MICROCHIP

AN730

CRC Generating and Checking

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INTRODUCTION

This application note describes the Cyclic Redundancy Check (CRC) theory and implementation. The CRC check is used to detect errors in a message. Two implementations are shown:

- Table driven CRC calculation
- Loop driven CRC calculation

This application describes the implementation of the CRC-16 polynomial. However, there are several formats for the implementation of CRC such as CRC-CCITT, CRC-32 or other polynomials.

CRC is a common method for detecting errors in transmitted messages or stored data. The CRC is a very powerful, but easily implemented technique to obtain data reliability.

THEORY OF OPERATION

The theory of a CRC calculation is straight forward. The data is treated by the CRC algorithm as a binary number. This number is divided by another binary number called the polynomial. The rest of the division is the CRC checksum, which is appended to the transmitted message. The receiver divides the message (including the calculated CRC), by the same polynomial the transmitter used. If the result of this division is zero, then the transmission was successful. However, if the result is not equal to zero, an error occurred during the transmission.

The CRC-16 polynomial is shown in Equation 1. The polynomial can be translated into a binary value, because the divisor is viewed as a polynomial with binary coefficients. For example, the CRC-16 polynomial translates to 1000000000000101b. All coefficients, like x^2 or x^{15}, are represented by a logical 1 in the binary value.

The division uses the Modulo-2 arithmetic. Modulo-2 calculation is simply realized by XOR'ing two numbers.

EXAMPLE 1: MODULO-2 CALCULATION

```
      1 0 0 1 1 0 0 1 0 1
XOR   0 1 0 0 1 1 0 1 1 1
      -------------------
=     1 1 0 1 0 1 0 0 1 0
      ===================
```

XOR-Function

X1	X2	Y
0	0	0
0	1	1
1	0	1
1	1	0

EQUATION 1: THE CRC-16 POLYNOMIAL

$$P(x) = x^{16}+x^{15}+x^{2}+1$$

Example Calculation

In this example calculation, the message is two bytes long. In general, the message can have any length in bytes. Before we can start calculating the CRC value 1, the message has to be augmented by n-bits, where n is the length of the polynomial. The CRC-16 polynomial has a length of 16-bits, therefore, 16-bits have to be augmented to the original message. In this example calculation, the polynomial has a length of 3-bits, therefore, the message has to be extended by three zeros at the end. An example calculation for a CRC is shown in Example 1. The reverse calculation is shown in Example 2.

EXAMPLE 2: CALCULATION FOR GENERATING A CRC

```
Message    = 110101
Polynomial = 101

1 1 0 1 0 1 0 0 ÷ 1 0 1 = 1 1 1  0 1
1 0 1
-----
  1 1 1                    Quotient (has no function in CRC calculation)
  1 0 1
  -----
    1 0 0
    1 0 1
    -----
        1 1 0
        1 0 1
        -----
          1 1 0
          1 0 1
          -----
            1 1   <-- Remainder = CRC checksum
            ===

Message with CRC  = 1 1 0 1 0 1 1 1
```

EXAMPLE 3: CHECKING A MESSAGE FOR A CRC ERROR

```
Message with CRC = 11010111
Polynomial = 101

1 1 0 1 0 1 1 1 ÷ 1 0 1 = 1 1 1  0 1
1 0 1
-----
  1 1 1                    Quotient
  1 0 1
  -----
    1 0 0
    1 0 1
    -----
        1 1 1
        1 0 1
        -----
          1 0 1
          1 0 1
          -----
            0 0   <-- Checksum is zero, therefore, no transmission error
            ===
```


FIGURE 1: HARDWARE CRC-16 GENERATOR

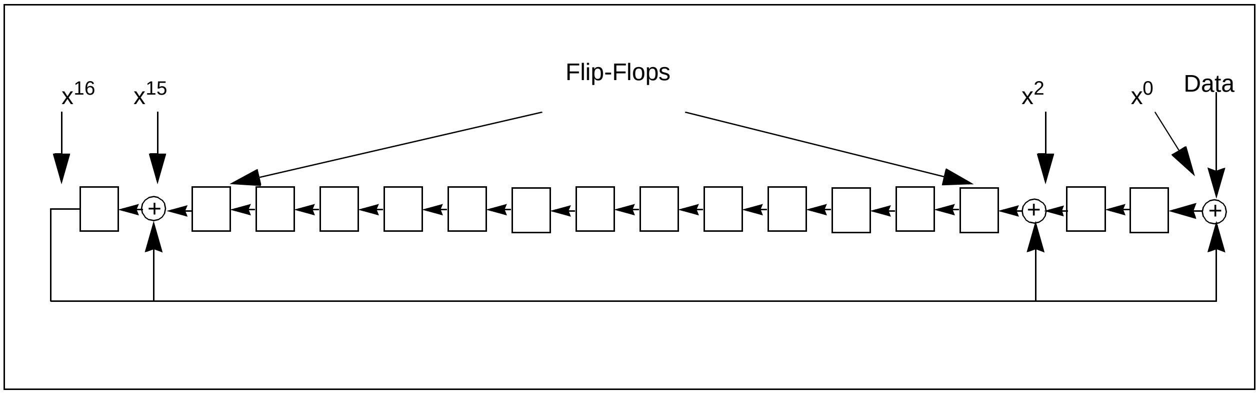
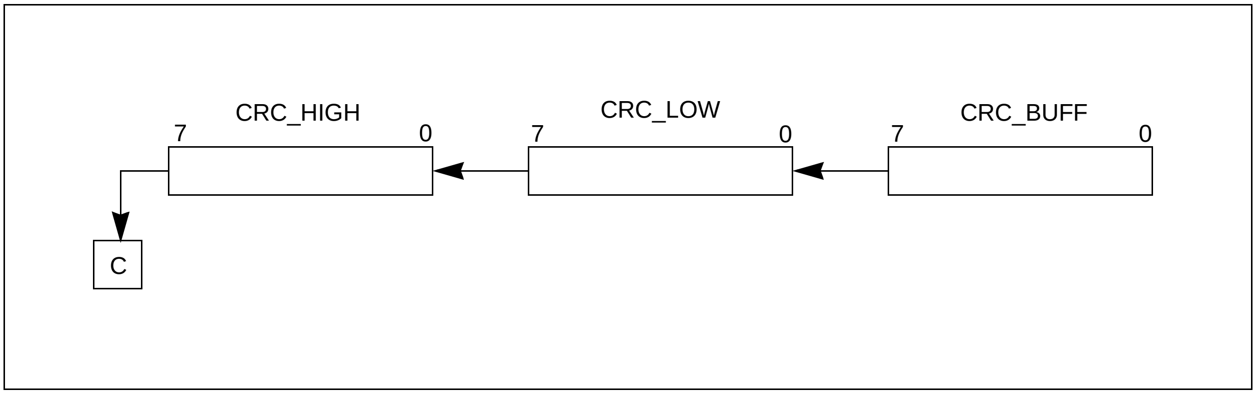


FIGURE 2: LOOP DRIVEN CRC IMPLEMENTATION



CRC Hardware Implementation

The CRC calculation is realized with a shift register and XOR gates. Figure 1 shows a CRC generator for the CRC-16 polynomial. Each bit of the data is shifted into the CRC shift register (Flip-Flops) after being XOR'ed with the CRC's most significant bit.

