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                        |
  1 0 1                        Quotient (has no function in CRC calculation)
    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                        |
  1 0 1                        Quotient
    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

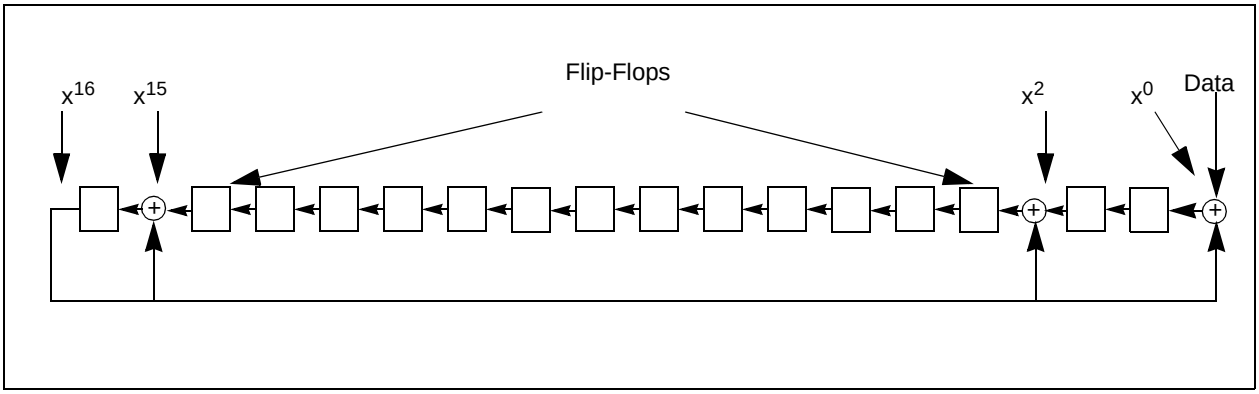
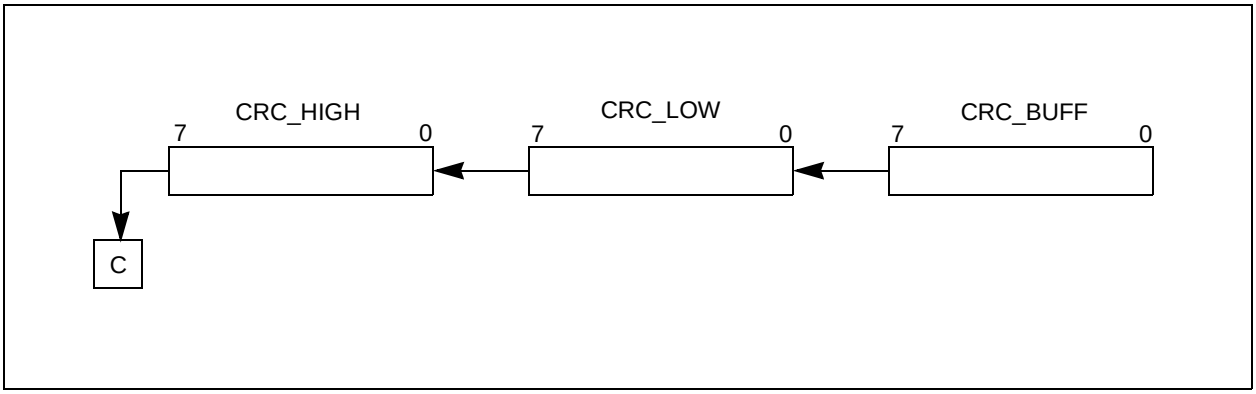


FIGURE 2: LOOP DRIVEN CRC IMPLEMENTATION



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)

