AN542

Implementation of Fast Fourier Transforms

INTRODUCTION

Fourier transforms are one of the fundamental operations in signal processing. In digital computations, Discrete Fourier Transforms (DFT) are used to describe, represent and analyze discrete-time signals. However, direct implementation of DFT is computationally very inefficient. Of the various available high speed algorithms to compute DFT, the Cooley-Tukey algorithm is the simplest and most commonly used. These efficient algorithms to compute DFTs are called Fast Fourier Transforms (FFTs).

This application note provides the source code to compute the FFT using PIC17C42. The theory behind the FFT algorithms is well established and described in the literature and hence not described in this application note. A Radix-2 Cooley- Tukey FFT is implemented with no limits on the length of FFT. The length is only limited by the amount of available program memory space. All computations are done using double precision arithmetic.

IMPLEMENTATION

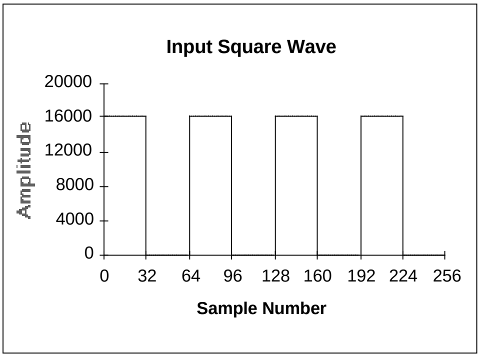
Since the PIC17C42 has only 232 x 8 general purpose RAM (equivalent of 116 x 16), at most a 32 point FFT (16-bit REAL & IMAGINARY data) can be implemented using on chip RAM. To compute higher point FFT, the data is stored in program memory space of PIC17C42. The PIC17C42 has instructions (TABLRD & TABLWT) to transfer data between program memory space and on chip file registers. In extended microcontroller mode, the PIC17C42 has 2K x 16 (0000h:07FFh) on chip program memory space and 62K x 16 (0800h:0FFFFh) of external program memory space. In this mode, the code (in this case, the FFT code) may reside on the on chip EPROM and the data to be analyzed may be stored in external RAMs (up to 62K). A suggested method of connecting external RAMs (appropriate EEPROMs may also be used) is shown in Figure 3.

If PIC17C42 is used in extended microcontroller mode and if all the code resides on chip, then the cost may further be reduced by using only one external SRAM instead of two. The block diagram is shown in Figure 2. The 16-bit data stored in the external RAM is organized as low byte followed by high byte. To achieve this, the code presented in this application note needs minor modifications, especially where TABLRD and TABLWR instructions are used. Address indexing must be incremented by two since 2 reads/writes must be performed to access a 16-bit data.

The FFT is implemented with Decimation In Frequency. Thus the input data before calling the FFT routine ("R2FFT") should be in normal order and the transformed data is in scrambled order. The original data is overwritten by the transformed data to conserve memory. This is achieved by use of in-place calculations. This in-place calculations causes the order of the DFT terms to be permuted. So at the end of the transform, all the data needs to be unscrambled to get the right order of the DFT terms. In some applications the order of terms is not necessary. Keeping this in mind, the unscrambling code is written as a separate subroutine ("Unscramble") and may be called if necessary.

Before implementing the FFT using PIC17C42, a "C" program was written and tested. This high level programming helps in writing the assembly code and the results of both programs can be compared against while debugging the assembly code. The "C" source code for the Radix-2 FFT is shown in Appendix A. The assembly code source file of the FFT program is shown in Appendix B. For a listing of the header file "17C42.h" and the macro definition file "17C42.mac" please refer to Appendices C and D respectively of the application note AN00540.

FIGURE 1 - TEST WAVE FORM



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TESTING

The assembly code was developed and debugged using Microchip's PICMASTER™ In-Circuit Emulator System. A main program generates a test pattern (like a square wave) and calls the FFT routines "R2FFT" & "Unscramble". After the DFT terms are computed, the results are captured into PICMASTER's real time trace buffer by putting a trace point on a dummy TABLRD instruction and capturing only the 2nd cycle (data cycle of TABLRD) of the instruction. The data from Trace buffer was hot linked to Microsoft Excel™ using DDE and then the graphs were plotted and analyzed.

The code was tested on various wave forms (a rectangular pulse, a triangular wave, square wave and a sine wave) and using FFT lengths of 64, 256 & 1024. The results of a 256 Point FFT on a square wave is shown below. The test wave form is shown in Figure 1 and the frequency spectrum of it computed by PIC17C42 is shown in Figure 2. As expected, the spectra appears at the odd harmonics of the input waveform's fundamental frequency (At N*256/64, N = 0,1,3,5,..).

PERFORMANCE

The performance of FFT using PIC17C42 is quite impressive noting that for an 8-bit machine with no hardware multiplier. Also note that all computations are performed using double precision arithmetic (16- and 32- bits) which is the case in most of the low end DSPs. Table 1 provides the real time performance in total number of Instruction cycles for both the "R2FFT" and "Unscramble" routines using 64, 256 and 1024 Point FFT. Note that the timings are in a worst case situation and in general will be a lot better than shown in the table. The worst case situation arises because the 16 x 16 software multiplier ("DblMult") does not have a uniform timing and depends on the input data. The worst case timing of the multiplier is used in the computation of performance.

FIGURE 2 - FFT (MAGNITUDE SPECTRUM) OF FIGURE 1 COMPUTED BY PIC17C42

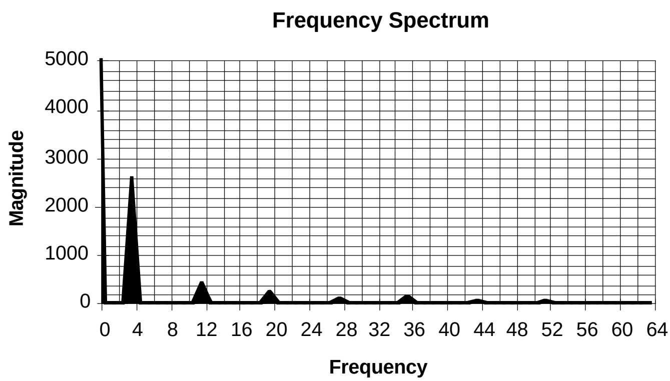

TABLE 1 - WORST CASE PERFORMANCE OF FFT IN INSTRUCTION CYCLES AND REAL TIME @ 25 MHZ

N (FFT Length)	64 Point	256 Point	1024 Point
R2FFT	34116 + 768*Mult = 171588	178024 + 4096*Mult= 911208	878752 + 20480*Mult = 4544672
Unscramble	5143	22495	93525
Total	176731 (28.28 mS)	933703 (149.39 mS)	4638197 (742.11 mS)

Table 2 shows the Program Memory and Data RAM requirements for an N Point FFT. The multiplier routine and other general purpose macro requirements are included in the memory requirements. The speed performance for the square wave test data differs from Table 1 since "worst case timings" is not used, and reflects a more reasonable data.

FFT APPLICATIONS

Although the FFT does not find a place in many microcontroller applications, it is very useful in providing a benchmark of the processor. As can be seen from table 2, the performance is very satisfactory, considering the fact that PIC17C42 is a Microcontroller and not a DSP. Also it should be borne in mind that all computations are performed in 16/32 bit arithmetic and that PIC17C42 is a low-cost 8-bit device unlike the DSPs which are relatively expensive.

