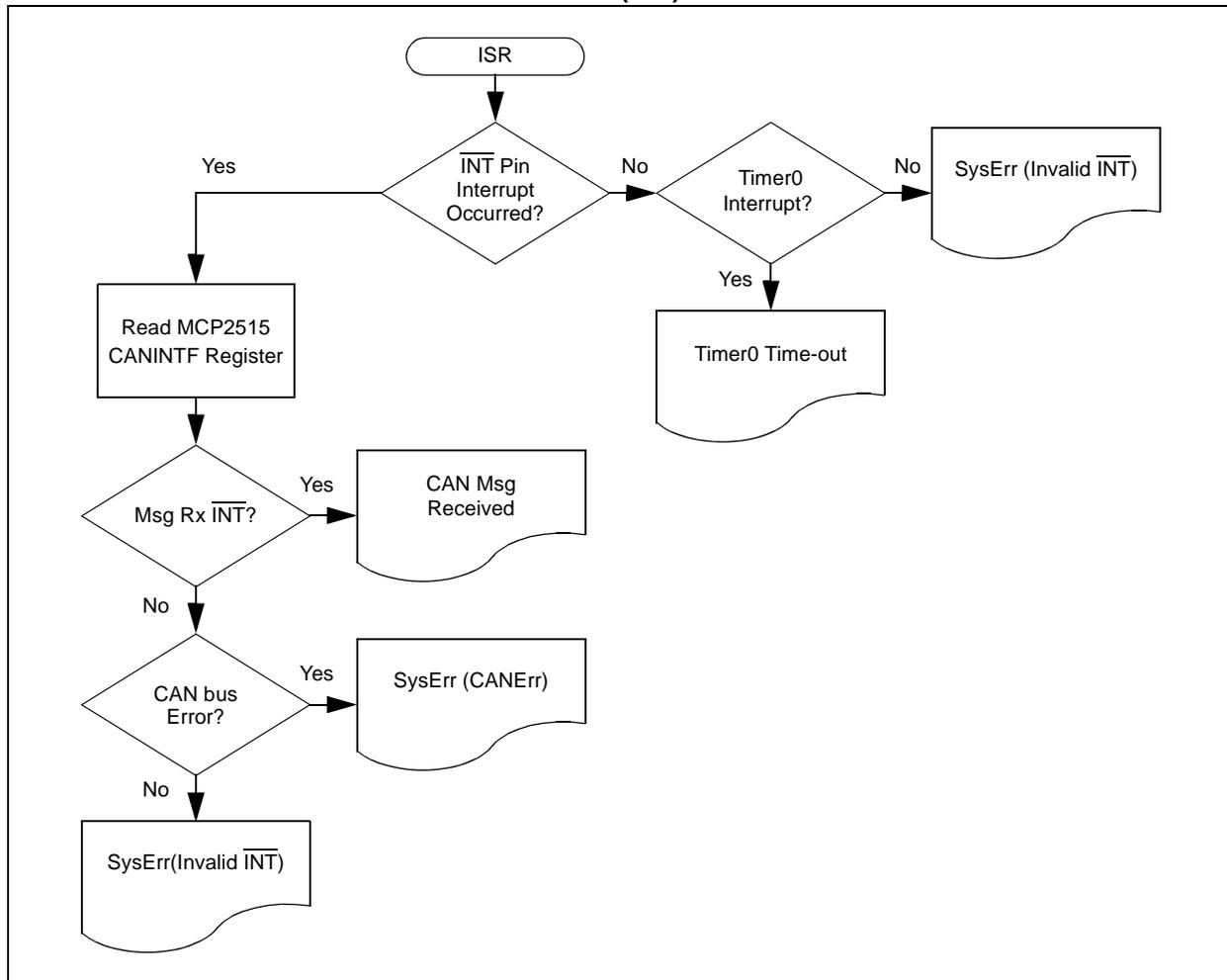
Interrupt Service Routine

When an interrupt occurs, the PIC MCU begins executing the ISR routine. [Figure 3](#) shows the flowchart for the ISR. The ISR first determines the source of the interrupt, Timer0 or external $\overline{\text{INT}}$ pin and then branches to the appropriate code to process the interrupt. [Figure 4](#) and [Figure 5](#) show the program flow for the Timer0 and CAN message received interrupts, respectively.

TIMER0 INTERRUPT

When the Timer0 interrupt occurs (see [Figure 4](#)), the PIC MCU initiates an A/D conversion on AN0, constantly polling the ADDONE bit until the conversion is complete. Once the conversion is complete, the ADRES value is loaded into the MCP2515 Transmit Buffer 0, Data Byte 0, and an RTS command is issued for Buffer 0. The TMR0 register is then reloaded and the interrupt flag is cleared. The interrupts are re-enabled by the execution of the RETIE command at the end of the ISR.

FIGURE 3: INTERRUPT SERVICE ROUTINE (ISR) FLOWCHART



MESSAGE RECEIVED INTERRUPT

When an interrupt is generated by the MCP2515, the PIC12C672 reads the CANINTF register of the MCP2515 to determine the source of the interrupt. If a valid message has been received, then the `MsgRcvd` subroutine is executed (see [Figure 5](#)), and if an error has occurred, the error handling subroutine is executed (see [Figure 6](#)).

When a valid message is received, the `FILHIT<2:0>` bits of the `RXB1CTRL` register are read to determine which message has been received.

If the match occurred on Filter 2, then the PIC MCU initiates an A/D conversion on AN1, waits for the conversion to complete, loads the `ADRES` register value into the MCP2515 Transmit Buffer 0 and Data Byte 0, and sends the RTS command.

If the match occurred on Filter 3, then the PIC MCU reads the `TXRTSCTRL` register for the value of the three input pins, loads this value into the MCP2515 transmit buffer and sends the RTS command.

