# AN597

# Implementing Ultrasonic Ranging

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## INTRODUCTION

Object ranging is essential in many types of systems. One of the most popular ranging techniques is ultrasonic ranging. Ultrasonic ranging is used in a wide variety of applications including:

- Autofocus cameras
- Motion detection
- Robotics guidance
- Proximity sensing
- Object ranging

This application note describes a method of interfacing PIC16CXXX microcontrollers to the Polaroid 6500 Ranging Module. This implementation uses a minimum of microcontroller resources, a CCP module and two I/O pins. The two major components of the system are:

- Microcontroller
- Polaroid 6500 Ranging Module

The microcontroller performs the intelligence and arithmetic functions for ultrasonic ranging, while the Polaroid 6500 Ranging Module performs the ultrasonic signal transmissions and echo detection.

## THEORY OF OPERATION

Ultrasonic ranging entails transmitting a sound wave and measuring the time that it takes for the sound wave to reflect off of an object and back to the origin. The reflection time is proportional to the distance that the object is from the source. In this implementation, the sound wave is transmitted and received from the same transducer. Therefore, a blanking interval is required between signal transmission and reception to eliminate false echoes (i.e., a transmitted signal being detected as its own echo).

## CIRCUIT CONFIGURATION

In this implementation, a PIC16C74 is connected to the ranging module as shown in Figure 1. The RE0 and RE1 I/O pins are configured as digital outputs and are tied to INIT and BINH, respectively. The CCP1 pin is configured as a digital input and is tied to ECHO through a pull-up resistor. The pull-up resistor is needed since the ECHO signal is an open-collector output. The CCP1 pin is configured for capture mode (CCP1CON). Figure 2 shows the timing relationship for $V_{DD}$ and the three signal lines (INIT, BINH, and ECHO).

| **Note:** | The ranging module requires 5.0 milliseconds to stabilize during power-up. |
|---|---|

**FIGURE 1: RANGING MODULE INTERFACE**

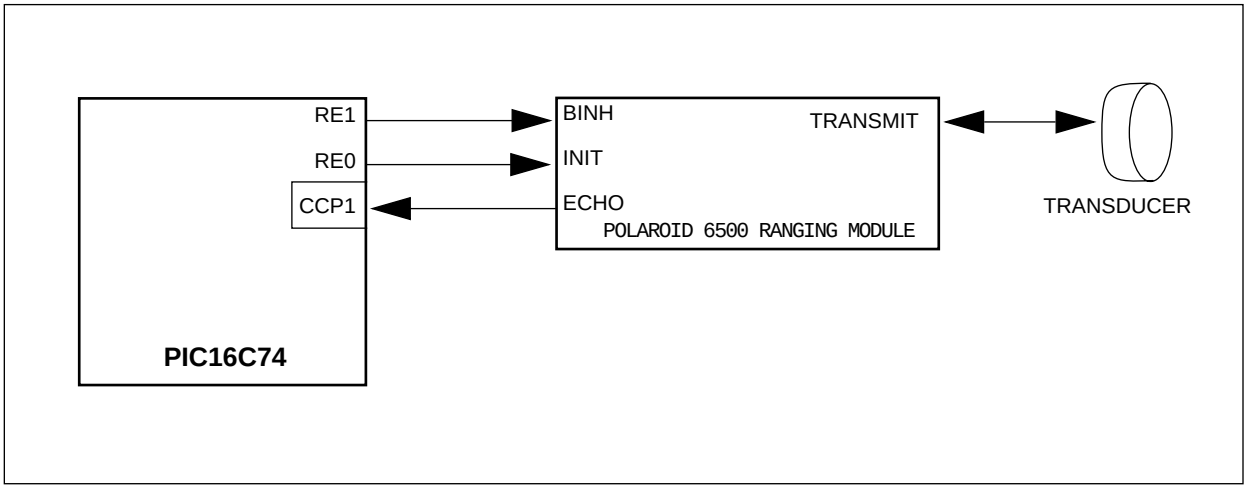
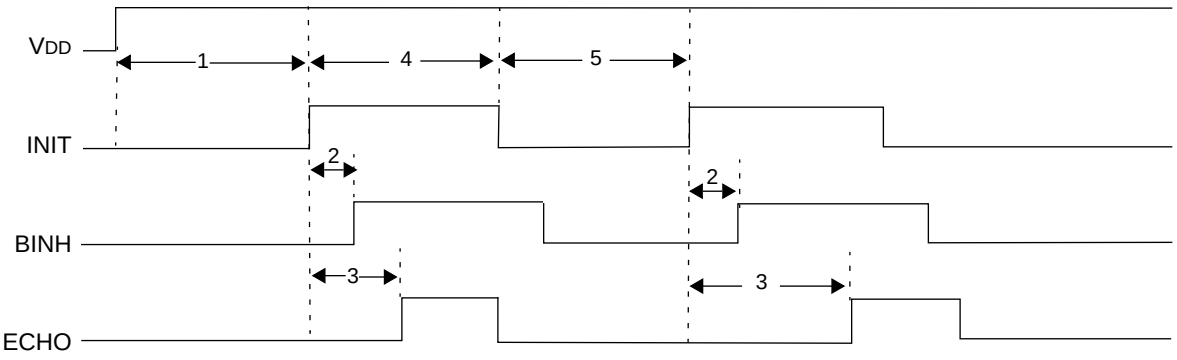