In applications like Instrumentation, where real time FFT computation is not required, PIC17C42 can be used as a single chip solution instead of a Microcontroller and a Digital Signal Processor.

Suggested Reading :

[1] Rabiner. L.R., and Gold, B., Theory and Application Of Digital Signal Processing, Englewood Cliffs, NJ : Prentice-Hall, 1975.

[2] Burrs, C.S., and Parks, T.W., DFT/FFT and Convolution Alogorithms, New York : Wiley, 1985.

[3] Rodriguez,Jeffrey J., "An Improved FFT Digit-Reversal Algorithm," IEEE Transactions On Acoustics, Speech, And Signal Processing, Vol. 37, No. 8, Aug 1989.

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TABLE 2 - REQUIREMENTS FOR RADIX-2 FFT @ 25 MHZ

N (FFT Length)	64 Point	256 Point	1024 Point
Code Space (locations)	603 + 0.75*N = 651	603 + 0.75*N = 795	603 + 0.75*N= 1371
Data Storage in Program Memory Space	2*N = 128	2*N = 512	2*N = 2048
Scratch RAM	49	49	49
Performance (Square Wave Input Data)	122384 (19.58 mS)	644416 (103.11 mS)	3192176 (510.75mS)

FIGURE 3 - EXTERNAL MEMORY CONNECTION

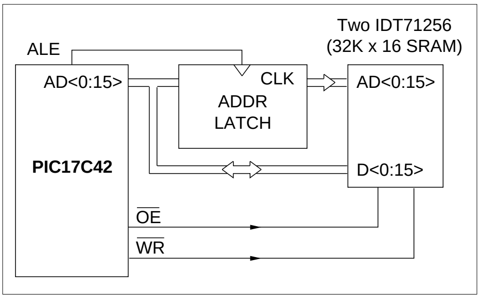
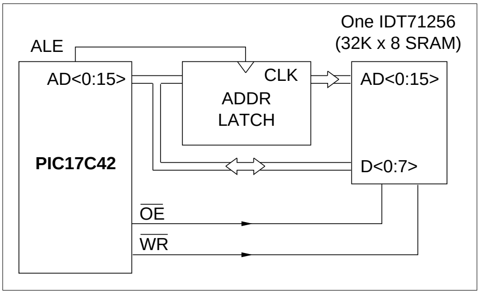