A match on Filter 4 or Filter 5 causes the PIC MCU to read the first byte of the received message and write it to the appropriate output pin via the MCP2515 `BFPCTRL` register.

FIGURE 4: TIMER0 ISR FLOW

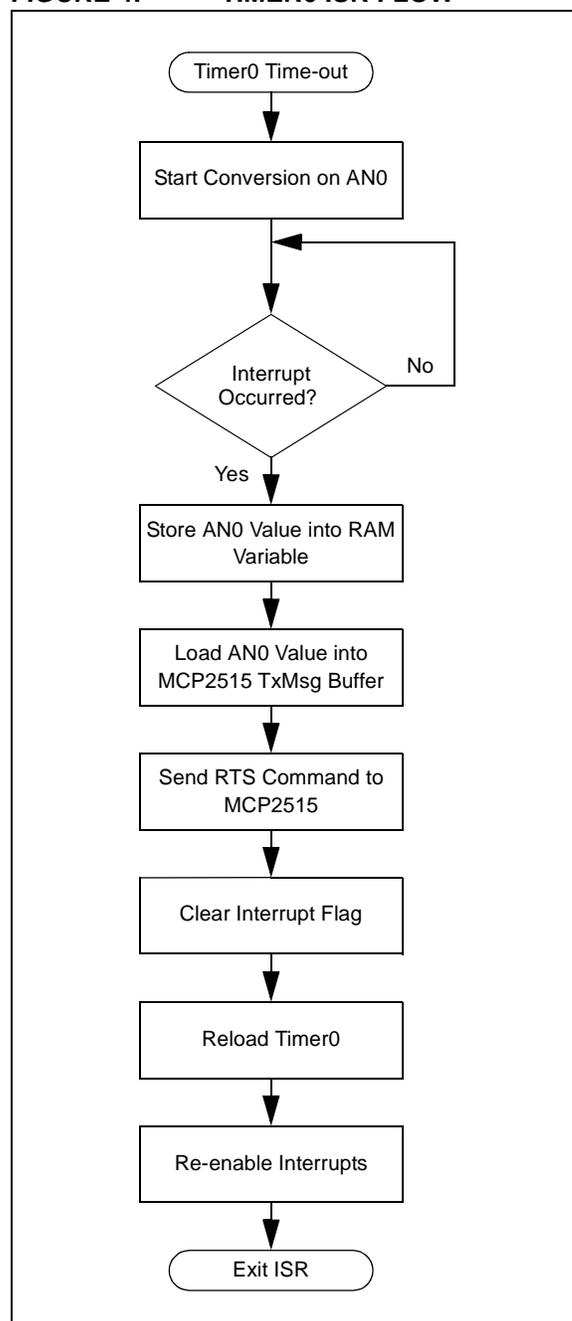


FIGURE 5: CAN MSG RECEIVED FLOW

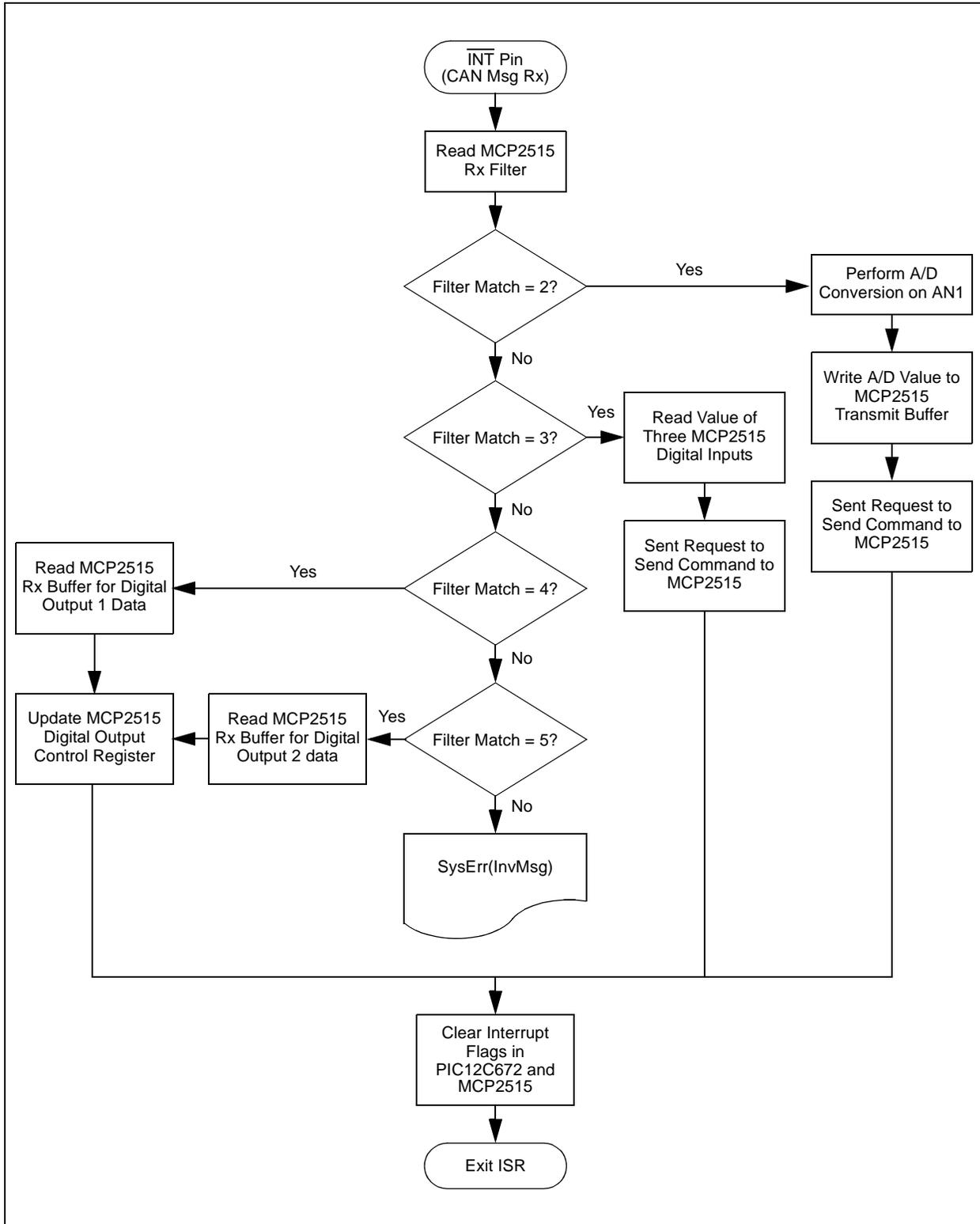
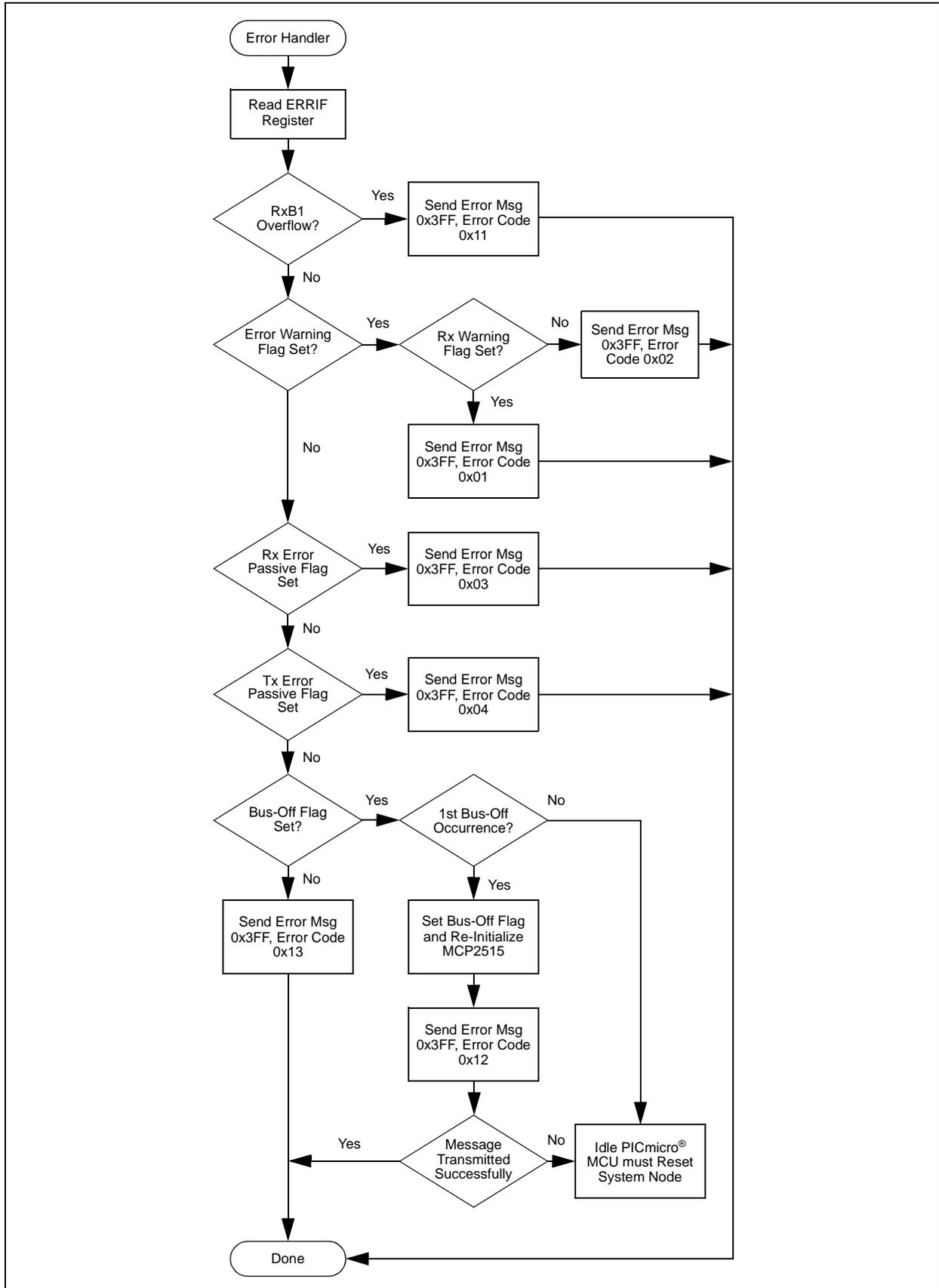


FIGURE 6: ERROR HANDLER FLOW



Error Handling

The system also provides for error detection for a number of different types of errors that may occur, including CAN bus errors detected by the MCP2515, as well as invalid system state errors (see [Figure 6](#)). When any of these errors are detected, the system transmits a message with the ID of 0x3FF. This message contains one data byte which is a code used to represent the type of error that occurred. Refer to [Appendix B: "Source Code"](#) for a listing of the various errors and the associated code. The one exception to this, is the Bus-Off condition that the MCP2515 may enter if a large number of transmit errors are detected. If the Bus-Off condition is detected, the PIC MCU performs a re-initialization of the MCP2515 and then attempts to transmit the error message (ID = 0x3FF) with an error code of 0x12. After initiating a request to send for the error message, the PIC MCU checks to ensure that the message was transmitted successfully. If it was successfully transmitted, the PIC MCU sets an internal flag to indicate that a Bus-Off condition occurred and then resumes normal operation. If the error message fails to transmit correctly, or if the Bus-Off condition is detected a second time, the PIC MCU automatically enters an Idle loop and remains there until a system Reset occurs via power-on.