Software Implementations

There are two different techniques for implementing a CRC in software. One is a loop driven implementation and the other is a table driven implementation.

The loop driven implementation works like the calculation shown in Figure 2. The data is fed through a shift register. If a one pops out at the MSb, the content is XORed with the polynomial. In the other, the registers are shifted by one position to the left.

Another method to calculate a CRC is to use precalculated values and XOR them to the shift register.

Note:	The mathematical details are not given within this application note. The interested reader may refer to the material shown in the Reference section.

LOOP DRIVEN CRC IMPLEMENTATION

This section describes the loop driven CRC implementation. This implementation is derived from the hardware implementation shown in Figure 1. The program for the loop driven CRC generation and CRC checking is shown in Appendix A.

CRC Generation

The implementation of a loop driven CRC generation is shown in Figure 2. In the first step the registers, CRC_HIGH and CRC_LOW, are initialized with the first two bytes of data. CRC_BUFF is loaded with the third byte of data. After that, the MSb of CRC_BUFF is shifted into the LSb of CRC_LOW and the MSb of CRC_LOW is shifted into the LSb of CRC_HIGH. The MSb of CRC_HIGH, which is now stored in the Carry flag, is tested to see if it is set. If the bit is set, the registers, CRC_HIGH and CRC_LOW, will be XORed with the CRC-16 polynomial. If the bit is not set, the next bit from CRC_BUFF will be shifted into the LSb of CRC_LOW.

This process is repeated until all data from CRC_BUFF is shifted into CRC_LOW. After this, CRC_BUFF is loaded with the next data byte. Then all data bytes are processed, and 16 zeros are appended to the message. The registers, CRC_HIGH and CRC_LOW, contain the calculated CRC value. The message can have any length. In this application note, the CRC value for 8 data bytes is calculated.

CRC Checking

The CRC check uses the same technique as the CRC generation, with the only difference being that zeros are not appended to the message.

TABLE DRIVEN CRC IMPLEMENTATION

A table driven CRC routine uses a different technique than a loop driven CRC routine. The idea behind a table driven CRC implementation is that instead of calculating the CRC bit by bit, precomputed bytes are XORed to the data. The source code for the table driven implementation is given in Appendix B.

The advantage of the table driven implementation is that it is faster than the loop driven solution. The drawback is that it consumes more program memory because of the size of the look-up table.

CRC Generation

The CRC at the table driven implementation is generated by reading a precomputed value out of a table and XOR, the result with the low and high byte of the CRC shift registers.

In the first step, the registers, CRC_BUFF, CRC_HIGH and CRC_LOW, are initialized with the first three bytes of data. After that, the value in CRC_BUFF is used as an offset to get the value for the precomputed CRC value out of the look-up table. Since the CRC-16 is 16 bits long, the look-up table is split up into two separate look-up tables. One for the high byte of the CRC register and one for the low byte of the CRC register (see Figure 3). The result from the look-up table of the high byte is XORed to the content of the CRC_HIGH register. The result for the low byte is XORed to the content of CRC_LOW. The results are stored back in CRC_LOW.

The next step is that the content from CRC_HIGH is shifted into CRC_BUFF and the content from CRC_LOW is shifted into the register, CRC_HIGH. Then the register, CRC_LOW, is loaded with the new data byte.

This process repeats for all data bytes. At the end of the CRC generation, the message has to be appended by 16 zeros. The 16 zeros are treated like the data bytes.

After the calculation is done, the content of the registers, CRC_HIGH and CRC_LOW, are appended to the message.

CRC Checking

The CRC check uses the same technique as the CRC generation, with the difference being that zeros are not appended to the message.

COMPARISON

Table 1 shows a comparison between the loop driven implementation and the table driven implementation. For the calculation, 8 data bytes were used.

TABLE 1: CRC-16 COMPARISON TABLE

Implementation	CRC Generation (in cycles)	CRC Check (in cycles)	Program Memory Usage (words)	Data Bytes
Loop Driven	865	870	85	6
Table Driven	348	359	612	5

ADVANTAGES OF CRC VS. SIMPLE SUM TECHNIQUES

The CRC generation has many advantages over simple sum techniques or parity check. CRC error correction allows detection of:

1. single bit errors
2. double bit errors
3. bundled bit errors (bits next to each other)

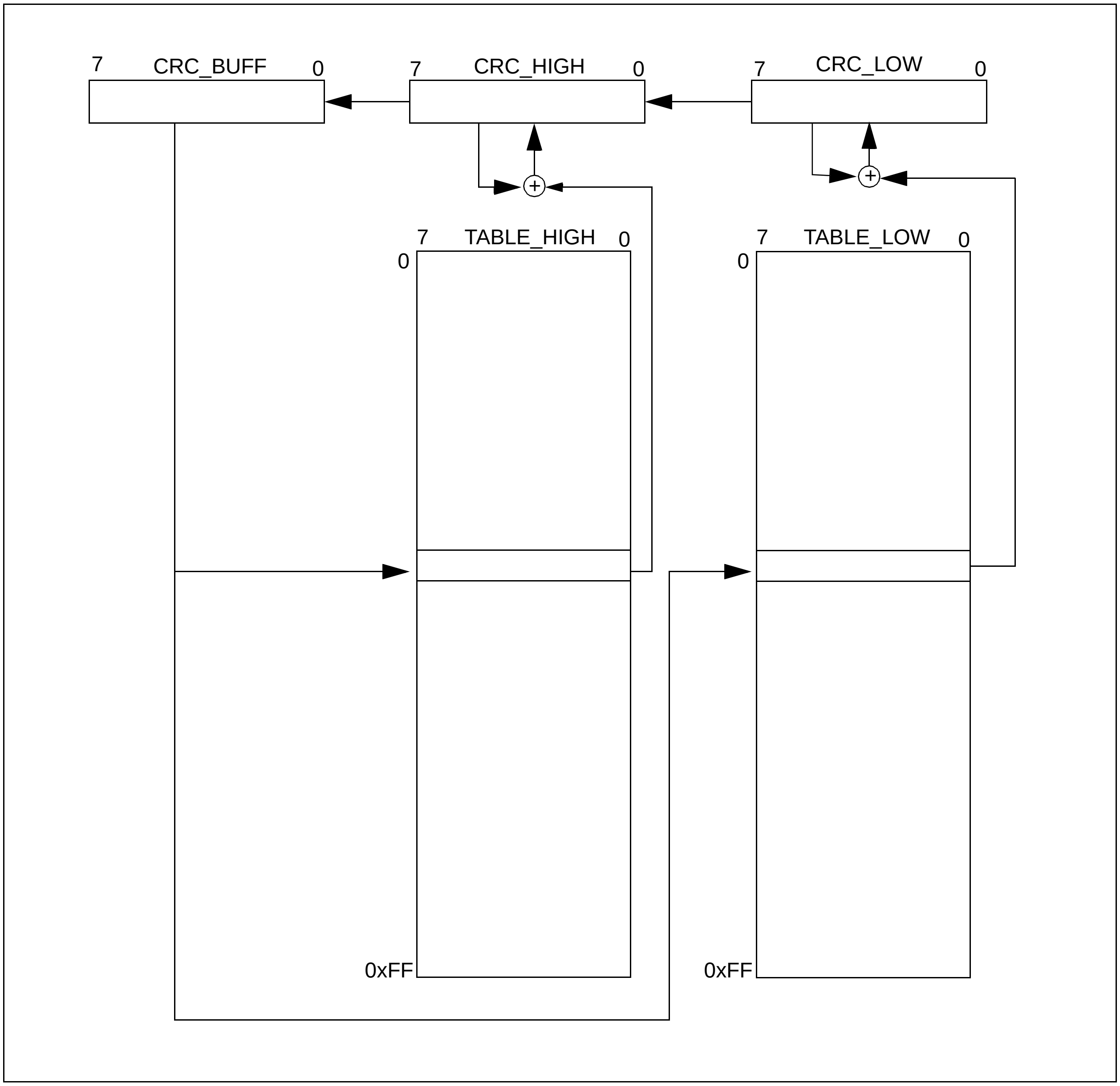
A parity bit check detects only single bit errors. The CRC error correction is mostly used where large data packages are transmitted, for example, in local area networks such as Ethernet.