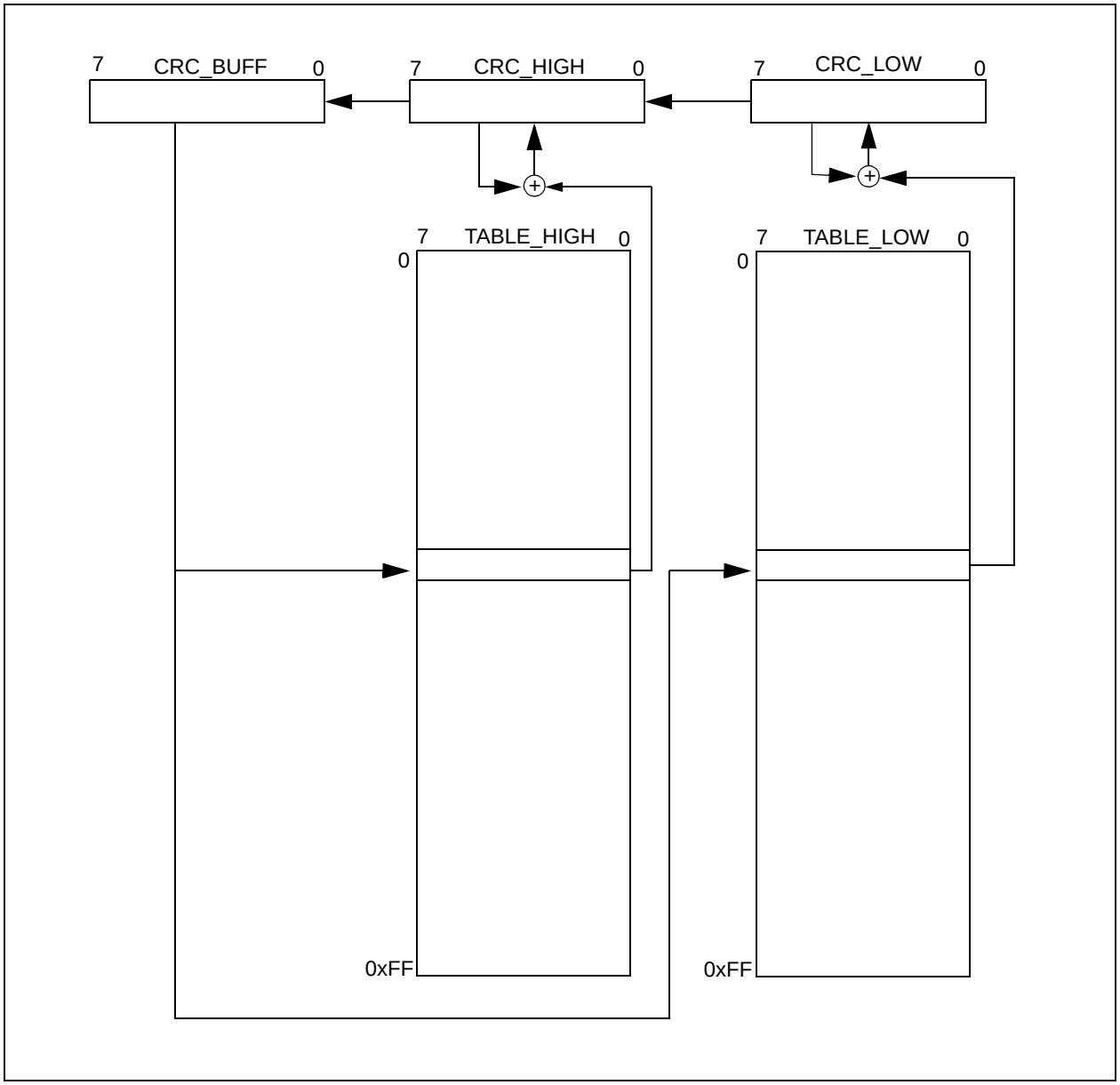
A parity bit check detects only single bit errors. The CRC error correction is mostly used where large data packages are transmitted, for example, in local area networks such as Ethernet.