FIGURE 4 - ALTERNATE EXTERNAL MEMORY CONNECTION



APPENDIX A: FFT ALGORITHM

```
MPASM B0.54                                                            PAGE  1

                     ;*************************************************************************
                     ;               A Cooley-Tukey Radix-2 DIF FFT
                     ;
                     ;       Radix-2 implementation
                     ;       Decimation In Frequency
                     ;       Single Butterfly
                     ;       Table Lookup of Twiddle Factors
                     ;       Complex Input & Complex Output
                     ;
                     ;       All data is assumed to be 16 bits and the intermediate
                     ;       results are stored in 32 bits
                     ;
                     ;       Length Of FFT must be a Power Of 2
                     ;       Max Length Possible is 2**15
                     ;
                     ;       The input/output complex data is organized as a single array
                     ;       of real data followed by imaginary data
                     ;               Data is stored in External Memory and is accessed by
                     ;       TABLRD & TABLWT Instructions
                     ;
                     ;*************************************************************************
                     ;
                             LIST    P=17C42, C=120, T=ON, R=DEC, N=0
                             include “17c42.h”
                     ;
                             include “17c42.mac”
                     ;***************************************************************************
                     ;       RLC16AB
                     ;
                     ; DESCRIPTION:
                     ;       16 bit rotate left A into B
                     ;
                     ; ARGUMENTS:
                     ;       2*a => b
                     ;
                     ; TIMING (in cycles):
                     ;       3
                     ;
                     ;
                     RLC16AB MACRO   a,b

                              BCF     _carry
                              RLCF    a+B0,W
                              MOVWF   b+B0
                              RLCF    a+B1,W
                              MOVWF   b+B1
                              ENDM
                     ;***************************************************************************
                     ;       TBLADDR
                     ;
                     ; DESCRIPTION:
                     ;       Load 16 bit table pointer with specified label
                     ;
                     ; TIMING (in cycles):
                     ;       4
                     ;

                     TBLADDR MACRO   label

                              MOVLW   (label) & 0xff
                              MOVWF   tblptrl
                              MOVLW   page    (label)
                              MOVWF   tblptrh
                              ENDM

                     ;***************************************************************************
```

```
                    ;       ADDLBL
                    ;
                    ; DESCRIPTION:
                    ;       Add A Label (16 bit constant) To A File Register (16 bit)
                    ;
                    ; TIMING (in cycles):
                    ;       4
                    ;
                    ADDLBL  MACRO   label,f
                             MOVLW   (label) & 0xff
                             ADDWF   f+B0
                             MOVLW   page    (label)
                             ADDWFC  f+B1
                             ENDM
                    ;***************************************************************************
                    ;
0100                FftLen  .set    256                     ; FFT Length
0008                Power   .set    8                       ; (2**Power = FftLen)
00EF                DigitRevCount   .set    239             ; (FftLen-1) - (2**((Power+1)/2))

0001                SCALE_BUTTERFLY .set    TRUE            ; intermediate scaling performed

0800                EXT_RAM_START_ADDR      .set    0x0800  ; External Memory Data Storage Start Addr
                    ;
                    ;*************************************************************************
                    ;
                            CBLOCK  0
0000 0004                         B0,B1,B2,B3               ; RAM offset constants
        `                  ENDC
                    ;
                            CBLOCK  0x18
0018 0002                         AARG,AARG1                ; 16 bit multiplier A
001A 0002                         BARG,BARG1                ; 16 bit multiplicand B
001C 0004                         DPX,DPX1,DPX2,DPX3        ; 32 bit multiplier result = A*B
                             ENDC
                    ;
                            CBLOCK
0020 0004                         ACC, ACC1, ACC2, ACC3     ; 32 bit accumulator for computa
                             ENDC
                    ;
                            CBLOCK
0024 0002                         count1,count11            ; N1
0026 0002                         count2,count22            ; N2
0028 0002                        QuartLen,QuartLen1         ; FftLen/4
                             ENDC
                    ;
                            CBLOCK
002A 0002                         TF_Offset,TF_Offset1
002C 0002                         TF_Addr,TF_Addr1          ; twiddle factor address computa
002E 0002                         Cos,Cos1,
0030 0002                         Sin,Sin1
                             ENDC
                    ;
                            CBLOCK
0032 0002                         VarIloop,VarIloop1
0034 0002                         VarJloop,VarJloop1
0036 0001                         VarKloop
0037 0002                         VarL,VarL1
                             ENDC
                    ;
                            CBLOCK
0039 0002                         Xi,Xi1
003B 0002                         Yi,Yi1
003D 0002                         Xl,Xl1
003F 0002                         Yl,Yl1
                             ENDC
                    ;
```

```
                            CBLOCK
0041 0002                        Xt,Xt1
0043 0002                        Yt,Yt1
                            ENDC
                            CBLOCK
0045 0004                        temp,temp1,temp2,temp3
0049 0002                        testCount,testCount1
004B 0002                        PulseCount, PulseCount1
                            ENDC
                     ;
                     ;
                     ;*******************************************************************
                     ;               Test Program For FFT Subroutine
                     ;*******************************************************************
                     ;
                             ORG     0x0000
                     ;
                              include “square.asm”           ; Generate Test Vector Data
                     ;********************************************************************
                     ;               Test Routine For FFT
                     ; FFT Of Square Wave Pulse
                     ;********************************************************************

0008                 PulseWidthFactor        .set    8
                     ;
                     testFft
                            MOVK16  2*PulseWidthFactor,testCount

0000 B010                   MOVLW   (2*PulseWidthFactor) & 0xff
0001 0149                   MOVWF   testCount+B0
0002 B000                   MOVLW   (2*PulseWidthFactor)/256
0003 014A                   MOVWF   testCount+B1
                            CLR16    Yi
0004 293B                   CLRF    Yi+B0
0005 293C                   CLRF    Yi+B1
                            TBLADDR ExtRamAddr        ; load table pointers with data start addr
0006 B000                   MOVLW   (ExtRamAddr) & 0xff
0007 010D                   MOVWF   tblptrl
0008 B008                   MOVLW   page    (ExtRamAddr)
0009 010E                   MOVWF   tblptrh
                     ;
                     nextPulse
                            MOVK    FftLen/PulseWidthFactor,PulseCount
000A B020                   MOVLW   FftLen/PulseWidthFactor
000B 014B                   MOVWF   PulseCount
                            MOVK    FftLen/PulseWidthFactor,PulseCount1
000C B020                   MOVLW   FftLen/PulseWidthFactor
000D 014C                   MOVWF   PulseCount1

                     ;
                            MOVK16  0x3FFF,Xi
000E B0FF                   MOVLW   (0x3FFF) & 0xff
000F 0139                   MOVWF   Xi+B0
0010 B03F                   MOVLW   (0x3FFF)/256
0011 013A                   MOVWF   Xi+B1
                            LX1
0012 E034                   call    write
0013 174B                   decfsz  PulseCount
0014 C012                   goto    LX1
                     ;
                            CLR16   Xi
0015 2939                   CLRF    Xi+B0
0016 293A                   CLRF    Xi+B1
                            LX2
0017 E034                   call    write
0018 174C                   decfsz  PulseCount1
0019 C017                   goto    LX2
                     ;
                            DEC16   testCount
```

```
001A 2900               CLRF    WREG
001B 0749               DECF    testCount+B0
001C 034A               SUBWFB  testCount+B1
                        TFSZ16  testCount
001D 6049               MOVFP   testCount+B0,WREG
001E 084A               IORWF   testCount+B1,W
001F 3300               TSTFSZ  WREG
0020 C00A               goto    nextPulse
                ;
0021 E039               call    R2FFT           ; Compute Fourier Transform
0022 E116               call    Unscramble      ; Digit Reverse the scrambled data
                ;
                ; Fourier Transform Completed
                ;
                ; capture data to PIC-MASTER Trace Buffer
                        MOVK16  FftLen*2,temp
0023 B000               MOVLW   (FftLen*2) & 0xff
0024 0145               MOVWF   temp+B0
0025 B002               MOVLW   (FftLen*2)/256
0026 0146               MOVWF   temp+B1
                        TBLADDR ExtRamAddr     ; load table pointers with data start addr
0027 B000               MOVLW   (ExtRamAddr) & 0xff
0028 010D               MOVWF   tblptrl
0029 B008               MOVLW   page    (ExtRamAddr)
002A 010E               MOVWF   tblptrh
                        capture
002B A930               tablrd  0,1,Sin        ; table latch = mem(tblptr)
                        DEC16   temp
002C 2900               CLRF    WREG
002D 0745               DECF    temp+B0
002E 0346               SUBWFB  temp+B1
                        TFSZ16  temp
002F 6045               MOVFP   temp+B0,WREG
0030 0846               IORWF   temp+B1,W
0031 3300               TSTFSZ  WREG
0032 C02B               goto    capture
                ;
0033 C033       self    goto    self
                ;
                write
0034 A439               tlwt    0,Xi
0035 AF3A               tablwt  1,1,Xi+B1         ; auto increment for Imag Data
0036 A43B               tlwt    0,Yi
0037 AF3C               tablwt  1,1,Yi+B1
0038 0002               return
                ;
                ;*******************************************************************
                ;                       RADIX-2 FFT
                ;
                ;       Decimation In Frequency
                ;
                ; Input Data should be unscrambled
                ; Output Data at the end is in scrambled form
                ; To obtain the unscrambled form, the digit reverse counter
                ; subroutine, “Unscramble” should be called (see the example)
                ;
                ;*******************************************************************
                R2FFT
                        MOVK16  FftLen,count2     ; count2 = N
0039 B000               MOVLW   (FftLen) & 0xff
003A 0126               MOVWF   count2+B0
003B B001               MOVLW   (FftLen)/256
003C 0127               MOVWF   count2+B1
                        MOVK16  FftLen/4,QuartLen ; QuartLen = FftLen/4
003D B040               MOVLW   (FftLen/4) & 0xff
003E 0128               MOVWF   QuartLen+B0
003F B000               MOVLW   (FftLen/4)/256
0040 0129               MOVWF   QuartLen+B1
```

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```
0041 292B                                           clrf    TF_Offset+B1
                             MOVK    1,TF_Offset           ; Init TF_Offset = 1
0042 B001                    MOVLW   1
0043 012A                    MOVWF   TF_Offset
                             MOVK    Power,VarKloop        ; Kloop
0044 B008                    MOVLW   Power
0045 0136                    MOVWF   VarKloop
                             Kloop                         ; for K = 1 to Power-1
                             MOV16   count2,count1         ; count1 = count2
0046 6026                    MOVFP   count2+B0,WREG        ; get byte of count2 into w
0047 0124                    MOVWF   count1+B0             ; move to count1(B0)
0048 6027                    MOVFP   count2+B1,WREG        ; get byte of count2 into w
0049 0125                    MOVWF   count1+B1             ; move to count1(B1)
                             RRC16   count2                 ; count2 = count2/2
004A 1A27                    RLCF    count2+B1,W           ; move sign into carry bit
004B 1927                    RRCF    count2+B1
004C 1926                    RRCF    count2+B0
                             CLR16   VarJloop              ; J = 0
004D 2934                    CLRF    VarJloop+B0
004E 2935                    CLRF    VarJloop+B1
                             CLR16   TF_Addr                ; TF_Addr = 0
004F 292C                    CLRF    TF_Addr+B0
0050 292D                    CLRF    TF_Addr+B1
                             Jloop
                     ;
                     ; Read Twiddle factors from Sine/Cosine Table from Prog Mem
                     ;
                             MOVFP16 TF_Addr,tblptrl       ; load sine table address to table