References

Ross N. Williams - *A Painless Guide to CRC Error Detection Algorithms*

Donald E. Knuth - *The Art of Computer Programming,* Volume 2, Addisson Wesley

FIGURE 3: TABLE DRIVEN CRC CALCULATION IMPLEMENTATION



APPENDIX A: SOURCE CODE FOR LOOP DRIVEN CRC IMPLEMENATION

```
MPASM 02.30.11 Intermediate  CRC16_04.ASM   3-9-2000  13:00:00         PAGE  1


LOC  OBJECT CODE     LINE SOURCE TEXT
  VALUE

                      00001 ; *********************************************************************************************
                      00002 ; * Title           : CRC16 calculation                                                    *
                      00003 ; * Author          : Thomas Schmidt                                                       *
                      00004 ; * Date            : 15.04.1999                                                           *
                      00005 ; * Revision        : 0.4                                                                  *
                      00006 ; * Last Modified   : 15.04.1999                                                           *
                      00007 ; * Core            : 12-bit, 14-bit (12-bit core tested)                                  *
                      00008 ; * Peripherals used: none                                                                 *
                      00009 ; * Registers used  :                                                                      *
                      00010 ; * Modifications   : crc16_01.asm Checksum check was added                                *
                      00011 ; *                   crc16_03.asm Number of data bytes was increased from 2 to 8 bytes    *
                      00012 ; *                   crc16_04.asm added revers CRC
                      00013 ; * Description     :                                                                      *
                      00014 ; *                                                                                        *
                      00015 ; * This module calculates the checksum for the CRC16 polynom. The CRC16 polynome is defined    *
                      00016 ; * as x16+x15+x2+x0. The calculation is done by bitwise checking. The algorithm is designed    *
                      00017 ; * for a two byte wide message. The algorithm can easily be modified for longer messages. The  *
                      00018 ; * only thing what has to be done is to check after the low byte is shifted into the high byte *
                      00019 ; * that the low byte is loaded with a new data byte. The number of iteration has to be adjusted*
                      00020 ; * to the number of extra bytes in the data message. The number is calculated as follows:      *
                      00021 ; * n=16+x*messagebits. For example if the message is 4 bytes long the number of iterations is  *
                      00022 ; * n=16+16bits. The extra iterations have to be done because the message is extended with 16   *
```

```
                              00023 ; * zeros at the end of the message.                                                     *
                                                                                                                     *
                              00024 ; ***********************************************************************************************
                              00025
                              00026
                              00027                 LIST P=16C54B, r=hex
                              00028
                              00029                 #include "p16c5x.inc"
                              00001         LIST
                              00002 ; P16C5X.INC  Standard Header File, Version 4.00    Microchip Technology, Inc.
                              00313         LIST
                              00030
                              00031                 #define PolynomLow      b'00000101'     ; low byte of polynome
                              00032                 #define PolynomHigh     b'10000000'     ; high byte of polynome
                              00033                 #define PolynomLength   0x10            ; 16-bit polynome length
                              00034                 #define DataLength      0x09            ; Data length in Bits
                              00035                 #define Iterations      0x08            ; number of iterations for CRC calculation
                              00036
                              00037                 cblock  0x07
  00000007                    00038                         CRC_HIGH                ; CRC shift registers
  00000008                    00039                         CRC_LOW                 ; second CRC shift register
  00000009                    00040                         CRC_BUFF                ; CRC buffer register
  0000000A                    00041                         BITS                    ; number of data bits
  0000000B                    00042                         DATABYTES               ; number of bytes of data
  0000000C                    00043                         TEMP                    ; temporary register
                              00044                 endc
                              00045
01FF                          00046                 ORG 0x1ff
01FF   0A00                   00047                 goto    Begin
                              00048
                              00049
                              00050
0000                          00051                 ORG 0x00
0000   0C10                   00052 Begin           movlw   0x10                    ; Data for CRC generation
0001   0024                   00053                 movwf   FSR                     ; Set point to begin of data block
0002   0CAA                   00054                 movlw   0xAA                    ; data
                              00055
                              00056
                              00057                 ; initialization what has to be done before CRC16 routine can be
                              00058                 ; called. The FSR register contains the pointer to the first byte of
                              00059                 ; data and the register DATABYTES contains the number of data bytes
                              00060                 ; of the message.
0003   0C10                   00061                 movlw   0x10                    ; set pointer to first data location
0004   0024                   00062                 movwf   FSR                     ; initialize FSR register
                              00063
0005   0910                   00064 Main            call    CRC16Generate           ; calculate CRC16 value
                              00065
```

```
                         ; append CRC to message
0006   02A4              incf    FSR, f              ; point to position behind last data byte
0007   0207              movf    CRC_HIGH, w         ; copy CRC_HIGH data into w-register
0008   0020              movwf   INDF                ; copy CRC_HIGH behing last data byte
0009   02A4              incf    FSR, f              ; point to next location
000A   0208              movf    CRC_LOW, w          ; copy CRC_LOW data into w-register
000B   0020              movwf   INDF                ; copy data into next location
000C   0C10              movlw   0x10                ; set pointer to first data location
000D   0024              movwf   FSR                 ; initialize FSR register
000E   0924              call    CRC16Restore        ; restore CRC16 value
000F   0A0F      Stop    goto    Stop                ; do forever
                         ; ***************************************************************************
                         ; * Title:              CRC16 calculation                                    *
                         ; * Input parameter:    Pointer to first data byte (pointer in FSR register) *
                         ; *                     Number of data bytes stored in register DATABYTES    *
                         ; * Output:             CRC result stored in CRC_HIGH and CRC_LOW            *
                         ; ***************************************************************************
0010   0938      CRC16Generate  call    CRC16Init    ; initialize registers
0011   0C03              movlw   0x03                ; initialize TEMP register with 2
0012   002C              movwf   TEMP                ; move 0x02 into TEMP
0013   0947      NextCRC16      call    CRC16Engine  ; Calculate CRC16 for one byte