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
```

```
                    00066                ; append CRC to message
0006   02A4         00067                incf    FSR, f                  ; point to position behind last data byte
0007   0207         00068                movf    CRC_HIGH, w             ; copy CRC_HIGH data into w-register
0008   0020         00069                movwf   INDF                    ; copy CRC_HIGH behing last data byte
0009   02A4         00070                incf    FSR, f                  ; point to next location
000A   0208         00071                movf    CRC_LOW, w              ; copy CRC_LOW data into w-register
000B   0020         00072                movwf   INDF                    ; copy data into next location
000C   0C10         00073                movlw   0x10                    ; set pointer to first data location
000D   0024         00074                movwf   FSR                     ; initialize FSR register
000E   0924         00075                call    CRC16Restore            ; restore CRC16 value
                    00076
000F   0A0F         00077 Stop           goto    Stop                    ; do forever
                    00078
                    00079                ; *************************************************************************
                    00080                ; * Title:              CRC16 calculation                                 *
                    00081                ; * Input parameter:    Pointer to first data byte (pointer in FSR register)    *
                    00082                ; *                     Number of data bytes stored in register DATABYTES       *
                    00083                ; * Output:             CRC result stored in CRC_HIGH and CRC_LOW               *
                    00084                ; *************************************************************************
0010   0938         00085 CRC16Generate  call    CRC16Init               ; initialize registers
0011   0C03         00086                movlw   0x03                    ; initialize TEMP register with 2
0012   002C         00087                movwf   TEMP                    ; move 0x02 into TEMP
                    00088
0013   0947         00089 NextCRC16      call    CRC16Engine             ; Calculate CRC16 for one byte
0014   02EB         00090                decfsz  DATABYTES, f            ; Decrement the number of data bytes by one
0015   0A1E         00091                goto    Reload                  ; reload CRC_BUFF register with new data byte
                    00092
0016   02EC         00093                decfsz  TEMP, f                 ; decrement TEMP register
0017   0A19         00094                goto    AppendZeros             ; Append zeros to message
0018   0800         00095                retlw   0x00                    ; return to main
0019   0069         00096 AppendZeros    clrf    CRC_BUFF                ; append data with zeros
001A   0C08         00097                movlw   Iterations              ; initialize BITS register
001B   002A         00098                movwf   BITS                    ; with 0x08
001C   02AB         00099                incf    DATABYTES, f            ; increment data bytes
001D   0A13         00100                goto    NextCRC16               ; last iteration
                    00101
                    00102
                    00103                ; Reload CRC buffer register with new data word.
001E   02A4         00104 Reload         incf    FSR, f                  ; point to next data byte
001F   0200         00105                movf    INDF, w                 ; copy data into w-register
0020   0029         00106                movwf   CRC_BUFF                ; move data into CRC_BUFF register
0021   0C08         00107                movlw   Iterations              ; initialize register BITS with 8
0022   002A         00108                movwf   BITS                    ; move 8 into register BITS
0023   0A13         00109                goto    NextCRC16               ; calculate next CRC
                    00110
                    00111
                    00112                ; *************************************************************************
```

```
                    00113                ; * Titel: Restore CRC function                                          *
                    00114                ; * Input: Pointer to first data byte in FSR register                     *
                    00115                ; * Output: w=0 CRC was restore sucessfull                               *
                    00116                ; *         w=1 CRC was not restored sucessfull                          *
                    00117                ; ***************************************************************************
0024   0938         00118 CRC16Restore   call    CRC16Init              ; initialize CRC registers
0025   0C02         00119                movlw   0x02                   ; add offset to DATABYTES
0026   01EB         00120                addwf   DATABYTES, f           ; add offset to register DATABYTES
                    00121
0027   0947         00122 NextCRCRestore call    CRC16Engine
0028   02EB         00123                decfsz  DATABYTES, f           ; Decrement the number of data bytes by one
0029   0A32         00124                goto    ReloadRestore          ; reload CRC_BUFF register with new data byte
                    00125
                    00126                ; check if CRC_HIGH and CRC_LOW equal to zero
002A   0227         00127                movf    CRC_HIGH, f            ; copy CRC_HIGH onto itself
002B   0743         00128                btfss   STATUS, Z              ; is content zero?
002C   0A31         00129                goto    CRCError               ; no, CRC error occured
002D   0228         00130                movf    CRC_LOW, f             ; copy CRC_LOW register onto itself
002E   0743         00131                btfss   STATUS, Z              ; is content zero?
002F   0A31         00132                goto    CRCError               ; no, CRC error occured
0030   0800         00133                retlw   0x00                   ; return to main (0= no error)
                    00134
0031   0801         00135 CRCError       retlw   0x01                   ; return to main with error code 1
                    00136
                    00137
                    00138                ; Reload CRC buffer register with new data word.
0032   02A4         00139 ReloadRestore  incf    FSR, f                 ; point to next data byte
0033   0200         00140                movf    INDF, w                ; copy data into w-register
0034   0029         00141                movwf   CRC_BUFF               ; move data into CRC_BUFF register
0035   0C08         00142                movlw   Iterations             ; initialize register BITS with 8
0036   002A         00143                movwf   BITS                   ; move 8 into register BITS
0037   0A27         00144                goto    NextCRCRestore         ; calculate next CRC
                    00145
                    00146
                    00147                ; ***************************************************************************
                    00148                ; * Titel: CRC16 Initialization                                           *
                    00149                ; * Input: Pointer to first data byte in FSR register                     *
                    00150                ; * Output: none                                                          *
                    00151                ; ***************************************************************************
0038   0200         00152 CRC16Init      movf    INDF, w                ; copy data into W-register
0039   0027         00153                movwf   CRC_HIGH               ; copy w-register into CRC_HIGH register
003A   02A4         00154                incf    FSR, f                 ; set pointer to next location
003B   0200         00155                movf    INDF, w                ; copy data into w-register