**FIGURE 2: TIMING DIAGRAM OF RANGING MODULE CONTROL LINES**




| Parameter Number | Symbol | Characteristic | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|
| 1 | TPU | Ranging Module Stabilization Time | 5.0 | – | – | ms |
| 2 | TBINH | Blank Inhibit Time | 0.9 | 2.38 | – | ms |
| 3 | TECHO | Echo Time | – | – | – | – |
| 4 | TINIT_H | High Time for INIT | 100 | – | – | ms |
| 5 | TINIT_L | Low Time for INIT | 100 | – | – | ms |

The PIC16C74 is configured to use one of its internal timers, Timer1, in capture mode to measure the time between signal transmission and echo detection. The resolution of the timer is determined by the microcontroller clock frequency. For this application, a 4 MHz external oscillator was used, giving a resolution of 1 ms per bit. The PIC16C74 initiates a ranging cycle by first clearing Timer1. Timer1 is then enabled and INIT is immediately asserted on the ranging module. When INIT is asserted, the ranging module transmits a series of 16 pulses on the transducer at 49.4 kHz. The transmitted pulses reflect off the object and are received back at the transducer.

The transducer is used for both transmitting and receiving sound waves. A blanking interval is needed to ensure that the transmitted signal has decayed on the transducer, in order not to receive false echoes. In normal operation, the ranging module has a blanking interval of 2.38 milliseconds, which corresponds to a minimum detection distance of approximately 17 inches. However, the BINH (blank inhibit) signal can be manipulated to reduce the blanking time on the transducer to allow for object ranging as close as 6 inches.

In this implementation, the PIC16C74 asserts the BINH signal approximately 0.9 milliseconds after signal transmission. This enables the transducer to receive reflections off objects at a distance of 6 inches. The ranging module asserts the ECHO signal when a valid reflection has been detected. The PIC16C74 uses the ECHO signal to trigger a capture of the Timer1 value. The capture register contains the 16-bit value representing the elapsed time between signal transmission and echo detection. The PIC16C74 then calculates object distance based on the Timer1 value, microcontroller clock speed, and the velocity of sound in the atmosphere. The basic equation for calculating distance is given below:

Distance (inches) = TECHO time / 147.9 microseconds

| **Note:** | The minimum high and low time for INIT is 100 milliseconds, as seen in Figure 2. |
|---|---|

## DESIGN CONSIDERATIONS

There are several design considerations which must be taken into account and are listed below.

The absolute measuring distance supported by the ranging module is 6 inches to 35 feet with an accuracy of +/- 1%.

The distance output from the ranging module can be averaged over time to filter distance calculations.

In some applications, the gain of the receiver amplifier may be too low or too high and may need to be adjusted. For example, if the transducer is mounted in a cylinder, the gain may need to be lowered to reduce false echoes within the cylinder. In this case, R1 (refer to the Polariod Ultrasonic Ranging System manual) may be replaced with a 20 kΩ potentiometer to tweak the gain of the receiver amplifier to reduce false echoes.

In order for the Polaroid 6500 ranging module to operate properly, the power supply must be capable of handling high current transients (2.5 A) during the

transmit pulse. The instantaneous drain on the power supply can be mitigated by installing a storage capacitor across the power lines at the ranging module. A value of 500 microfarads is recommended.

A 200 millisecond interval is recommended between ranging cycles (Figure 2) to allow the transducer to clear.

The ECHO line requires a pull-up resistor (4.7 kΩ was used in this application).

There must be a common ground between the PIC16C74 circuitry and the ranging module.

Some applications may not need the resources of the higher end PIC16CXXX devices. It is still possible to do this application using a device that does not contain a CCP module (for ECHO timing). The capture function can be implemented in firmware. The effect of a firmware implementation is that the resolution of the ECHO time would be 3 $T_{CY}$ cycles versus 1 $T_{CY}$ cycle for the CCP module. Also, the firmware implementation would not allow other tasks to be performed while the capture function was occurring.

Refer to Appendix A for general ranging module specifications.