0051 6D2C                    MOVFP   TF_Addr+B0,tblptrl+B0 ; move TF_Addr(B0) to tblptrl(B0)
0052 6E2D                    MOVFP   TF_Addr+B1,tblptrl+B1 ; move TF_Addr(B1) to tblptrl(B1)
                             ADDLBL  SineTable,tblptrl      ; add table offset
0053 B094                    MOVLW   (SineTable) & 0xff
0054 0F0D                    ADDWF   tblptrl+B0
0055 B002                    MOVLW   page(SineTable)
0056 110E                    ADDWFC  tblptrl+B1
0057 A830                    tablrd  0,0,Sin               ; Read Sine Value from lookup table
0058 A030                    tlrd    0,Sin
0059 A231                    tlrd    1,Sin+B1
                             ADD16   QuartLen,tblptrl
005A 6028                    MOVFP   QuartLen+B0,WREG      ; get lowest byte of QuartLen into w
005B 0F0D                    ADDWF   tblptrl+B0            ; add lowest byte of tblptrl, save in
005C 6029                    MOVFP   QuartLen+B1,WREG      ; get 2nd byte of QuartLen into w
005D 110E                    ADDWFC  tblptrl+B1            ; add 2nd byte of tblptrl, save in
005E A82E                    tablrd  0,0,Cos               ; Read Cosine Value from table
005F A02E                    tlrd    0,Cos
0060 A22F                    tlrd    1,Cos+B1
                     ;
                             ADD16   TF_Offset,TF_Addr     ; TF_Addr = TF_Addr + TF_Offset
0061 602A                    MOVFP   TF_Offset+B0,WREG     ; get lowest byte of TF_Offset into w
0062 0F2C                    ADDWF   TF_Addr+B0            ; add lowest byte of TF_Addr, save in
0063 602B                    MOVFP   TF_Offset+B1,WREG     ; get 2nd byte of TF_Offset into w
0064 112D                    ADDWFC  TF_Addr+B1            ; add 2nd byte of TF_Addr, save in
                    ;
                             RLC16AB VarJloop,VarIloop
0065 8804                    BCF     _carry
0066 1A34                    RLCF    VarJloop+B0,W
0067 0132                    MOVWF   VarIloop+B0
0068 1A35                    RLCF    VarJloop+B1,W
0069 0133                    MOVWF   VarIloop+B1
                     ;
                             Iloop
                             RLC16AB count2,VarL           ; VarL = count2*2
006A 8804                    BCF     _carry
006B 1A26                    RLCF    count2+B0,W
006C 0137                    MOVWF   VarL+B0
006D 1A27                    RLCF    count2+B1,W
006E 0138                    MOVWF   VarL+B1
                             ADD16   VarIloop,VarL          ; VarL = (I+count2)*2
```

```
006F 6032               MOVFP   VarIloop+B0,WREG      ; get lowest byte of VarIloop into w
0070 0F37               ADDWF   VarL+B0               ; add lowest byte of VarL, save in
0071 6033               MOVFP   VarIloop+B1,WREG      ; get 2nd byte of VarIloop into w
0072 1138               ADDWFC  VarL+B1               ; add 2nd byte of VarL, save in VarL(B1)
                ;
                ; Get Real & Imag Data from external RAMs (Program Memory)
                ; load table pointers with data start addr
                ;
                        MOVFP16 VarL,tblptrl           ; read data(L)
0073 6D37               MOVFP   VarL+B0,tblptrl+B0    ; move VarL(B0) to tblptrl(B0)
0074 6E38               MOVFP   VarL+B1,tblptrl+B1    ; move VarL(B1) to tblptrl(B1)
                        ADDLBL  ExtRamAddr,tblptrl    ; add data addr offset
0075 B000               MOVLW   (ExtRamAddr) & 0xff
0076 0F0D               ADDWF   tblptrl+B0
0077 B008               MOVLW   page    (ExtRamAddr)
0078 110E               ADDWFC  tblptrl+B1
0079 A93D               tablrd  0,1,Xl                ; auto increment for Imag Data
007A A03D               tlrd    0,Xl
007B A23E               tlrd    1,Xl+B1               ; real data XL
007C A83F               tablrd  0,0,Yl
007D A03F               tlrd    0,Yl
007E A240               tlrd    1,Yl+B1               ; imag data YL
                        MOVFP16 VarIloop,tblptrl      ; read data(I)
007F 6D32               MOVFP   VarIloop+B0,tblptrl+B0; move VarIloop(B0) to tblptrl(B0)
0080 6E33               MOVFP   VarIloop+B1,tblptrl+B1  move VarIloop(B1) to tblptrl(B1)
                        ADDLBL  ExtRamAddr,tblptrl    ; add data addr offset
0081 B000               MOVLW   (ExtRamAddr) & 0xff
0082 0F0D               ADDWF   tblptrl+B0
0083 B008               MOVLW   page    (ExtRamAddr)
0084 110E               ADDWFC  tblptrl+B1
0085 A939               tablrd  0,1,Xi                ; auto increment for Imag Data
0086 A039               tlrd    0,Xi
0087 A23A               tlrd    1,Xi+B1               ; real data XI
0088 A83B               tablrd  0,0,Yi
0089 A03B               tlrd    0,Yi
008A A23C               tlrd    1,Yi+B1               ; imag data YI
                ;
                ; Real & Imag Data is fetched
                ; Compute Butterfly
                ;
                       SUB16ACC        Xl,Xi,Xt       ; Xt = Xi - Xl
008B 603D               MOVFP   Xl+B0,WREG            ; get lowest byte of Xl into w
008C 0439               SUBWF   Xi+B0,W               ; sub lowest byte of Xi, save in Xi(B0)
008D 0141               MOVWF   Xt+B0
008E 603E               MOVFP   Xl+B1,WREG            ; get 2nd byte of Xl into w
008F 023A               SUBWFB  Xi+B1,W               ; sub 2nd byte of Xi, save in Xi(B1)
0090 0142               MOVWF   Xt+B1
                        ADD16   Xl,Xi                 ; Xi = Xi + Xl
0091 603D               MOVFP   Xl+B0,WREG            ; get lowest byte of Xl into w
0092 0F39               ADDWF   Xi+B0                 ; add lowest byte of Xi, save in Xi(B0)
0093 603E               MOVFP   Xl+B1,WREG            ; get 2nd byte of Xl into w
0094 113A               ADDWFC  Xi+B1                 ; add 2nd byte of Xi, save in Xi(B1)
                        SUB16ACC        Yl,Yi,Yt      ; Yt = Yi - Yl
0095 603F               MOVFP   Yl+B0,WREG            ; get lowest byte of Yl into w
0096 043B               SUBWF   Yi+B0,W               ; sub lowest byte of Yi, save in Yi(B0)
0097 0143               MOVWF   Yt+B0
0098 6040               MOVFP   Yl+B1,WREG            ; get 2nd byte of Yl into w
0099 023C               SUBWFB  Yi+B1,W               ; sub 2nd byte of Yi, save in Yi(B1)
009A 0144               MOVWF   Yt+B1
                        ADD16           Yl,Yi         ; Yi = Yi + Yl
009B 603F               MOVFP   Yl+B0,WREG            ; get lowest byte of Yl into w
009C 0F3B               ADDWF   Yi+B0                 ; add lowest byte of Yi, save in Yi(B0)
009D 6040               MOVFP   Yl+B1,WREG            ; get 2nd byte of Yl into w
009E 113C               ADDWFC  Yi+B1                 ; add 2nd byte of Yi, save in Yi(B1)
                ;
                        if SCALE_BUTTERFLY
                        RRC16   Xi
009F 1A3A               RLCF    Xi+B1,W            ; move sign into carry bit
00A0 193A               RRCF    Xi+B1
```

4