SUMMARY

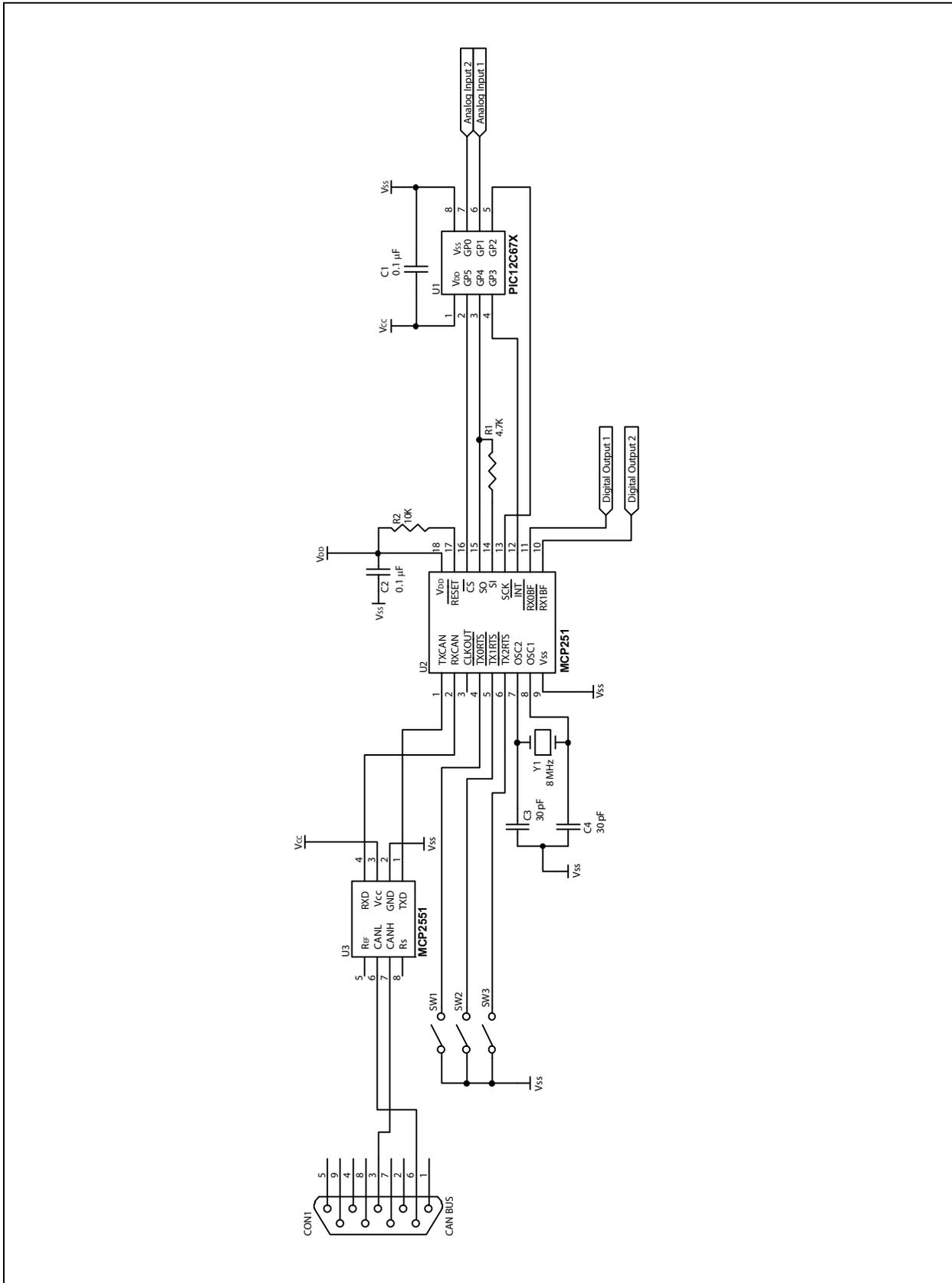
This application note demonstrates that a smart CAN node can be implemented with low-cost, low pin count devices, such as the PIC12C672 microcontroller and MCP2515 Stand-Alone CAN controller, providing a very flexible and effective solution for a variety of applications.

REFERENCE DOCUMENTS

For additional information, the reader is directed to the following documents:

- PIC12C67X 8-Pin, 8-Bit CMOS Microcontroller with A/D Converter and EEPROM Data Memory Data Sheet, DS30561; Microchip Technology, Inc.
- MCP2515 Stand Alone CAN Controller with SPI Interface Data Sheet, DS21801; Microchip Technology, Inc.
- AN713, Controller Area Network (CAN) Basics, DS00713; Microchip Technology, Inc.
- MCP2551 High-Speed CAN Transceiver Data Sheet, DS21667; Microchip Technology, Inc.