003C   0028         00156                movwf   CRC_LOW                ; copy w-register into CRC_LOW
003D   02A4         00157                incf    FSR, f                 ; set pointer to next location
003E   0200         00158                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

                     00001 ; ********************************************************************************************
                     00002 ; * Title           : CRC16 calculation table driven implementation                          *
                     00003 ; * Author          : Thomas Schmidt                                                         *
                     00004 ; * Date            : 22.03.1999                                                             *
                     00005 ; * Revision        : 0.1                                                                    *
                     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   : crctab01.asm: first program CRC generation                            *
                     00011 ; * Description     :                                                                        *
                     00012 ; *                                                                                          *
                     00013 ; * This module calculates the checksum for the CRC16 polynom. The CRC16 polynome is defined    *
                     00014 ; * as x16+x15+x2+x0. The calculation is done by bitwise checking. The algorithm is designed    *
                     00015 ; * for a two byte wide message. The algorithm can easily be modified for longer messages. The  *
                     00016 ; * only thing what has to be done is to check after the low byte is shifted into the high byte *
                     00017 ; * that the low byte is loaded with a new data byte. The number of iteration has to be adjusted*
                     00018 ; * to the number of extra bytes in the data message. The number is calculated as follows:      *
                     00019 ; * n=16+x*messagebits. For example if the message is 4 bytes long the number of iterations is  *
                     00020 ; * n=16+16bits. The extra iterations have to be done because the message is extended with 16   *
                     00021 ; * zeros at the end of the message.                                                          *
                                                                                                                        *
                     00022 ; ********************************************************************************************
                     00023
                     00024                 LIST P=16C58B, r=hex
                     00025
                     00026                 #include “p16c5x.inc”
                     00001         LIST
                     00002 ; P16C5X.INC  Standard Header File, Version 4.00    Microchip Technology, Inc.
                     00313         LIST
                     00027
                     00028                 #define DataLength              0x09            ; length of data field
                     00029                 #define LastTableElementHigh    0x2             ; last table element of high byte
                     00030                 #define LastTableElementLow     0x2             ; last table element of low byte
                     00031
                     00032                 cblock 0x07
  00000007           00033                         CRC_LOW         ; low byte of CRC register
  00000008           00034                         CRC_HIGH        ; high byte of CRC register
```