```
00A1 1939                   RRCF    Xi+B0
                            RRC16   Yi
00A2 1A3C                   RLCF    Yi+B1,W            ; move sign into carry bit
00A3 193C                   RRCF    Yi+B1
00A4 193B                   RRCF    Yi+B0
                            RRC16   Xt
00A5 1A42                   RLCF    Xt+B1,W            ; move sign into carry bit
00A6 1942                   RRCF    Xt+B1
00A7 1941                   RRCF    Xt+B0
                            RRC16   Yt
00A8 1A44                   RLCF    Yt+B1,W            ; move sign into carry bit
00A9 1944                   RRCF    Yt+B1
00AA 1943                   RRCF    Yt+B0
                            endif
                    ;

                            MOVFP16 Cos,AARG
00AB 782E                   MOVFP   Cos+B0,AARG+B0     ; move Cos(B0) to AARG(B0)
00AC 792F                   MOVFP   Cos+B1,AARG+B1     ; move Cos(B1) to AARG(B1)
                            MOVFP16 Yt,BARG
00AD 7A43                   MOVFP   Yt+B0,BARG+B0      ; move Yt(B0) to BARG(B0)
00AE 7B44                   MOVFP   Yt+B1,BARG+B1      ; move Yt(B1) to BARG(B1)
00AF E182                   Call    DblMult ; COS*Yt
                            MOVPF32 DPX,ACC
00B0 5C20                   MOVPF   DPX+B0,ACC+B0      ; move DPX(B0) to ACC(B0)
00B1 5D21                   MOVPF   DPX+B1,ACC+B1      ; move DPX(B1) to ACC(B1)
00B2 5E22                   MOVPF   DPX+B2,ACC+B2      ; move DPX(B2) to ACC(B2)
00B3 5F23                   MOVPF   DPX+B3,ACC+B3      ; move DPX(B3) to ACC(B3)
                            MOVFP16 Sin,AARG
00B4 7830                   MOVFP   Sin+B0,AARG+B0     ; move Sin(B0) to AARG(B0)
00B5 7931                   MOVFP   Sin+B1,AARG+B1     ; move Sin(B1) to AARG(B1)
                            MOVFP16 Xt,BARG
00B6 7A41                   MOVFP   Xt+B0,BARG+B0      ; move Xt(B0) to BARG(B0)
00B7 7B42                   MOVFP   Xt+B1,BARG+B1      ; move Xt(B1) to BARG(B1)
00B8 E182                   Call    DblMult ; SIN*Xt, Scale if necessary
                            ADD32   ACC,DPX
00B9 6020                   MOVFP   ACC+B0,WREG        ; get lowest byte of ACC into w
00BA 0F1C                   ADDWF   DPX+B0             ; add lowest byte of DPX, save in DPX(B0)
00BB 6021                   MOVFP   ACC+B1,WREG        ; get 2nd byte of ACC into w
00BC 111D                   ADDWFC  DPX+B1             ; add 2nd byte of DPX, save in DPX(B1)
00BD 6022                   MOVFP   ACC+B2,WREG        ; get 3rd byte of ACC into w
00BE 111E                   ADDWFC  DPX+B2             ; add 3rd byte of DPX, save in DPX(B2)
00BF 6023                   MOVFP   ACC+B3,WREG        ; get 4th byte of ACC into w
00C0 111F                   ADDWFC  DPX+B3             ; add 4th byte of DPX, save in DPX(B3)
                            MOVPF16 DPX+B2,Yl          ; Yl = COS*Yt + SIN*Xt, Scale if neces
00C1 5E3F                   MOVPF   DPX+B2+B0,Yl+B0    ; move DPX+B2(B0) to Yl(B0)
00C2 5F40                   MOVPF   DPX+B2+B1,Yl+B1    ; move DPX+B2(B1) to Yl(B1)
                    ;
                            MOVFP16 Yt,BARG            ; AARG = SIN, BARG = Yt
00C3 7A43                   MOVFP   Yt+B0,BARG+B0      ; move Yt(B0) to BARG(B0)
00C4 7B44                   MOVFP   Yt+B1,BARG+B1      ; move Yt(B1) to BARG(B1)
00C5 E182                   Call    DblMult ; SIN*Yt
                            MOVPF32 DPX,ACC
00C6 5C20                   MOVPF   DPX+B0,ACC+B0      ; move DPX(B0) to ACC(B0)
00C7 5D21                   MOVPF   DPX+B1,ACC+B1      ; move DPX(B1) to ACC(B1)
00C8 5E22                   MOVPF   DPX+B2,ACC+B2      ; move DPX(B2) to ACC(B2)
00C9 5F23                   MOVPF   DPX+B3,ACC+B3      ; move DPX(B3) to ACC(B3)
                            MOVFP16 Cos,AARG
00CA 782E                   MOVFP   Cos+B0,AARG+B0     ; move Cos(B0) to AARG(B0)
00CB 792F                   MOVFP   Cos+B1,AARG+B1     ; move Cos(B1) to AARG(B1)
                            MOVFP16 Xt,BARG
00CC 7A41                   MOVFP   Xt+B0,BARG+B0      ; move Xt(B0) to BARG(B0)
00CD 7B42                   MOVFP   Xt+B1,BARG+B1      ; move Xt(B1) to BARG(B1)
00CE E182                   Call    DblMult            ; COS*Xt, Scale if necessary
                            SUB32   ACC,DPX            ; DPX = COS*Xt - SIN*Yt
00CF 6020                   MOVFP   ACC+B0,WREG        ; get lowest byte of ACC into w
00D0 051C                   SUBWF   DPX+B0             ; sub lowest byte of DPX, save in DPX(B0)
00D1 6021                   MOVFP   ACC+B1,WREG        ; get 2nd byte of ACC into w
00D2 031D                   SUBWFB  DPX+B1             ; sub 2nd byte of DPX, save in DPX(B1)
```