0014   02EB              decfsz  DATABYTES, f        ; Decrement the number of data bytes by one
0015   0A1E              goto    Reload              ; reload CRC_BUFF register with new data byte
0016   02EC              decfsz  TEMP, f             ; decrement TEMP register
0017   0A19              goto    AppendZeros         ; Append zeros to message
0018   0800              retlw   0x00                ; return to main
0019   0069      AppendZeros    clrf    CRC_BUFF     ; append data with zeros
001A   0C08              movlw   Iterations          ; initialize BITS register
001B   002A              movwf   BITS                ; with 0x08
001C   02AB              incf    DATABYTES, f        ; increment data bytes
001D   0A13              goto    NextCRC16           ; last iteration
                         ; Reload CRC buffer register with new data word.
001E   02A4      Reload  incf    FSR, f              ; point to next data byte
001F   0200              movf    INDF, w             ; copy data into w-register
0020   0029              movwf   CRC_BUFF            ; move data into CRC_BUFF register
0021   0C08              movlw   Iterations          ; initialize register BITS with 8
0022   002A              movwf   BITS                ; move 8 into register BITS
0023   0A13              goto    NextCRC16           ; calculate next CRC
                         ; ***************************************************************************
```

```
                          ; * Titel: Restore CRC function                                          *
                          ; * Input: Pointer to first data byte in FSR register                    *
                          ; * Output: w=0 CRC was restore sucessfull                               *
                          ; *         w=1 CRC was not restored sucessfull                          *
                          ; ************************************************************************
0024  0938  CRC16Restore    call    CRC16Init             ; initialize CRC registers
0025  0C02                  movlw   0x02                  ; add offset to DATABYTES
0026  01EB                  addwf   DATABYTES, f          ; add offset to register DATABYTES

0027  0947  NextCRCRestore  call    CRC16Engine
0028  02EB                  decfsz  DATABYTES, f          ; Decrement the number of data bytes by one
0029  0A32                  goto    ReloadRestore         ; reload CRC_BUFF register with new data byte

                          ; check if CRC_HIGH and CRC_LOW equal to zero
002A  0227                  movf    CRC_HIGH, f           ; copy CRC_HIGH onto itself
002B  0743                  btfss   STATUS, Z             ; is content zero?
002C  0A31                  goto    CRCError              ; no, CRC error occured
002D  0228                  movf    CRC_LOW, f            ; copy CRC_LOW register onto itself
002E  0743                  btfss   STATUS, Z             ; is content zero?
002F  0A31                  goto    CRCError              ; no, CRC error occured
0030  0800                  retlw   0x00                  ; return to main (0= no error)

0031  0801  CRCError        retlw   0x01                  ; return to main with error code 1


                          ; Reload CRC buffer register with new data word.
0032  02A4  ReloadRestore   incf    FSR, f                ; point to next data byte
0033  0200                  movf    INDF, w               ; copy data into w-register
0034  0029                  movwf   CRC_BUFF              ; move data into CRC_BUFF register
0035  0C08                  movlw   Iterations            ; initialize register BITS with 8
0036  002A                  movwf   BITS                  ; move 8 into register BITS
0037  0A27                  goto    NextCRCRestore        ; calculate next CRC


                          ; ************************************************************************
                          ; * Titel: CRC16 Initialization                                          *
                          ; * Input: Pointer to first data byte in FSR register                    *
                          ; * Output: none                                                         *
                          ; ************************************************************************
0038  0200  CRC16Init       movf    INDF, w               ; copy data into W-register
0039  0027                  movwf   CRC_HIGH              ; copy w-register into CRC_HIGH register
003A  02A4                  incf    FSR, f                ; set pointer to next location
003B  0200                  movf    INDF, w               ; copy data into w-register

003C  0028                  movwf   CRC_LOW               ; copy w-register into CRC_LOW
003D  02A4                  incf    FSR, f                ; set pointer to next location
003E  0200                  movf    INDF, w               ; copy next data into w-register
```

```
003F   0029         00159                    movwf   CRC_BUFF                ; copy data into CRC buffer register
0040   0C08         00160                    movlw   Iterations              ; initialize register BITs with
0041   002A         00161                    movwf   BITS                    ; length of polynome for iteration
0042   0C09         00162                    movlw   DataLength              ; copy number of data bytes
0043   002B         00163                    movwf   DATABYTES               ; into register DataBytes
0044   0C03         00164                    movlw   0x03                    ; decrement three from the number
0045   00AB         00165                    subwf   DATABYTES, f            ; of data bytes, because three register
                    00166                                                    ; are now initialized
0046   0800         00167                    retlw   0x00                    ; return from subroutine
                    00168
                    00169
                    00170
                    00171                    ; ******************************************************************************
                    00172                    ; * Titel: CRC16 Engine                                                        *
                    00173                    ; * Input: Pointer to first data byte in FSR register                          *
                    00174                    ; * Output: none                                                               *
                    00175                    ; ******************************************************************************
0047   0403         00176 CRC16Engine        bcf     STATUS, C               ; clear carry flag
0048   0369         00177                    rlf     CRC_BUFF, f             ; shift bit7 of CRC_BUFF into carry flag
0049   0368         00178                    rlf     CRC_LOW, f              ; shift bit7 of CRC_LOW into carry flag
                    00179                                                    ; and shift 0 into bit7 of CRC_LOW
004A   0367         00180                    rlf     CRC_HIGH, f             ; rotate carry flag into bit0 of CRC_HIGH
                    00181                                                    ; and rotate bit7 of CRC_HIGH into carry
                    00182                                                    ; flag
004B   0703         00183                    btfss   STATUS, C               ; is carry flag set?
004C   0A51         00184                    goto    NextBitEngine           ; carry flag is clear there next rotation
004D   0C80         00185                    movlw   PolynomHigh             ; carry flag is set therefore XOR CRCSHIFT
                    00186                                                    ; registers
004E   01A7         00187                    xorwf   CRC_HIGH, f             ; XOR CRC_HIGH register
004F   0C05         00188                    movlw   PolynomLow              ; load w-register with low byte of polynom
0050   01A8         00189                    xorwf   CRC_LOW, f              ; XOR CRC_LOW register
0051   02EA         00190 NextBitEngine      decfsz  BITS, f                 ; do for all bits
0052   0A47         00191                    goto    CRC16Engine             ; calculate CRC for next bit
0053   0800         00192                    retlw   0x00                    ; return from Subroutine
                    00193
                    00194                    END

Program Memory Words Used:    85
Program Memory Words Free:   427


Errors   :     0
Warnings :     0 reported,     0 suppressed
Messages :     0 reported,     0 suppressed
```