## APPENDIX A: POLAROID MODULE SPECIFICATIONS

| | |
|---|---|
| **Note:** | This appendix contains general specifications from the Polaroid Ultrasonic Ranging System Manual. Please refer to the current Polaroid Ultrasonic Ranging System Manual for current information regarding ranging module design considerations. |

## DESIGN CONSIDERATIONS IN ULTRASONICS

**Range:** (with user custom designed processing electronics)

Farther

a) Use an acoustic horn to “focus” the sound (narrowing the beamwidth).
b) Use two transducers – 1 receiver and 1 transmitter – facing each other.
c) Lower the transmitting frequency (which will decrease the attenuation in air).

Closer

a) Use a shorter transmit signal (such as four cycles).
a) Use two transducers – one to transmit, one to receive (eliminates waiting for damping time).

Resolution

a) Above all, know the target and range well, and design a system with them in mind.
b) Use a higher transmit frequency.
c) Look at phase differences of a given cycle of the transmitted signal and received echo (as opposed to using and integration technique).
d) Increase the clock frequency of the timer.

**Accuracy:** (again, you must have a well defined target)

Temperature Compensate

a) Use a second small target, as a reference, at a known distance in the ranging path (such as a 1/4” rod several feet away), process both echoes, then normalize the second distance with respect to the first, since t1/d1 = t2/d2.
b) Incorporate a temperature sensing integrated circuit to drive a VCO to do the distance interval clocking.
c) To increase sensitivity of detection circuit change the value of C4 from 3300 pF to 1000 pF on the 6500 Series Ranging Module.

**Beam Width:**

Increase

a) Use an acoustic lens (to disperse the signal).
b) Decrease the transmitting frequency.
c) Use several transducers to span an area.

Decrease

a) Use an acoustic horn (to focus the sound).
b) Increase the transmitting frequency.

**TABLE 1: RECOMMENDED OPERATING CONDITIONS**

| | | Min. | Max. | Unit |
|---|---|---|---|---|
| Supply Voltage, $V_{CC}$ | | 4.5 | 6.8 | V |
| High-level input voltage, $V_{IH}$ | BINH, INIT | 2.1 | — | V |
| Low-level input voltage, $V_{IL}$ | BINH, INIT | — | 0.6 | V |
| ECHO and OSC output voltage | | — | 6.8 | V |
| Delay time, power up to INIT high | | 5 | — | ms |
| Recycle period | | 80 | — | ms |
| Operating free-air temperature, $T_A$ | | 0 | 40 | °C |

**TABLE 2: ELECTRICAL CHARACTERISTICS OVER RECOMMENDED RANGES OF SUPPLY VOLTAGE AND OPERATING FREE-AIR TEMPERATURE (UNLESS OTHERWISE NOTED)**

| Parameter | | Test Conditions | Min. | Typ. | Max. | Unit |
|---|---|---|---|---|---|---|
| Input current | BINH, INIT | V1 = 2.1V | — | — | 1 | mA |
| High-level output current, $I_{OH}$ | ECHO, OSC | $V_{OH}$ = 5.5V | — | — | 100 | µA |
| Low-level output voltage, $V_{OL}$ | ECHO, OSC | $I_{OL}$ = 1.6 mA | — | — | 0.4 | V |
| Transducer bias voltage | | $T_A$ = 25°C | — | 200 | | V |
| Transducer output voltage (peak-to-peak) | | $T_A$ = 25°C | — | 400 | | V |
| Number of cycles for XDCR output to reach 400V | | C= 500 pF | — | — | 7 | |
| Internal blanking interval | | | — | 2.38* | — | ms |
| Frequency during 16-pulse transmit period | OSC output | | — | 49.4* | — | kHz |
| | XMIT output | | — | 49.4* | — | |
| Frequency after 16 pulse transmit period | OSC output | | — | 93.3* | — | kHz |
| | XMIT output | | — | 0 | — | |
| Supply current, $I_{CC}$ | During transmit period | | — | — | 2000 | mA |
| | After transmit period | | — | — | 100 | |

* These typical values apply for a 420 kHz ceramic resonator.

Please check the Microchip BBS for the latest version of the source code. Microchip's Worldwide Web Address: www.microchip.com; Bulletin Board Support: MCHIPBBS using CompuServe® (CompuServe membership not required).