```
00D3 6022              MOVFP   ACC+B2,WREG        ; get 3rd byte of ACC into w
00D4 031E              SUBWFB  DPX+B2             ; sub 3rd byte of DPX, save in DPX(B2)
00D5 6023              MOVFP   ACC+B3,WREG        ; get 4th byte of ACC into w
00D6 031F              SUBWFB  DPX+B3             ; sub 4th byte of DPX, save in DPX(B3)
                       MOVPF16 DPX+B2,Xl          ; Xl = COS*Xt - SIN*Yt, Scale if neces
00D7 5E3D              MOVPF   DPX+B2+B0,Xl+B0    ; move DPX+B2(B0) to Xl(B0)
00D8 5F3E              MOVPF   DPX+B2+B1,Xl+B1    ; move DPX+B2(B1) to Xl(B1)
                  ;
                  ;
                  ; Store results of butterfly
                  ;
                       DEC16   tblptrl            ; table pointer already loaded with I
00D9 2900              CLRF    WREG
00DA 070D              DECF    tblptrl+B0
00DB 030E              SUBWFB  tblptrl+B1
00DC A439              tlwt    0,Xi
00DD AF3A              tablwt  1,1,Xi+B1          ; auto increment for Imag Data
00DE A43B              tlwt    0,Yi
00DF AE3C              tablwt  1,0,Yi+B1          ; Xi & Yi stored
                       MOVFP16 VarL,tblptrl       ; read data(L)
00E0 6D37              MOVFP   VarL+B0,tblptrl+B  ; move VarL(B0) to tblptrl(B0)
00E1 6E38              MOVFP   VarL+B1,tblptrl+B1 ; move VarL(B1) to tblptrl(B1)
                       ADDLBL  ExtRamAddr,tblptrl ; add data addr offset
00E2 B000              MOVLW   (ExtRamAddr) & 0xff
00E3 0F0D              ADDWF   tblptrl+B0
00E4 B008              MOVLW   page    (ExtRamAddr)
00E5 110E              ADDWFC  tblptrl+B1
00E6 A43D              tlwt    0,Xl
00E7 AF3E              tablwt  1,1,Xl+B1          ; auto increment for Imag Data
00E8 A43F              tlwt    0,Yl
00E9 AE40              tablwt  1,0,Yl+B1          ; X(L) & Y(L) stored
                  ;
                  ; Increment for next Iloop
                  ;
                       RLC16AB count1,temp        ; temp = count1*2
00EA 8804              BCF     _carry
00EB 1A24              RLCF    count1+B0,W
00EC 0145              MOVWF   temp+B0
00ED 1A25              RLCF    count1+B1,W
00EE 0146              MOVWF   temp+B1
                       ADD16   temp,VarIloop      ; I = I + temp
00EF 6045              MOVFP   temp+B0,WREG       ; get lowest byte of temp into w
00F0 0F32              ADDWF   VarIloop+B0        ; add lowest byte of VarIloop,save in VarIloop(B0)
00F1 6046              MOVFP   temp+B1,WREG       ; get 2nd byte of temp into w
00F2 1133              ADDWFC  VarIloop+B1        ; add 2nd byte of VarIloop,save in VarIloop(B1)
                  ;
                       MOVK16  (FftLen*2),temp
00F3 B000              MOVLW   ((FftLen*2)) & 0xff
00F4 0145              MOVWF   temp+B0
00F5 B002              MOVLW   ((FftLen*2))/256
00F6 0146              MOVWF   temp+B1
                       SUB16   VarIloop,temp      ; temp = 2*FftLen - I
00F7 6032              MOVFP   VarIloop+B0,WREG   ; get lowest byte of VarIloop into w
00F8 0545              SUBWF   temp+B0            ; sub lowest byte of temp, save in temp(B0)
00F9 6033              MOVFP   VarIloop+B1,WREG   ; get 2nd byte of VarIloop into w
00FA 0346              SUBWFB  temp+B1            ; sub 2nd byte of temp, save in temp(B1)
                       DEC16   temp
00FB 2900              CLRF    WREG
00FC 0745              DECF    temp+B0
00FD 0346              SUBWFB  temp+B1
00FE 9746              btfss   temp+B1,MSB
00FF C06A              goto    Iloop              ; while I < 2*FftLen
                  ;
                  ; I Loop end
```

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```
                     ;
                     ; increment for next J Loop
                     ;

                             INC16   VarJloop          ; J = J + 1
0100 2900                    CLRF    WREG
0101 1534                    INCF    VarJloop+B0
0102 1135                    ADDWFC  VarJloop+B1
                             MOV16   count2,temp
0103 6026                    MOVFP   count2+B0,WREG     ; get byte of count2 into w
0104 0145                    MOVWF   temp+B0            ; move to temp(B0)
0105 6027                    MOVFP   count2+B1,WREG     ; get byte of count2 into w
0106 0146                    MOVWF   temp+B1            ; move to temp(B1)
                             SUB16   VarJloop,temp      ; temp = count2 - J
0107 6034                    MOVFP   VarJloop+B0,WREG   ; get lowest byte of VarJloop into w
0108 0545                    SUBWF   temp+B0            ; sub lowest byte of temp, save in temp(B0)
0109 6035                    MOVFP   VarJloop+B1,WREG   ; get 2nd byte of VarJloop into w
010A 0346                    SUBWFB  temp+B1            ; sub 2nd byte of temp, save in temp(B1)
                             DEC16   temp
010B 2900                    CLRF    WREG
010C 0745                    DECF    temp+B0
010D 0346                    SUBWFB  temp+B1
010E 9746                    btfss   temp+B1,MSB
010F C051                    goto    Jloop              ; while J < count2
                     ;
                     ; J Loop end
                     ;
                     ; increment for next K Loop
                     ;
                             RLC16   TF_Offset          ; TF_Offset = 2 * TF_Offset
0110 8804                    BCF     _carry
0111 1B2A                    RLCF    TF_Offset+B0
0112 1B2B                    RLCF    TF_Offset+B1
0113 1736                    decfsz  VarKloop
0114 C046                    goto    Kloop              ; while K < Power
                     ;
0115 0002                    return                      ; FFT complete
                     ;
                     ; K Loop End
                     ; FFT Computation Over with data scrambled
                     ; Descramble the data using “Unscramble” Routine
                     ;
                     ;*******************************************************************
                     ;       Unscramble Data Order Sequence
                     ;       A digit reverse counter
                     ;*******************************************************************
                     include “reverse.asm”
                     ;*******************************************************************
                     ;                       A digit reverse counter
                     ;
                     ;       Unscramble Data Order Sequence Of Radix-2 FFT
                     ;       Length (must be a power of 2) is limited only by
                     ;       the amount of External RAM available and must be
                     ;       a number less than 2**15
                     ;
                     ;*******************************************************************
                     Unscramble
                             CLR16   VarJloop            ; J = 0
0116 2934                    CLRF    VarJloop+B0
0117 2935                    CLRF    VarJloop+B1
0118 2933                    clrf    VarIloop+B1
                             MOVK    1,VarIloop          ; I = 1
0119 B001                    MOVLW   1
011A 0132                    MOVWF   VarIloop
                    nextI
                             MOVK16  FftLen/2,VarKloop
011B B080                    MOVLW   (FftLen/2) & 0xff
011C 0136                    MOVWF   VarKloop+B0
011D B000                    MOVLW   (FftLen/2)/256
```

```
011E 0137               MOVWF   VarKloop+B1
011F C127               goto    testK
                KlessJ
                        SUB16   VarKloop,VarJloop  ; J = J - K
0120 6036              MOVFP   VarKloop+B0,WREG   ; get lowest byte of VarKloop into w
0121 0534              SUBWF   VarJloop+B0        ; sub lowest byte of VarJloop,save in VarJloop(B0)
0122 6037              MOVFP   VarKloop+B1,WREG   ; get 2nd byte of VarKloop into w
0123 0335              SUBWFB  VarJloop+B1        ; sub 2nd byte of VarJloop,save in VarJloop(B1)
                       RRC16   VarKloop           ; K = K/2
0124 1A37              RLCF    VarKloop+B1,W      ; move sign into carry bit
0125 1937              RRCF    VarKloop+B1
0126 1936              RRCF    VarKloop+B0
                testK
                       MOV16   VarJloop,temp

0127 6034              MOVFP   VarJloop+B0,WREG   ; get byte of VarJloop into w
0128 0145              MOVWF   temp+B0            ; move to temp(B0)
0129 6035              MOVFP   VarJloop+B1,WREG   ; get byte of VarJloop into w
012A 0146              MOVWF   temp+B1            ; move to temp(B1)
                       SUB16   VarKloop,temp      ; temp = J - K
012B 6036              MOVFP   VarKloop+B0,WREG   ; get lowest byte of VarKloop into w
012C 0545              SUBWF   temp+B0            ; sub lowest byte of temp, save in temp(B0)
012D 6037              MOVFP   VarKloop+B1,WREG   ; get 2nd byte of VarKloop into w
012E 0346              SUBWFB  temp+B1            ; sub 2nd byte of temp, save in temp(B1)
012F 9746              btfss   temp+B1,MSB
0130 C120              goto    KlessJ             ; while K < J
                       ADD16   VarKloop,VarJloop  ; J = J + K
0131 6036              MOVFP   VarKloop+B0,WREG   ; get lowest byte of VarKloop into w
0132 0F34              ADDWF   VarJloop+B0        ; add lowest byte of VarJloop,save in VarJloop(B0)
0133 6037              MOVFP   VarKloop+B1,WREG   ; get 2nd byte of VarKloop into w
0134 1135              ADDWFC  VarJloop+B1        ; add 2nd byte of VarJloop,save in VarJloop(B1)
                ;
                ; if (i < j) then swap data(i) & data(j)
                ;
                       MOV16   VarJloop,temp
0135 6034              MOVFP   VarJloop+B0,WREG   ; get byte of VarJloop into w
0136 0145              MOVWF   temp+B0            ; move to temp(B0)
0137 6035              MOVFP   VarJloop+B1,WREG   ; get byte of VarJloop into w
0138 0146              MOVWF   temp+B1            ; move to temp(B1)
                       SUB16   VarIloop,temp      ; temp = J - I
0139 6032              MOVFP   VarIloop+B0,WREG   ; get lowest byte of VarIloop into w
013A 0545              SUBWF   temp+B0            ; sub lowest byte of temp, save in temp(B0)
013B 6033              MOVFP   VarIloop+B1,WREG   ; get 2nd byte of VarIloop into w
013C 0346              SUBWFB  temp+B1            ; sub 2nd byte of temp, save in temp(B1)
                       DEC16   temp
013D 2900              CLRF    WREG
013E 0745              DECF    temp+B0
013F 0346              SUBWFB  temp+B1
0140 9F46              btfsc   temp+B1,MSB
0141 C174              goto    incI
                ;
                ; swap data
                ; read data(i)
                       RLC16AB VarIloop,tblptrl   ; add twice the addr, since Real Data
0142 8804              BCF     _carry
0143 1A32              RLCF    VarIloop+B0,W
0144 010D              MOVWF   tblptrl+B0
0145 1A33              RLCF    VarIloop+B1,W
0146 010E              MOVWF   tblptrl+B1
                       ADDLBL  ExtRamAddr,tblptrl ; is followed by Imag Data
0147 B000              MOVLW   (ExtRamAddr) & 0xff
0148 0F0D              ADDWF   tblptrl+B0
0149 B008              MOVLW   page    (ExtRamAddr)
014A 110E              ADDWFC  tblptrl+B1
014B A939              tablrd  0,1,Xi   ; auto increment for Imag Data
014C A039              tlrd    0,Xi
014D A23A              tlrd    1,Xi+B1  ; real data XI
014E A83B              tablrd  0,0,Yi
014F A03B              tlrd    0,Yi
```