APPENDIX B: SOURCE CODE TABLE DRIVEN CRC IMPLEMENTATION

```
MPASM 02.30.11 Intermediate  CRCTAB01.ASM   3-9-2000  13:02:59        PAGE  1


LOC  OBJECT CODE     LINE SOURCE TEXT
  VALUE

                      ; *********************************************************************************************
                      ; * Title           : CRC16 calculation table driven implementation                           *
                      ; * Author          : Thomas Schmidt                                                          *
                      ; * Date            : 22.03.1999                                                              *
                      ; * Revision        : 0.1                                                                     *
                      ; * Last Modified   : 15.04.1999                                                              *
                      ; * Core            : 12-bit, 14-bit (12-bit core tested)                                     *
                      ; * Peripherals used: none                                                                    *
                      ; * Registers used  :                                                                         *
                      ; * Modifications   : crctab01.asm: first program CRC generation                              *
                      ; * Description     :                                                                         *
                      ; *                                                                                           *
                      ; * This module calculates the checksum for the CRC16 polynom. The CRC16 polynome is defined    *
                      ; * as x16+x15+x2+x0. The calculation is done by bitwise checking. The algorithm is designed    *
                      ; * for a two byte wide message. The algorithm can easily be modified for longer messages. The  *
                      ; * only thing what has to be done is to check after the low byte is shifted into the high byte *
                      ; * that the low byte is loaded with a new data byte. The number of iteration has to be adjusted*
                      ; * to the number of extra bytes in the data message. The number is calculated as follows:      *
                      ; * n=16+x*messagebits. For example if the message is 4 bytes long the number of iterations is  *
                      ; * n=16+16bits. The extra iterations have to be done because the message is extended with 16   *
                      ; * zeros at the end of the message.                                                          *
                                                                                                              *
                      ; *********************************************************************************************

                                LIST P=16C58B, r=hex

                                #include "p16c5x.inc"
                        LIST
                      ; P16C5X.INC  Standard Header File, Version 4.00    Microchip Technology, Inc.
                        LIST

                                #define DataLength              0x09            ; length of data field
                                #define LastTableElementHigh    0x2             ; last table element of high byte
                                #define LastTableElementLow     0x2             ; last table element of low byte

                                cblock 0x07
  00000007                              CRC_LOW         ; low byte of CRC register
  00000008                              CRC_HIGH        ; high byte of CRC register
```

```
00000009                    CRC_BUFF        ; CRC buffer register
0000000A                    DATABYTES       ; contains number of data bytes
0000000B                    TEMP            ; temporary register
                    endc

07FF                org 0x7ff
07FF   0A00         goto    Begin

0000                org 0x00
0000       Begin
                    ; initialization what has to be done before CRC16 routine can be
                    ; called. The FSR register contains the pointer to the first byte of
                    ; data and the register DATABYTES contains the number of data bytes
                    ; of the message.
0000   0C10         movlw   0x10                    ; set pointer to first data location
0001   0024         movwf   FSR                     ; initialize FSR register

0002   090C Main    call    CRC16Generate           ; calculate CRC16 value

0003   0208         movf    CRC_HIGH, w             ; copy CRC_HIGH data into w-register
0004   0020         movwf   INDF                    ; copy CRC_HIGH behing last data byte
0005   02A4         incf    FSR, f                  ; point to next location
0006   0207         movf    CRC_LOW, w              ; copy CRC_LOW data into w-register
0007   0020         movwf   INDF                    ; copy data into next location
0008   0C10         movlw   0x10                    ; set pointer to first data location
0009   0024         movwf   FSR                     ; initialize FSR register
000A   093A TestPoint call  CRC16Restore            ; Restore CRC
000B   0A0B Stop    goto    Stop                    ; do forever


                    ; ********************************************************************************
                    ; * Title:              CRC16 Table driven calculation                          *
                    ; * Input parameter:    Pointer to first data byte (pointer in FSR register)    *
                    ; *                     Number of data bytes stored in register DATABYTES       *
                    ; * Output:             CRC result stored in CRC_HIGH and CRC_LOW               *
                    ; ********************************************************************************
000C   095E CRC16Generate call CRC16Init              ; initialize CRC registers
000D   0C03         movlw   0x03                    ; initialize TEMP register
000E   002B         movwf   TEMP                    ; with 0x02

                    ; check if last CRC_BUFF points to last element in table. These elements
                    ; cannot be read from the look up table, because they are beyond the
                    ; program memory page.
000F   0209 NextValueGen movf CRC_BUFF, w           ; load CRC_BUFF into w-register
0010   0FFF         xorlw   0xff                    ; check if content equals to 0xff
0011   0743         btfss   STATUS, Z               ; is result from XOR = 0?
0012   0A18         goto    CalculateCRC            ; no, calculate CRC
```

```
0013   0C02        00082                movlw   LastTableElementHigh    ; yes, get last table element for high byte
0014   01A8        00083                xorwf   CRC_HIGH, f             ; XOR with high byte
0015   0C02        00084                movlw   LastTableElementLow     ; get last table element for low byte
0016   01A7        00085                xorwf   CRC_LOW, f              ; XOR with low byte
0017   0A22        00086                goto    DecDATABYTES            ; goto end of loop
                   00087
0018   0209        00088 CalculateCRC   movf    CRC_BUFF, w             ; copy high byte of CRC into w-register
0019   04C3        00089                bcf     STATUS, PA1             ; select page 1
001A   05A3        00090                bsf     STATUS, PA0             ; select page 1
001B   0900        00091                call    CRC16TableHigh          ; get value for high byte
001C   01A8        00092                xorwf   CRC_HIGH,f              ; XOR table element with high byte
001D   0209        00093                movf    CRC_BUFF, w             ; get value for low byte
001E   05C3        00094                bsf     STATUS, PA1             ; select page 2
001F   04A3        00095                bcf     STATUS, PA0             ; select page 2