APPENDIX A: SCHEMATIC



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APPENDIX B: SOURCE CODE

```
; *****
; * 8pincan.asm *
; * Revision 1.0 September 2000 *
; * Developed by Rick Stoneking *
; * Developed using MPLAB V4.12 and MPASM V2.3 *
; * *
; * This code demonstrates how a very low cost *
; * CAN node can be implemented using a *
; * Microchip PIC12C672 8 pin microcontroller *
; * and a Microchip MCP2515 Stand Alone CAN *
; * controller. *
; * *
; *****

; *****
; * Setup the MPASM assembler options *
; *****

LIST p=12C672

; *****
; * Include the standard PIC12C672 include file *
; * and the custom MCP2515 support files *
; *****

#include <p12c672.inc>
#include "MCP2515.inc"

; *****
; * Setup the PIC12C672 configuration Word *
; *****

__CONFIG __CP_OFF & __WDT_OFF & __MCLRE_OFF & __INTRC_OSC

; *****
; * Constants definitions *
; *****
TMR_COUNT EQU 0xD9 ; Timer Reload value:
; 0xD9 = 38 * 256 * 1us = 9.728ms

; *****
; * Variable definitions *
; *****
temp EQU 0x20
temp1 EQU 0x21
byte_cnt EQU 0x22
addr EQU 0x23
tmp_data EQU 0x24
```

```
; *****
; * PIC Initialization *
; *****

    org    0x00
    goto   start           ; Jump around ISR vector

; *****
; * Interrupt service vector initialization *
; *****

    org    0x04
    goto   isr           ; Point ISR vector to the ISR handler

; *****
; * Start of Main Code *
; *****
start
    bsf    STATUS,RP0     ; select bank1
    movlw  0x87           ; Disable internal pullups
                                ; Interrupt on negative going edge on GP2
                                ; Prescaler = 1:256

    movwf  OPTION_REG     ; Load the OPTION register

    movlw  0x0B           ; --001011
    movwf  TRISIO        ; set all ports output except GP3/1/0

    bsf    INTCON,GPIE    ; enable GPIO Interrupt on change

    movlw  0x04           ; GP4&2 = DIO, GP0&1= ADC, Vref=VDD
    movwf  ADCON1        ;

    movlw  0x04           ; GPIE set - interrupt on pin change
                                ; GIE cleared - global interrupts disabled
    bcf    STATUS,RP0    ; select bank0

; Initialize the A/D converter

    movlw  0x40           ; AN0 conversion clock = Fosc/8 (TAD=2us)
    movwf  ADCON0        ; Turn off A/D module

; Initialize Timer0

    movlw  TMR_COUNT     ; Initialize Timer0
    movwf  TMR0          ; Timer0 interrupt every 9.728mS

; Set up initial conditions for the SPI

    movlw  0x24           ; CS high, INT high, data/clock low
    movwf  GPIO          ; write to port

    bsf    GPIO,cs_pin   ; set CS pin high
    bcf    GPIO,sck_pin  ; clear the sck pin
    bcf    GPIO,sdo_pin  ; clear the sdo pin

    call   MCP2515_init   ; initialize the MCP2515
```

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```
; *****
; * Main wait loop *
; *****

wait                ; wait for interrupt to occur
    sleep           ; sleep while not processing a message
    nop             ; NOP executed when waking up from sleep
    nop             ; NOP executed after ISR completes
    goto    wait    ; go back to sleep and wait

; *****
; * MCP2515 Initialization *
; *****

MCP2515_init
    movlw    CAN_WRITE        ; write command
    bcf      GPIO,cs_pin      ; lower CS to enable MCP2515
    call     spi_send         ; send command
    movlw    CANCTRL          ; select CANCTRL register address
    call     spi_send         ; and send it
    movlw    REQOP_CONFIG     ; Request Config Mode
    call     spi_send         ; send data
    bsf      GPIO,cs_pin      ; raise CS to terminate operation
    bcf      GPIO,sck_pin     ; set clock and
    bcf      GPIO,sdo_pin     ; data pins low

    movlw    0x71             ; number of addresses to be written
    movwf    byte_cnt         ; load into byte counter
    movlw    CAN_WRITE        ; write command
    bcf      GPIO,cs_pin      ; enable MCP2515
    call     spi_send         ; send command
    movlw    0x00             ; start writing at address 0x00
    call     spi_send         ; send address
    movlw    0x01
    movwf    addr

seq_wr              ; sequential write loop
    movlw    HIGH reg_init_tbl ; get high byte of reg_int_tbl address
    movwf    PCLATH           ; load into high byte of PC counter
    movfw    addr             ; write into jump table pointer (addr)
    decf     addr, 1          ;
    movf     addr, W          ;
    call     reg_init_tbl     ; fetch byte to be written
    call     spi_send         ; send it to MCP2515
    incf     addr,1           ; increment the jump table pointer
    incf     addr,1           ; twice to point to the next byte
    decfsz  byte_cnt,1       ; decrement the byte counter and test for zero
    goto    seq_wr           ; not done so repeat
    bsf      GPIO,cs_pin     ; raise CS to terminate operation

    movlw    CAN_WRITE        ; write command
    bcf      GPIO,cs_pin      ; enable MCP2515
    call     spi_send         ;
    movlw    CANCTRL          ; write to CANCTRL register
    call     spi_send         ;
    movlw    REQOP_NORMAL     ; Normal Mode
    call     spi_send         ;
    bsf      GPIO,cs_pin      ; terminate operation

    movlw    0x00             ; clear byte_cnt variable
    movwf    byte_cnt

    bsf      INTCON,GIE       ; Enable Interrupts
    return
```

```

; *****
; * Interrupt Service Routine *
; * The ISR determines whether a TMR0 interrupt or an external INT *
; * pin interrupt occurs and then proceeds accordingly *
; *****
ISR
    bcf     STATUS,RP1           ; select bank 0/1

    btfss  INTCON,T0IE         ; Timer0 interrupt?
    goto   intpin              ; No, so jump to external interrupt pin ISR

    movlw  TMR_COUNT           ; reload
    movwf  TMR0                ; Timer0

    bcf    ADCON0,CHS0         ; select ADC channel 0
    call   adc_cnv              ; go do the conversion

    bcf    GPIO,cs_pin         ; enable MCP2515

    movlw  CAN_WRITE           ; send write command to MCP2515
    call   spi_send             ;

    movlw  TXB0D0              ; set write address to TXB0D0
    call   spi_send             ;

    movfw  ADRES                ; write ADC conversion result
    call   spi_send             ;
    bsf    GPIO,cs_pin         ; terminate SPI operation

    bcf    GPIO,cs_pin         ; enable MCP2515
    movlw  CAN_RTS_TXB0        ; Send RTS command for TXB0
    call   spi_send             ;
    bsf    GPIO,cs_pin         ; terminate operation

    bcf    INTCON, T0IF        ; clear TMR0 interrupt flag
    return                       ; exit isr

intpin                               ; Message received interrupt

    movlw  CAN_READ
    bcf    GPIO,cs_pin         ; lower CS line
    call   spi_send             ; send read command to MCP2515