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```
0150 A23C                   tlrd    1,Yi+B1  ; imag data YI
                     ;
                     ; read data(j)
                     ;
                            RLC16AB VarJloop,tblptrl   ; add twice the addr, since Real Data
0151 8804                   BCF     _carry
0152 1A34                   RLCF    VarJloop+B0,W
0153 010D                   MOVWF   tblptrl+B0
0154 1A35                   RLCF    VarJloop+B1,W
0155 010E                   MOVWF   tblptrl+B1
                            ADDLBL  ExtRamAddr,tblptrl ; is followed by Imag Data
0156 B000                   MOVLW   (ExtRamAddr) & 0xff
0157 0F0D                   ADDWF   tblptrl+B0
0158 B008                   MOVLW   page    (ExtRamAddr)
0159 110E                   ADDWFC  tblptrl+B1
015A A93D                   tablrd  0,1,Xl  ; auto increment for Imag Data
015B A03D                   tlrd    0,Xl
015C A23E                   tlrd    1,Xl+B1 ; real data XL
015D A83F                   tablrd  0,0,Yl
015E A03F                   tlrd    0,Yl
015F A240                   tlrd    1,Yl+B1 ; imag data YL
                     ;
                     ; Interchange data(I) & data(J)
                     ;
                     ; J addr already loaded into table pointers, bu autoincremented
                     ;
                            DEC16   tblptrl
0160 2900                   CLRF    WREG
0161 070D                   DECF    tblptrl+B0
0162 030E                   SUBWFB  tblptrl+B1
0163 A439                   tlwt    0,Xi
0164 AF3A                   tablwt  1,1,Xi+B1          ; auto increment for Imag Data
0165 A43B                   tlwt    0,Yi
0166 AE3C                   tablwt  1,0,Yi+B1          ; X(I) & Y(I) stored
                            RLC16AB VarIloop,tblptrl   ; add twice the addr, since Real Data
0167 8804                   BCF     _carry
0168 1A32                   RLCF    VarIloop+B0,W
0169 010D                   MOVWF   tblptrl+B0
016A 1A33                   RLCF    VarIloop+B1,W
016B 010E                   MOVWF   tblptrl+B1
                            ADDLBL  ExtRamAddr,tblptrl ; is followed by Imag Data
016C B000                   MOVLW   (ExtRamAddr) & 0xff
016D 0F0D                   ADDWF   tblptrl+B0
016E B008                   MOVLW   page    (ExtRamAddr)
016F 110E                   ADDWFC  tblptrl+B1
0170 A43D                   tlwt    0,Xl
0171 AF3E                   tablwt  1,1,Xl+B1          ; auto increment for Imag Data
0172 A43F                   tlwt    0,Yl
0173 AE40                   tablwt  1,0,Yl+B1          ; X(L) & Y(L) stored
                     ;
                     ; increment I
                     ;
                     incI
                            INC16   VarIloop
0174 2900                   CLRF    WREG
0175 1532                   INCF    VarIloop+B0
0176 1133                   ADDWFC  VarIloop+B1
                            MOVK16  DigitRevCount,temp
0177 B0EF                   MOVLW   (DigitRevCount) & 0xff
0178 0145                   MOVWF   temp+B0
0179 B000                   MOVLW   (DigitRevCount)/256
017A 0146                   MOVWF   temp+B1
                            SUB16   VarIloop,temp      ; temp = DigitRevCount - I
017B 6032                   MOVFP   VarIloop+B0,WREG   ; get lowest byte of VarIloop into w
017C 0545                   SUBWF   temp+B0            ; sub lowest byte of temp, save in temp(B0)
017D 6033                   MOVFP   VarIloop+B1,WREG   ; get 2nd byte of VarIloop into w
017E 0346                   SUBWFB  temp+B1            ; sub 2nd byte of temp, save in temp(B1)
017F 9746                   btfss   temp+B1,MSB
0180 C11B                   goto    nextI              ; while i < DigitRevCount
```

```
0181 0002                      return
                         ;
                         ; End digit reverse counter
                         ;
                         ;*************************************************************************



                         ;*****************************************************************
                         ;       Include Double Precision Multiplication Routine
                         ;*****************************************************************
0001                     SIGNED   equ     TRUE