```
  00000009            00035                         CRC_BUFF        ; CRC buffer register
  0000000A            00036                         DATABYTES       ; contains number of data bytes
  0000000B            00037                         TEMP            ; temporary register
                      00038                 endc
                      00039
07FF                  00040                 org 0x7ff
07FF   0A00           00041                 goto    Begin
                      00042
0000                  00043                 org 0x00
0000                  00044 Begin
                      00045                 ; initialization what has to be done before CRC16 routine can be
                      00046                 ; called. The FSR register contains the pointer to the first byte of
                      00047                 ; data and the register DATABYTES contains the number of data bytes
                      00048                 ; of the message.
0000   0C10           00049                 movlw   0x10                    ; set pointer to first data location
0001   0024           00050                 movwf   FSR                     ; initialize FSR register
                      00051
0002   090C           00052 Main            call    CRC16Generate           ; calculate CRC16 value
                      00053
0003   0208           00054                 movf    CRC_HIGH, w             ; copy CRC_HIGH data into w-register
0004   0020           00055                 movwf   INDF                    ; copy CRC_HIGH behing last data byte
0005   02A4           00056                 incf    FSR, f                  ; point to next location
0006   0207           00057                 movf    CRC_LOW, w              ; copy CRC_LOW data into w-register
0007   0020           00058                 movwf   INDF                    ; copy data into next location
0008   0C10           00059                 movlw   0x10                    ; set pointer to first data location
0009   0024           00060                 movwf   FSR                     ; initialize FSR register
000A   093A           00061 TestPoint       call    CRC16Restore            ; Restore CRC
000B   0A0B           00062 Stop            goto    Stop                    ; do forever
                      00063
                      00064
                      00065                 ; ***************************************************************************
                      00066                 ; * Title:              CRC16 Table driven calculation                      *
                      00067                 ; * Input parameter:    Pointer to first data byte (pointer in FSR register)    *
                      00068                 ; *                     Number of data bytes stored in register DATABYTES       *
                      00069                 ; * Output:             CRC result stored in CRC_HIGH and CRC_LOW               *
                      00070                 ; ***************************************************************************
000C   095E           00071 CRC16Generate   call    CRC16Init               ; initialize CRC registers
000D   0C03           00072                 movlw   0x03                    ; initialize TEMP register
000E   002B           00073                 movwf   TEMP                    ; with 0x02
                      00074
                      00075                 ; check if last CRC_BUFF points to last element in table. These elements
                      00076                 ; cannot be read from the look up table, because they are beyond the
                      00077                 ; program memory page.
000F   0209           00078 NextValueGen    movf    CRC_BUFF, w             ; load CRC_BUFF into w-register
0010   0FFF           00079                 xorlw   0xff                    ; check if content equals to 0xff
0011   0743           00080                 btfss   STATUS, Z               ; is result from XOR = 0?
0012   0A18           00081                 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                    dt     0x82,   0x2,    0x2,    0x82
       0882
02D5   0802 0882 0882                    dt     0x2,    0x82,   0x82,   0x2
       0802
02D9   0802 0882 0882                    dt     0x2,    0x82,   0x82,   0x2
       0802
02DD   0882 0802 0802                    dt     0x82,   0x2,    0x2,    0x82
       0882
02E1   0882 0802 0802                    dt     0x82,   0x2,    0x2,    0x82
       0882
02E5   0802 0882 0882                    dt     0x2,    0x82,   0x82,   0x2
       0802
02E9   0802 0882 0882                    dt     0x2,    0x82,   0x82,   0x2
       0802
02ED   0882 0802 0802                    dt     0x82,   0x2,    0x2,    0x82
       0882
02F1   0802 0882 0882                    dt     0x2,    0x82,   0x82,   0x2
       0802
02F5   0882 0802 0802                    dt     0x82,   0x2,    0x2,    0x82
       0882
02F9   0882 0802 0802                    dt     0x82,   0x2,    0x2,    0x82
       0882
02FD   0802 0882 0882                    dt     0x2,    0x82,   0x82
                                        ; ********************************************************************************
                                        ; * Titel: CRC16 Table for low byte                                              *
                                        ; * Input: Pointer to table element in w-register                                *
                                        ; * Output: look-up value in w-register                                          *
                                        ; ********************************************************************************
0400                                    org 0x400
0400   01E2             CRC16TableLow   addwf  PCL, f          ; add to low byte of PC
0401   0800 0805 080F                    dt     0,      0x5,    0xf,    0xa
       080A
0405   081B 081E 0814                    dt     0x1b,   0x1e,   0x14,   0x11
       0811
0409   0833 0836 083C                    dt     0x33,   0x36,   0x3c,   0x39
       0839
040D   0828 082D 0827                    dt     0x28,   0x2d,   0x27,   0x22
       0822
0411   0863 0866 086C                    dt     0x63,   0x66,   0x6c,   0x69
       0869
0415   0878 087D 0877                    dt     0x78,   0x7d,   0x77,   0x72
       0872
0419   0850 0855 085F                    dt     0x50,   0x55,   0x5f,   0x5a
       085A
041D   084B 084E 0844                    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:

WORLDWIDE SALES AND SERVICE

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