                                ; Check for RXB1IF flag by reading
                                ; the interrupt flag register (CANINTF)
    movlw  CANINTF
    call   spi_send
    call   spi_rx               ; read the data from the MCP2515
    bsf    GPIO,cs_pin         ; terminate SPI read

    movwf  tmp_data            ; save CANINTF value

    btfsc  tmp_data,1           ; test CANINTF for RX1IF
    call   msg_rcvd            ; if RX1IF set go process message

    btfss  tmp_data,5           ; test CANINTF for ERRIF
    call   can_err             ; if ERRIF set go process CAN error

    movlw  B'11011101'         ; mask off RXB1IF and ERRIF bits
    andwf  tmp_data,1          ; of CANINTF
    btfsc  STATUS,Z            ; if any bit set process invalid interrupt

    call   sys_err             ; Not an error interrupt so initiate an invalid interrupt
                                ; occurred message.

    bcf    INTCON,GPIF         ; reset interrupt flag
    retfie                       ; return to main routine

```

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```
; *****
; * CAN Error routine *
; * This routine reads the value of the MCP2515 Error flag (EFLG) *
; * register, writes it to byte 0 of TXB1, and then transmits the *
; * TXB1 message *
; *****
can_err

    movlw    CAN_READ            ; SPI Read operation
    bcf     GPIO,cs_pin         ; enable MCP2515
    call    spi_send            ;
    movlw   EFLG                ; EFLG register to be read
    call    spi_send            ;
    call    spi_rx              ; read the data
    bsf    GPIO,cs_pin         ; terminate SPI operation
    movwf   tmp_data            ; save the value of EFLG register

    movlw   CAN_WRITE          ; now write to MCP2515
    bcf     GPIO,cs_pin         ;
    call    spi_send            ;
    movlw   TXB1D0             ; write to data byte 0 of TXB1
    call    spi_send            ;
    movfw   tmp_data           ; write EFLG register contents
    call    spi_send            ;
    bsf     GPIO,cs_pin         ; terminate SPI operation

    movlw   CAN_RTS_TXB1       ; send request to send
    bcf     GPIO,cs_pin         ; for transmit buffer 1
    call    spi_send            ;
    bsf     GPIO,cs_pin         ;

                                ; exit isr and re-enable interrupts
    retfie

; *****
; * System Error Handler Routine *
; * This routines transmits the TXB2 message to indicate that a *
; * unidentifiable system error has occurred. *
; *****
sys_err

    movlw   CAN_RTS_TXB2       ; send request to send
    bcf     GPIO,cs_pin         ; for transmit buffer 2
    call    spi_send            ; when a system error occurs
    bsf     GPIO,cs_pin         ;

    retfie

; *****
; * CAN Msg Received Routine *
; * This routine is called when a message has been received into *
; * TXB0 of the MCP2515. This routine reads the filter bits to *
; * determine the type of message received and then initiates the *
; * appropriate response. *
; *****
msg_rcvd

    movlw   CAN_READ            ; SPI read command
    bcf     GPIO,cs_pin         ; enable MCP2515
    call    spi_send            ;

    movlw   RXB0CTRL           ; Read buffer 0 control register
    call    spi_send            ;
    call    spi_rx              ;
    bsf     GPIO,cs_pin         ; terminate function
```

```

    andlw  B'00000111'      ; mask off all but the FILHIT bits
    movwf  temp             ; store value in temp

    movlw  0x01             ;
    subwf  temp,1           ;
    btfsc  STATUS,Z         ; filter 1 match?
    goto   filter1

    movlw  0x02             ;
    subwf  temp,1           ;
    btfsc  STATUS,Z         ; filter 2 match
    goto   filter2

    movlw  0x03             ;
    subwf  temp,1           ;
    btfsc  STATUS,Z         ; filter 3 match
    goto   filter3

    movlw  0x04             ;
    subwf  temp,1           ;
    btfsc  STATUS,Z         ; filter 4 match
    goto   filter4

filter1
    call   wrt_txb0sidh     ; load the transmit buffer SIDH register

    bsf    ADCON0,CHS0     ; select ADC channel 1
    call   adc_cnv         ; go do the conversion

    bcf    GPIO,cs_pin     ; enable MCP2515
    movlw  CAN_WRITE       ; send write command to MCP2515
    call   spi_send        ;
    movlw  TXB0D0          ; set write address to TXB0D0
    call   spi_send        ;
    movfw  ADRES           ; write ADC conversion result
    call   spi_send        ;
    bsf    GPIO,cs_pin     ; terminate SPI operation

    goto   filter_done

filter2
    call   wrt_txb0sidh     ; load the transmit buffer SIDH register

    bcf    GPIO,cs_pin     ; enable MCP2515
    movlw  CAN_READ        ; send read command to MCP2515
    call   spi_send        ;
    movlw  TXRTSCTRL       ; set read address to TXRTSCTRL
    call   spi_send        ;
    call   spi_rx          ; read data
    bsf    GPIO,cs_pin     ;

    bcf    GPIO,cs_pin     ; write TXRTSCTRL value
    movlw  CAN_WRITE       ; to data byte zero of
    call   spi_send        ;
    movlw  TXB0D0          ; transmit buffer zero
    call   spi_send        ;
    bsf    GPIO,cs_pin     ; terminate SPI operation

    goto   filter_done

filter3
    call   wrt_txb0sidh     ; load the transmit buffer SIDH register

    movlw  CAN_READ        ; Read contents of receive buffer zero
    bcf    GPIO,cs_pin     ; byte zero to get value to write to