0020   0900        00096                call    CRC16TableLow           ; get value out of table
0021   01A7        00097                xorwf   CRC_LOW,f               ; XOR with low byte
0022   04A3        00098 DecDATABYTES   bcf     STATUS, PA0             ; select page 0
0023   04C3        00099                bcf     STATUS, PA1             ; select page 0
0024   02EA        00100                decfsz  DATABYTES, f            ; decrement data bytes
0025   0A30        00101                goto    ReloadGen               ; reload values
                   00102
0026   02EB        00103                decfsz  TEMP, f                 ; append two bytes with zeros
0027   0A29        00104                goto    AppendZeros             ; append zeros to message (do twice)
0028   0800        00105                retlw   0x00                    ; return to main
0029   0208        00106 AppendZeros    movf    CRC_HIGH, w             ; copy high byte into w-register
002A   0029        00107                movwf   CRC_BUFF                ; and from there to CRC_BUFF
002B   0207        00108                movf    CRC_LOW,w               ; Copy low byte into w-register
002C   0028        00109                movwf   CRC_HIGH                ; and from there into CRC_HIGH
002D   0067        00110                clrf    CRC_LOW                 ; and from there into CRC_LOW
002E   02AA        00111                incf    DATABYTES, f            ; increment for additonal iteration
002F   0A0F        00112                goto    NextValueGen            ; calculate CRC for next byte
                   00113
0030   0932        00114 ReloadGen      call    Reload                  ; reload registers
0031   0A0F        00115                goto    NextValueGen            ; calculate next CRC value
                   00116
                   00117                ; ***********************************************************************
                   00118                ; * Titel: Reload CRC_HIGH, CRC_LOW and CRC_BUFF register                  *
                   00119                ; * Input: Pointer to next data byte in FSR register                       *
                   00120                ; * Output:                                                                *
                   00121                ; ***********************************************************************
0032   0208        00122 Reload         movf    CRC_HIGH, w             ; copy high byte into w-register
0033   0029        00123                movwf   CRC_BUFF                ; and from there to CRC_BUFF
0034   0207        00124                movf    CRC_LOW,w               ; Copy low byte into w-register
0035   0028        00125                movwf   CRC_HIGH                ; and from there into CRC_HIGH
0036   0200        00126                movf    INDF, w                 ; copy next data into w-register
0037   0027        00127                movwf   CRC_LOW                 ; and from there into CRC_LOW
0038   02A4        00128                incf    FSR, f                  ; point to next data byte
```

```
0039   0800                       retlw   0x00                  ; calculate CRC for next byte


                                  ; ****************************************************************************
                                  ; * Titel: Restore CRC function                                              *
                                  ; * Input: Pointer to first data byte in FSR register                        *
                                  ; * Output: w=0 CRC was restore sucessfull                                   *
                                  ; *         w=1 CRC was not restored sucessfull                              *
                                  ; ****************************************************************************
003A   095E          CRC16Restore     call    CRC16Init             ; initialize CRC registers
003B   0C02                       movlw   0x02                  ; add two onto
003C   01EA                       addwf   DATABYTES, f          ; register DATABYTES

                                  ; check if last CRC_BUFF points to last element in table. These elements
                                  ; cannot be read from the look up table, because they are beyond the
                                  ; program memory page.
003D   0209          NextValueRes     movf    CRC_BUFF, w           ; load CRC_BUFF into w-register
003E   0FFF                       xorlw   0xff                  ; check if content equals to 0xff
003F   0743                       btfss   STATUS, Z             ; is result from XOR = 0?
0040   0A46                       goto    CalculateCRCRes       ; no, calculate CRC
0041   0C02                       movlw   LastTableElementHigh  ; yes, get last table element for high byte
0042   01A8                       xorwf   CRC_HIGH, f           ; XOR with high byte
0043   0C02                       movlw   LastTableElementLow   ; get last table element for low byte
0044   01A7                       xorwf   CRC_LOW, f            ; XOR with low byte
0045   0A50                       goto    DecDATABYTESRes       ; goto end of loop

0046   0209          CalculateCRCRes movf CRC_BUFF, w           ; copy high byte of CRC into w-register
0047   04C3                       bcf     STATUS, PA1           ; select page 1
0048   05A3                       bsf     STATUS, PA0           ; select page 1
0049   0900                       call    CRC16TableHigh        ; get value for high byte
004A   01A8                       xorwf   CRC_HIGH,f            ; XOR table element with high byte
004B   0209                       movf    CRC_BUFF, w           ; get value for low byte
004C   05C3                       bsf     STATUS, PA1           ; select page 2
004D   04A3                       bcf     STATUS, PA0           ; select page 2
004E   0900                       call    CRC16TableLow         ; get value out of table
004F   01A7                       xorwf   CRC_LOW,f             ; XOR with low byte
0050   04A3          DecDATABYTESRes bcf  STATUS, PA0           ; select page 0
0051   04C3                       bcf     STATUS, PA1           ; select page 0
0052   02EA                       decfsz  DATABYTES, f          ; decrement data bytes
0053   0A5C                       goto    ReloadRes             ; calculate next CRC16 value

                                  ; check if CRC_HIGH and CRC_LOW equal to zero
0054   0228                       movf    CRC_HIGH, f           ; copy CRC_HIGH onto itself
0055   0743                       btfss   STATUS, Z             ; is content zero?
0056   0A5B                       goto    CRCError              ; no, CRC error occured
0057   0227                       movf    CRC_LOW, f            ; copy CRC_LOW register onto itself
0058   0743                       btfss   STATUS, Z             ; is content zero?
```

```
0059   0A5B           00176                  goto    CRCError              ; no, CRC error occured
005A   0800           00177                  retlw   0x00                  ; return to main (0= no error)
                      00178
005B   0801           00179 CRCError         retlw   0x01                  ; return to main with error code 1
                      00180
005C   0932           00181 ReloadRes        call    Reload                ; reload register
005D   0A3D           00182                  goto    NextValueRes          ; calculate next value
                      00183
                      00184
                      00185                  ; ******************************************************************************
                      00186                  ; * Titel: CRC16 Initialization                                                *
                      00187                  ; * Input: Pointer to first data byte in FSR register                          *