                                  include "17c42mpy.mac"


                         ;
                         ;*****************************************************************
                         ;               Sine-Cosine Tables
                         ;*****************************************************************
                         ;
                                  include "fft256.tbl"
                         ;
                         ;        256 Point FFT Sine Table
                         ; coefficient table (size of table is 3n/4).
                         ;
                         SineTable
                         ;
0294 0000                        data           0
0295 0324                        data           804
0296 0648                        data           1608
0297 096A                        data           2410
0298 0C8C                        data           3212
0299 0FAB                        data           4011
029A 12C8                        data           4808
029B 15E2                        data           5602
029C 18F9                        data           6393
029D 1C0B                        data           7179
029E 1F1A                        data           7962
029F 2223                        data           8739
02A0 2528                        data           9512
02A1 2826                        data           10278
02A2 2B1F                        data           11039
02A3 2E11                        data           11793
02A4 30FB                        data           12539
02A5 33DF                        data           13279
02A6 36BA                        data           14010
02A7 398C                        data           14732
02A8 3C56                        data           15446
02A9 3F17                        data           16151
02AA 41CE                        data           16846
02AB 447A                        data           17530
02AC 471C                        data           18204
02AD 49B4                        data           18868
02AE 4C3F                        data           19519
02AF 4EBF                        data           20159
02B0 5133                        data           20787
02B1 539B                        data           21403
02B2 55F5                        data           22005
02B3 5842                        data           22594
02B4 5A82                        data           23170
02B5 5CB3                        data           23731
02B6 5ED7                        data           24279
02B7 60EB                        data           24811
02B8 62F1                        data           25329
02B9 64E8                        data           25832
02BA 66CF                        data           26319
02BB 68A6                        data           26790
02BC 6A6D                        data           27245
```

```
02BD 6C23                  data          27683
02BE 6DC9                  data          28105
02BF 6F5E                  data          28510
02C0 70E2                  data          28898
02C1 7254                  data          29268
02C2 73B5                  data          29621
02C3 7504                  data          29956
02C4 7641                  data          30273
02C5 776B                  data          30571
02C6 7884                  data          30852
02C7 7989                  data          31113
02C8 7A7C                  data          31356
02C9 7B5C                  data          31580
02CA 7C29                  data          31785
02CB 7CE3                  data          31971
02CC 7D89                  data          32137
02CD 7E1D                  data          32285
02CE 7E9C                  data          32412
02CF 7F09                  data          32521
02D0 7F61                  data          32609
02D1 7FA6                  data          32678
02D2 7FD8                  data          32728
02D3 7FF5                  data          32757
                     ;
                     CosTable
                     ;
02D4 7FFF                  data          32767
02D5 7FF5                  data          32757
02D6 7FD8                  data          32728
02D7 7FA6                  data          32678
02D8 7F61                  data          32609
02D9 7F09                  data          32521
02DA 7E9C                  data          32412
02DB 7E1D                  data          32285
02DC 7D89                  data          32137
02DD 7CE3                  data          31971
02DE 7C29                  data          31785
02DF 7B5C                  data          31580
02E0 7A7C                  data          31356
02E1 7989                  data          31113
02E2 7884                  data          30852
02E3 776B                  data          30571
02E4 7641                  data          30273
02E5 7504                  data          29956
02E6 73B5                  data          29621
02E7 7254                  data          29268
02E8 70E2                  data          28898
02E9 6F5E                  data          28510
02EA 6DC9                  data          28105
02EB 6C23                  data          27683
02EC 6A6D                  data          27245
02ED 68A6                  data          26790
02EE 66CF                  data          26319
02EF 64E8                  data          25832
02F0 62F1                  data          25329
02F1 60EB                  data          24811
02F2 5ED7                  data          24279
02F3 5CB3                  data          23731
02F4 5A82                  data          23170
02F5 5842                  data          22594
02F6 55F5                  data          22005
02F7 539B                  data          21403
02F8 5133                  data          20787
02F9 4EBF                  data          20159
02FA 4C3F                  data          19519
02FB 49B4                  data          18868
02FC 471C                  data          18204
02FD 447A                  data          17530
02FE 41CE                  data          16846
```

```
02FF 3F17               data        16151
0300 3C56               data        15446
0301 398C               data        14732
0302 36BA               data        14010
0303 33DF               data        13279
0304 30FB               data        12539
0305 2E11               data        11793
0306 2B1F               data        11039
0307 2826               data        10278
0308 2528               data        9512
0309 2223               data        8739
030A 1F1A               data        7962
030B 1C0B               data        7179
030C 18F9               data        6393
030D 15E2               data        5602
030E 12C8               data        4808
030F 0FAB               data        4011
0310 0C8C               data        3212
0311 096A               data        2410
0312 0648               data        1608
0313 0324               data        804
0314 0000               data        0
0315 FCDC               data       -804
0316 F9B8               data       -1608
0317 F696               data       -2410
0318 F374               data       -3212
0319 F055               data       -4011
031A ED38               data       -4808
031B EA1E               data       -5602
031C E707               data       -6393
031D E3F5               data       -7179
031E E0E6               data       -7962
031F DDDD               data       -8739
0320 DAD8               data       -9512
0321 D7DA               data       -10278
0322 D4E1               data       -11039
0323 D1EF               data       -11793
0324 CF05               data       -12539
0325 CC21               data       -13279
0326 C946               data       -14010
0327 C674               data       -14732
0328 C3AA               data       -15446
0329 C0E9               data       -16151
032A BE32               data       -16846
032B BB86               data       -17530
032C B8E4               data       -18204
032D B64C               data       -18868
032E B3C1               data       -19519
032F B141               data       -20159
0330 AECD               data       -20787
0331 AC65               data       -21403
0332 AA0B               data       -22005
0333 A7BE               data       -22594
0334 A57E               data       -23170
0335 A34D               data       -23731
0336 A129               data       -24279
0337 9F15               data       -24811
0338 9D0F               data       -25329
0339 9B18               data       -25832
033A 9931               data       -26319
033B 975A               data       -26790
033C 9593               data       -27245
033D 93DD               data       -27683
033E 9237               data       -28105
033F 90A2               data       -28510
0340 8F1E               data       -28898
0341 8DAC               data       -29268
0342 8C4B               data       -29621
0343 8AFC               data       -29956
```

```
0344 89BF              data          -30273
0345 8895              data          -30571
0346 877C              data          -30852
0347 8677              data          -31113
0348 8584              data          -31356
0349 84A4              data          -31580
034A 83D7              data          -31785
034B 831D              data          -31971
034C 8277              data          -32137
034D 81E3              data          -32285
034E 8164              data          -32412
034F 80F7              data          -32521
0350 809F              data          -32609
0351 805A              data          -32678
0352 8028              data          -32728
0353 800B              data          -32757
                     ;
                     ;*************************************************


                     ;
                     ;*****************************************************************
                     ;       FFT Input/Output Data Stored In External RAM
                     ; Operate Processor In Extended Microcontroller Mode
                     ; External Data Starts at Address 0x0800, with 2 bytes of
                     ; Real Data followed by 2 bytes of Imaginary Data.
                     ;*****************************************************************
                             ORG     EXT_RAM_START_ADDR
                     ;
                     ExtRamAddr
                     ;
                             END
Errors   :    0
Warnings :    0
```

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