```

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```
    call    spi_send          ; GP output pin of MCP2515
    movlw  RXB1D0            ;
    call    spi_send
    call    spi_rx
    bsf    GPIO,cs_pin
    movwf  tmp_data          ; store value in tmp_data

    movlw  CAN_BIT_MODIFY    ; use bit modify command to
    bcf    GPIO,cs_pin        ; set/reset the B0BFS bit of BFPCTRL register
    call    spi_send
    movlw  BFPCTRL
    call    spi_send
    movlw  B0BFS
    call    spi_send

    movlw  0xFF              ; assume that B0BFS is to be set
    btfss  tmp_data,0        ; test the value received in message and if it is 0
    movlw  0x00              ; load w register to reset bit in BFPCTRL register

    call    spi_send
    bsf    GPIO,cs_pin

    goto   filter_done

filter4
    call    wrt_txb0sidh      ; load the transmit buffer SIDH register

    movlw  CAN_READ          ; Read contents of receive buffer zero
    bcf    GPIO,cs_pin        ; byte zero to get value to write to
    call    spi_send          ; GP output pin of MCP2515
    movlw  RXB1D0            ;
    call    spi_send
    call    spi_rx
    bsf    GPIO,cs_pin
    movwf  tmp_data          ; store value in tmp_data

    movlw  CAN_BIT_MODIFY    ; use bit modify command to
    bcf    GPIO,cs_pin        ; set/reset the B0BFS bit of BFPCTRL register
    call    spi_send
    movlw  BFPCTRL
    call    spi_send
    movlw  B1BFS
    call    spi_send

    movlw  0xFF              ; assume that B1BFS is to be set
    btfss  tmp_data,0        ; test the value received in message and if it is 0
    movlw  0x00              ; load w register to reset bit in BFPCTRL register

    call    spi_send
    bsf    GPIO,cs_pin

filter_done
    movlw  CAN_RTS_TXB0      ; last step is to send the
    bcf    GPIO,cs_pin        ; request to send command for
    call    spi_send          ; transmit buffer zero
    bsf    GPIO,cs_pin

    return
```

```

; *****
; * write TXB0SIDH *
; * This routine reads the SIDH register from the received message *
; * and then sets the SID3 bit and writes the new value to the TX *
; * buffer. *
; *****
wrt_txb0sidh
    movlw    CAN_READ           ; SPI read command
    bcf     GPIO,cs_pin        ; enable MCP2515
    call    spi_send
    movlw    RXB0SIDH         ; Read received SIDH register
    call    spi_send
    call    spi_rx
    bsf     GPIO,cs_pin       ; terminate function

    movwf   tmp_data          ; store SIDH value in data

    bcf     GPIO,cs_pin
    movlw   CAN_WRITE
    call    spi_send
    movlw   TXB0SIDH         ; write to the SIDH register
    call    spi_send
    movwf   tmp_data         ; retrieve SIDH value of received message
    bsf     W,0              ; set bit SID3 high
    call    spi_send
    bsf     GPIO,cs_pin
    return

; *****
; * Analog to Digital Conversion Routine *
; * This routine initiates the A/D conversion. The ADC channel *
; * select bits (CHS1:0) have to be set prior to this routine being *
; * called. The routine waits for the conversion to complete *
; * before returning to the calling function. *
; *****
adc_cnv
    bsf     ADCON0,GO

adc_busy
    btfsc   ADCON0,GO_DONE    ; wait for ADC to complete
    goto   adc_busy

    movlw   CAN_WRITE         ; SPI write command
    bcf     GPIO,cs_pin       ; lower CS line
    call    spi_send          ; send write command to MCP2515
    movlw   TXB0D0           ; data being written to data byte zero of buff 0
    call    spi_send
    movf    ADRES,0          ; Move ADC value to W register
    call    spi_send          ; send to MCP2515
    bsf     GPIO,cs_pin       ; terminate SPI command
    return