                      00188                  ; * Output: none                                                               *
                      00189                  ; ******************************************************************************
005E   0200           00190 CRC16Init        movf    INDF, w               ; copy data into W-register
005F   0029           00191                  movwf   CRC_BUFF              ; copy w-register into CRC_BUFF register
0060   02A4           00192                  incf    FSR, f                ; set pointer to next location
0061   0200           00193                  movf    INDF, w               ; copy data into W-register
0062   0028           00194                  movwf   CRC_HIGH              ; copy w-register into CRC_HIGH register
0063   02A4           00195                  incf    FSR, f                ; set pointer to next location
0064   0200           00196                  movf    INDF, w               ; copy data into w-register
0065   0027           00197                  movwf   CRC_LOW               ; copy w-register into CRC_LOW
0066   02A4           00198                  incf    FSR, f                ; point to next location
0067   0C09           00199                  movlw   DataLength            ; copy number of data bytes
0068   002A           00200                  movwf   DATABYTES             ; into register DataBytes
0069   0C03           00201                  movlw   0x03                  ; decrement three from the number
006A   00AA           00202                  subwf   DATABYTES, f          ; of data bytes, because three register
                      00203                                                ; are now initialized
006B   0800           00204                  retlw   0x00                  ; return from subroutine
                      00205
                      00206                  ; ******************************************************************************
                      00207                  ; * Titel: CRC16 Table for High byte                                           *
                      00208                  ; * Input: Pointer to table element in w-register                              *
                      00209                  ; * Output: look-up value in w-register                                        *
                      00210                  ; ******************************************************************************
0200                  00211                  org 0x200
0200   01E2           00212 CRC16TableHigh   addwf   PCL, f         ; add to low byte of PC
0201   0800 0880 0880 00213                   dt     0,      0x80,   0x80,   0
       0800
0205   0880 0800 0800 00214                   dt     0x80,   0,      0,      0x80
       0880
0209   0880 0800 0800 00215                   dt     0x80,   0,      0,      0x80
       0880
020D   0800 0880 0880 00216                   dt     0,      0x80,   0x80,   0
       0800
0211   0880 0800 0800 00217                   dt     0x80,   0,      0,      0x80
       0880
```

```
0215   0800 0880 0880 00218                  dt    0,     0x80,  0x80,  0
       0800
0219   0800 0880 0880 00219                  dt    0,     0x80,  0x80,  0
       0800
021D   0880 0800 0800 00220                  dt    0x80,  0,     0,     0x80
       0880
0221   0880 0800 0800 00221                  dt    0x80,  0,     0,     0x80
       0880
0225   0800 0880 0880 00222                  dt    0,     0x80,  0x80,  0
       0800
0229   0800 0880 0880 00223                  dt    0,     0x80,  0x80,  0
       0800
022D   0880 0800 0800 00224                  dt    0x80,  0,     0,     0x80
       0880
0231   0800 0880 0880 00225                  dt    0,     0x80,  0x80,  0
       0800
0235   0880 0800 0800 00226                  dt    0x80,  0,     0,     0x80
       0880
0239   0880 0800 0800 00227                  dt    0x80,  0,     0,     0x80
       0880
023D   0800 0880 0880 00228                  dt    0,     0x80,  0x80,  0
       0800
0241   0881 0801 0801 00229                  dt    0x81,  0x1,   0x1,   0x81
       0881
0245   0801 0881 0881 00230                  dt    0x1,   0x81,  0x81,  0x1
       0801
0249   0801 0881 0881 00231                  dt    0x1,   0x81,  0x81,  0x1
       0801
024D   0881 0801 0801 00232                  dt    0x81,  0x1,   0x1,   0x81
       0881
0251   0801 0881 0881 00233                  dt    0x1,   0x81,  0x81,  0x1
       0801
0255   0881 0801 0801 00234                  dt    0x81,  0x1,   0x1,   0x81
       0881
0259   0881 0801 0801 00235                  dt    0x81,  0x1,   0x1,   0x81
       0881
025D   0801 0881 0881 00236                  dt    0x1,   0x81,  0x81,  0x1
       0801
0261   0801 0881 0881 00237                  dt    0x1,   0x81,  0x81,  0x1
       0801
0265   0881 0801 0801 00238                  dt    0x81,  0x1,   0x1,   0x81
       0881
0269   0881 0801 0801 00239                  dt    0x81,  0x1,   0x1,   0x81
       0881
026D   0801 0881 0881 00240                  dt    0x1,   0x81,  0x81,  0x1
       0801
0271   0881 0801 0801 00241                  dt    0x81,  0x1,   0x1,   0x81
```

```
              0881
0275          0801 0881 0881 00242                   dt      0x1,    0x81,   0x81,   0x1
              0801
0279          0801 0881 0881 00243                   dt      0x1,    0x81,   0x81,   0x1
              0801
027D          0881 0801 0801 00244                   dt      0x81,   0x1,    0x1,    0x81
              0881
0281          0883 0803 0803 00245                   dt      0x83,   0x3,    0x3,    0x83
              0883
0285          0803 0883 0883 00246                   dt      0x3,    0x83,   0x83,   0x3
              0803
0289          0803 0883 0883 00247                   dt      0x3,    0x83,   0x83,   0x3
              0803
028D          0883 0803 0803 00248                   dt      0x83,   0x3,    0x3,    0x83
              0883
0291          0803 0883 0883 00249                   dt      0x3,    0x83,   0x83,   0x3
              0803
0295          0883 0803 0803 00250                   dt      0x83,   0x3,    0x3,    0x83
              0883
0299          0883 0803 0803 00251                   dt      0x83,   0x3,    0x3,    0x83
              0883
029D          0803 0883 0883 00252                   dt      0x3,    0x83,   0x83,   0x3
              0803
02A1          0803 0883 0883 00253                   dt      0x3,    0x83,   0x83,   0x3
              0803
02A5          0883 0803 0803 00254                   dt      0x83,   0x3,    0x3,    0x83
              0883
02A9          0883 0803 0803 00255                   dt      0x83,   0x3,    0x3,    0x83
              0883
02AD          0803 0883 0883 00256                   dt      0x3,    0x83,   0x83,   0x3
              0803
02B1          0883 0803 0803 00257                   dt      0x83,   0x3,    0x3,    0x83
              0883
02B5          0803 0883 0883 00258                   dt      0x3,    0x83,   0x83,   0x3
              0803
02B9          0803 0883 0883 00259                   dt      0x3,    0x83,   0x83,   0x3
              0803
02BD          0883 0803 0803 00260                   dt      0x83,   0x3,    0x3,    0x83
              0883
02C1          0802 0882 0882 00261                   dt      0x2,    0x82,   0x82,   0x2
              0802
02C5          0882 0802 0802 00262                   dt      0x82,   0x2,    0x2,    0x82
              0882
02C9          0882 0802 0802 00263                   dt      0x82,   0x2,    0x2,    0x82
              0882
02CD          0802 0882 0882 00264                   dt      0x2,    0x82,   0x82,   0x2
              0802
```



```
02D1   0882 0802 0802 00265                dt     0x82,   0x2,    0x2,    0x82
       0882
02D5   0802 0882 0882 00266                dt     0x2,    0x82,   0x82,   0x2
       0802
02D9   0802 0882 0882 00267                dt     0x2,    0x82,   0x82,   0x2
       0802
02DD   0882 0802 0802 00268                dt     0x82,   0x2,    0x2,    0x82
       0882
02E1   0882 0802 0802 00269                dt     0x82,   0x2,    0x2,    0x82
       0882
02E5   0802 0882 0882 00270                dt     0x2,    0x82,   0x82,   0x2
       0802
02E9   0802 0882 0882 00271                dt     0x2,    0x82,   0x82,   0x2
       0802
02ED   0882 0802 0802 00272                dt     0x82,   0x2,    0x2,    0x82
       0882
02F1   0802 0882 0882 00273                dt     0x2,    0x82,   0x82,   0x2
       0802
02F5   0882 0802 0802 00274                dt     0x82,   0x2,    0x2,    0x82
       0882
02F9   0882 0802 0802 00275                dt     0x82,   0x2,    0x2,    0x82
       0882
02FD   0802 0882 0882 00276                dt     0x2,    0x82,   0x82
                     00277
                     00278                ; ********************************************************************************
                     00279                ; * Titel: CRC16 Table for low byte                                              *
                     00280                ; * Input: Pointer to table element in w-register                               *
                     00281                ; * Output: look-up value in w-register                                          *
                     00282                ; ********************************************************************************
0400                 00283                org 0x400
0400   01E2          00284 CRC16TableLow  addwf  PCL, f          ; add to low byte of PC
0401   0800 0805 080F 00285                dt     0,      0x5,    0xf,    0xa
       080A
0405   081B 081E 0814 00286                dt     0x1b,   0x1e,   0x14,   0x11
       0811
0409   0833 0836 083C 00287                dt     0x33,   0x36,   0x3c,   0x39
       0839
040D   0828 082D 0827 00288                dt     0x28,   0x2d,   0x27,   0x22
       0822
0411   0863 0866 086C 00289                dt     0x63,   0x66,   0x6c,   0x69
       0869
0415   0878 087D 0877 00290                dt     0x78,   0x7d,   0x77,   0x72
       0872
0419   0850 0855 085F 00291                dt     0x50,   0x55,   0x5f,   0x5a
       085A
041D   084B 084E 0844 00292                dt     0x4b,   0x4e,   0x44,   0x41
```

```
         0841
0421     08C3 08C6 08CC 00293               dt     0xc3,   0xc6,   0xcc,   0xc9
         08C9
0425     08D8 08DD 08D7 00294               dt     0xd8,   0xdd,   0xd7,   0xd2
         08D2
0429     08F0 08F5 08FF 00295               dt     0xf0,   0xf5,   0xff,   0xfa
         08FA
042D     08EB 08EE 08E4 00296               dt     0xeb,   0xee,   0xe4,   0xe1
         08E1
0431     08A0 08A5 08AF 00297               dt     0xa0,   0xa5,   0xaf,   0xaa
         08AA
0435     08BB 08BE 08B4 00298               dt     0xbb,   0xbe,   0xb4,   0xb1
         08B1
0439     0893 0896 089C 00299               dt     0x93,   0x96,   0x9c,   0x99
         0899
043D     0888 088D 0887 00300               dt     0x88,   0x8d,   0x87,   0x82
         0882
0441     0883 0886 088C 00301               dt     0x83,   0x86,   0x8c,   0x89
         0889
0445     0898 089D 0897 00302               dt     0x98,   0x9d,   0x97,   0x92
         0892
0449     08B0 08B5 08BF 00303               dt     0xb0,   0xb5,   0xbf,   0xba
         08BA
044D     08AB 08AE 08A4 00304               dt     0xab,   0xae,   0xa4,   0xa1
         08A1
0451     08E0 08E5 08EF 00305               dt     0xe0,   0xe5,   0xef,   0xea
         08EA
0455     08FB 08FE 08F4 00306               dt     0xfb,   0xfe,   0xf4,   0xf1
         08F1
0459     08D3 08D6 08DC 00307               dt     0xd3,   0xd6,   0xdc,   0xd9
         08D9
045D     08C8 08CD 08C7 00308               dt     0xc8,   0xcd,   0xc7,   0xc2
         08C2
0461     0840 0845 084F 00309               dt     0x40,   0x45,   0x4f,   0x4a
         084A
0465     085B 085E 0854 00310               dt     0x5b,   0x5e,   0x54,   0x51
         0851
0469     0873 0876 087C 00311               dt     0x73,   0x76,   0x7c,   0x79
         0879
046D     0868 086D 0867 00312               dt     0x68,   0x6d,   0x67,   0x62
         0862
0471     0823 0826 082C 00313               dt     0x23,   0x26,   0x2c,   0x29
         0829
0475     0838 083D 0837 00314               dt     0x38,   0x3d,   0x37,   0x32
         0832
0479     0810 0815 081F 00315               dt     0x10,   0x15,   0x1f,   0x1a
         081A
```

```
047D   080B 080E 0804 00316                    dt     0xb,    0xe,    0x4,    0x1
       0801
0481   0803 0806 080C 00317                    dt     0x3,    0x6,    0xc,    0x9
       0809
0485   0818 081D 0817 00318                    dt     0x18,   0x1d,   0x17,   0x12
       0812
0489   0830 0835 083F 00319                    dt     0x30,   0x35,   0x3f,   0x3a
       083A
048D   082B 082E 0824 00320                    dt     0x2b,   0x2e,   0x24,   0x21
       0821
0491   0860 0865 086F 00321                    dt     0x60,   0x65,   0x6f,   0x6a
       086A
0495   087B 087E 0874 00322                    dt     0x7b,   0x7e,   0x74,   0x71
       0871
0499   0853 0856 085C 00323                    dt     0x53,   0x56,   0x5c,   0x59
       0859
049D   0848 084D 0847 00324                    dt     0x48,   0x4d,   0x47,   0x42
       0842
04A1   08C0 08C5 08CF 00325                    dt     0xc0,   0xc5,   0xcf,   0xca
       08CA
04A5   08DB 08DE 08D4 00326                    dt     0xdb,   0xde,   0xd4,   0xd1
       08D1
04A9   08F3 08F6 08FC 00327                    dt     0xf3,   0xf6,   0xfc,   0xf9
       08F9
04AD   08E8 08ED 08E7 00328                    dt     0xe8,   0xed,   0xe7,   0xe2
       08E2
04B1   08A3 08A6 08AC 00329                    dt     0xa3,   0xa6,   0xac,   0xa9
       08A9
04B5   08B8 08BD 08B7 00330                    dt     0xb8,   0xbd,   0xb7,   0xb2
       08B2
04B9   0890 0895 089F 00331                    dt     0x90,   0x95,   0x9f,   0x9a
       089A
04BD   088B 088E 0884 00332                    dt     0x8b,   0x8e,   0x84,   0x81
       0881
04C1   0880 0885 088F 00333                    dt     0x80,   0x85,   0x8f,   0x8a
       088A
04C5   089B 089E 0894 00334                    dt     0x9b,   0x9e,   0x94,   0x91
       0891
04C9   08B3 08B6 08BC 00335                    dt     0xb3,   0xb6,   0xbc,   0xb9
       08B9
04CD   08A8 08AD 08A7 00336                    dt     0xa8,   0xad,   0xa7,   0xa2
       08A2
04D1   08E3 08E6 08EC 00337                    dt     0xe3,   0xe6,   0xec,   0xe9
       08E9
04D5   08F8 08FD 08F7 00338                    dt     0xf8,   0xfd,   0xf7,   0xf2
       08F2
04D9   08D0 08D5 08DF 00339                    dt     0xd0,   0xd5,   0xdf,   0xda
```

```
        08DA
04DD    08CB 08CE 08C4 00340                  dt     0xcb,   0xce,   0xc4,   0xc1
        08C1
04E1    0843 0846 084C 00341                  dt     0x43,   0x46,   0x4c,   0x49
        0849
04E5    0858 085D 0857 00342                  dt     0x58,   0x5d,   0x57,   0x52
        0852
04E9    0870 0875 087F 00343                  dt     0x70,   0x75,   0x7f,   0x7a
        087A
04ED    086B 086E 0864 00344                  dt     0x6b,   0x6e,   0x64,   0x61
        0861
04F1    0820 0825 082F 00345                  dt     0x20,   0x25,   0x2f,   0x2a
        082A
04F5    083B 083E 0834 00346                  dt     0x3b,   0x3e,   0x34,   0x31
        0831
04F9    0813 0816 081C 00347                  dt     0x13,   0x16,   0x1c,   0x19
        0819
04FD    0808 080D 0807 00348                  dt     0x8,    0xd,    0x7
                       00349
                       00350                 END

Program Memory Words Used:   621
Program Memory Words Free:  1427


Errors   :     0
Warnings :     0 reported,     0 suppressed
Messages :     5 reported,     0 suppressed
```

NOTES:

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