; *****
; * Include the custom three wire SPI support file *
; *****

#include "spi.inc"           ; SPI routines

```

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```
; *****
; * MCP2515 register initialization table *
; * Store at the end of ROM memory *
; * Note that all addresses are initialized to simplify the *
; * initialization code. *
; *****

reg_init_tbl
    org      0x0700          ; Initialization table address
    addwf   PCL, 1          ; Register Addr
                                ; -----
    retlw   0xff            ; RXF0SIDH 0x00
    retlw   0xff            ; RXF0SIDL 0x01
    retlw   0xff            ; RXF0EID8 0x02
    retlw   0xff            ; RXF0EID0 0x03
    retlw   0xff            ; RXF1SIDH 0x04
    retlw   0xff            ; RXF1SIDL 0x05
    retlw   0xff            ; RXF1EID8 0x06
    retlw   0xff            ; RXF1EID0 0x07
    retlw   0x7e            ; RXF2SIDH 0x08      Filter 2 matches 0x3f0
    retlw   0x00            ; RXF2SIDL 0x09
    retlw   0xff            ; RXF2EID8 0x0A
    retlw   0xff            ; RXF2EID0 0x0B
    retlw   0x3c            ; BFPCTRL 0x0C      BFP pins as digital outputs, initial
                                ; state hi
    retlw   0x00            ; TXRTSCTRL 0x0D      TXRTS pins as digital inputs
    retlw   0x80            ; CANSTAT 0x0E
    retlw   0x80            ; CANCTRL 0x0F

    retlw   0x7e            ; RXF3SIDH 0x10      Filter 3 matches 0x3f1
    retlw   0x20            ; RXF3SIDL 0x11
    retlw   0xff            ; RXF3EID8 0x12
    retlw   0xff            ; RXF3EID0 0x13
    retlw   0x7e            ; RXF4SIDH 0x14      Filter 4 matches 0x3f2
    retlw   0x40            ; RXF4SIDL 0x15
    retlw   0xff            ; RXF4EID8 0x16
    retlw   0xff            ; RXF4EID0 0x17
    retlw   0x7e            ; RXF5SIDH 0x18      Filter 5 matches 0x3f3
    retlw   0x50            ; RXF5SIDL 0x19
    retlw   0xff            ; RXF5EID8 0x1A
    retlw   0xff            ; RXF5EID0 0x1B
    retlw   0x00            ; TEC 0x1C
    retlw   0x00            ; REC 0x1D
    retlw   0x80            ; CANSTAT 0x1E
    retlw   0x80            ; CANCTRL 0x1F

    retlw   0xff            ; RXM0SIDH 0x20      Enable all mask bits so that no msg's
    retlw   0xff            ; RXM0SIDL 0x21      are received into RXB0
    retlw   0xff            ; RXM0EID8 0x22
    retlw   0xff            ; RXM0EID0 0x23
    retlw   0x7e            ; RXM1SIDH 0x24      Set RXM1 to match msg ID's of 0x3f0
                                ; to 0x3ff
    retlw   0x00            ; RXM1SIDL 0x25
    retlw   0x00            ; RXM1EID8 0x26
    retlw   0x00            ; RXM1EID0 0x27
    retlw   0x02            ; CNF3 0x28      PHSEG2 = 3TQ
    retlw   0x90            ; CNF2 0x29      PHSEG1 = 3TQ, PRSEG = 1TQ
    retlw   0x03            ; CNF1 0x2A      SJW = 1TQ, BRP set to 4
    retlw   0x22            ; CANINTE 0x2B      MERRIE and RX1IE enabled
    retlw   0x00            ; CANINTF 0x2C
    retlw   0x00            ; EFLG 0x2D
    retlw   0x80            ; CANSTAT 0x2E
    retlw   0x80            ; CANCTRL 0x2F

    retlw   0x03            ; TXB0CTRL 0x30      Highest priority
```

```

retlw 0x7e           ; TXB0SIDH 0x31
retlw 0x00           ; TXB0SIDL 0x32
retlw 0x00           ; TXB0EID8 0x33
retlw 0x00           ; TXB0EID0 0x34
retlw 0x01           ; TXB0DLC 0x35
retlw 0x00           ; TXB0DB0 0x36
retlw 0x00           ; TXB0DB1 0x37
retlw 0x00           ; TXB0DB2 0x38
retlw 0x00           ; TXB0DB3 0x39
retlw 0x00           ; TXB0DB4 0x3A
retlw 0x00           ; TXB0DB5 0x3B
retlw 0x00           ; TXB0DB6 0x3C
retlw 0x00           ; TXB0DB7 0x3D
retlw 0x80           ; CANSTAT 0x3E
retlw 0x80           ; CANCTRL 0x3F

retlw 0x03           ; TXB1CTRL 0x40   Highest priority
retlw 0x7e           ; TXB1SIDH 0x41
retlw 0xe0           ; TXB1SIDL 0x42
retlw 0x00           ; TXB1EID8 0x43
retlw 0x00           ; TXB1EID0 0x44
retlw 0x01           ; TXB1DLC 0x45
retlw 0x00           ; TXB1DB0 0x46
retlw 0x00           ; TXB1DB1 0x47
retlw 0x00           ; TXB1DB2 0x48
retlw 0x00           ; TXB1DB3 0x49
retlw 0x00           ; TXB1DB4 0x4A
retlw 0x00           ; TXB1DB5 0x4B
retlw 0x00           ; TXB1DB6 0x4C
retlw 0x00           ; TXB1DB7 0x4D
retlw 0x80           ; CANSTAT 0x4E
retlw 0x80           ; CANCTRL 0x4F

retlw 0x03           ; TXB2CTRL 0x50
retlw 0x7e           ; TXB2SIDH 0x51
retlw 0xe0           ; TXB2SIDL 0x52
retlw 0x00           ; TXB2EID8 0x53
retlw 0x00           ; TXB2EID0 0x54
retlw 0x00           ; TXB2DLC 0x55
retlw 0x00           ; TXB2DB0 0x56
retlw 0x00           ; TXB2DB1 0x57
retlw 0x00           ; TXB2DB2 0x58
retlw 0x00           ; TXB2DB3 0x59
retlw 0x00           ; TXB2DB4 0x5A
retlw 0x00           ; TXB2DB5 0x5B
retlw 0x00           ; TXB2DB6 0x5C
retlw 0x00           ; TXB2DB7 0x5D
retlw 0x80           ; CANSTAT 0x5E
retlw 0x80           ; CANCTRL 0x5F

retlw 0x20           ; RXB0CTRL 0x60   Receive only Standard Id's that match
                    ; Masks/Filters
retlw 0x00           ; RXB0SIDH 0x61
retlw 0x00           ; RXB0SIDL 0x62
retlw 0x00           ; RXB0EID8 0x63
retlw 0x00           ; RXB0EID0 0x64
retlw 0x00           ; RXB0DLC 0x65
retlw 0x00           ; RXB0DB0 0x66
retlw 0x00           ; RXB0DB1 0x67
retlw 0x00           ; RXB0DB2 0x68
retlw 0x00           ; RXB0DB3 0x69
retlw 0x00           ; RXB0DB4 0x6A
retlw 0x00           ; RXB0DB5 0x6B
retlw 0x00           ; RXB0DB6 0x6C
retlw 0x00           ; RXB0DB7 0x6D

```

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```
retlw 0x80          ; CANSTAT 0x6E
retlw 0x80          ; CANCTRL 0x6F

retlw 0x20          ; RXB1CTRL 0x70   Receive only Standard Id's that match
Masks/Filters
END
```

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