## APPENDIX B: FIRMWARE LISTING

```
MPASM 01.40 Released            XDCR.ASM   1-22-1997  10:55:26         PAGE  1


LOC  OBJECT CODE     LINE SOURCE TEXT
  VALUE

                     00001 ; XDCR.ASM
                     00002 ;
                     00003 ; This routine continually executes ranging cycles in the
                     00004 ; following order:
                     00005 ;
                     00006 ;       1) Timers and Flags are cleared
                     00007 ;       2) Ranging Cycle Executes
                     00008 ;       3) Distance is Calculated (to 0.5 inch)
                     00009 ;       4) HW is re-initialized for next cycle
                     00010 ;
                     00011 ; The processor uses a 4MHz oscillator, so all timing
                     00012 ; calculations are referenced to that.  The calculated
                     00013 ; distance is a 16-bit result in the ACCbHI:ACCbLO registers.
                     00014 ;
                     00015 ;       Program:          XDCR.ASM
                     00016 ;       Revision Date:
                     00017 ;                         1-22-97      Compatibility with MPASMWIN 1.40
                     00018 ;
                     00019 ;
                     00020
                     00021         LIST P=16C74
                     00022 ;
                     00001         LIST
                     00002 ; P16C74.INC  Standard Header File, Version 1.00  Microchip Technology, Inc.
                     00318         LIST
                     00025
  00000030           00026 TEMP    equ     0x30            ;Temporary storage location
  00000031           00027 TEMP1   equ     0x31            ;Temporary storage location
  00000032           00028 TEMP2   equ     0x32            ;Temporary storage location
  00000033           00029 TEMP3   equ     0x33            ;Temporary storage location
  00000034           00030 COUNT1  equ     0x34            ;Temporary count register
  00000035           00031 COUNT2  equ     0x35            ;Temporary count register
                     00032 ;
                     00033 #DEFINE      XDCR               ; Flag for conditional assemble of test code
                     00034                                 ; in file DBL_DIVF.ASM. END directive MUST be
                     00035                                 ; commented out in file DBL_DIVF.ASM
                     00036 ;
                     00037 ;*****************************************************************
                     00038         LIST
                     00039
                     00040 ;******************
                     00041 ; Bank 0 Registers
                     00042 ;******************
                     00043 ;
                     00044 ; TMR1 is off, Prescaler is 1 for a capture timeout of 65 msec
0000 0190            00045         clrf    T1CON
                     00046 ; Set to capture on every rising edge
0001 3005            00047         movlw   0x05
0002 0097            00048         movwf   CCP1CON
                     00049 ; Clear the Ports
0003 0185            00050         clrf    PORTA
0004 0186            00051         clrf    PORTB
0005 0187            00052         clrf    PORTC
0006 0188            00053         clrf    PORTD
```

```
0007 0189       00054         clrf    PORTE
                00055 ;
                00056 ;******************
                00057 ; Bank 1 Registers
                00058 ;******************
                00059 ;
0008 1683       00060         bsf     STATUS,RP0      ; Set Bank1
                00061 ; Port A is Digital, Port E is Digital
0009 3007       00062         movlw   0x07
Message[302]: Register in operand not in bank 0.  Ensure that bank bits are correct.
000A 009F       00063         movwf   ADCON1
                00064 ; Configure CCP1 (RC2) as an input, and all other ports
                00065 ; as Outputs, (RE0 = INIT, RE1 = BINH)
Message[302]: Register in operand not in bank 0.  Ensure that bank bits are correct.
000B 0185       00066         clrf    TRISA
Message[302]: Register in operand not in bank 0.  Ensure that bank bits are correct.
000C 0186       00067         clrf    TRISB
000D 3004       00068         movlw   0x04
Message[302]: Register in operand not in bank 0.  Ensure that bank bits are correct.
000E 0087       00069         movwf   TRISC
Message[302]: Register in operand not in bank 0.  Ensure that bank bits are correct.
000F 0188       00070         clrf    TRISD
Message[302]: Register in operand not in bank 0.  Ensure that bank bits are correct.
0010 0189       00071         clrf    TRISE
0011 1283       00072         bcf     STATUS,RP0      ; Clear RP0
0012            00073 Xdcr
                00074 ;
                00075 ; Initialize Timers and Flags
                00076 ;
0012 1010       00077         bcf     T1CON,0 ; Disable TMR1
0013 018C       00078         clrf    PIR1    ; Clear Timer1 Overflow Flag & Timer1 Capture Flag
0014 018E       00079         clrf    TMR1L   ; Clear TMR1L
0015 018F       00080         clrf    TMR1H   ; Clear TMR1H
0016 0195       00081         clrf    CCPR1L  ; Clear CCPR1L
0017 0196       00082         clrf    CCPR1H  ; Clear CCPR1H
0018 1409       00083         bsf     PORTE,0 ; Set INIT High on Ranging Module
0019 1410       00084         bsf     T1CON,0 ; Enable TMR1
001A 21F3       00085         call    DEL_9   ; Delay 0.9 msec for transducer to stabilize
001B 1489       00086         bsf     PORTE,1 ; Enable Transducer to Receive (BINH)
001C            00087 chk_t1
001C 190C       00088         btfsc   PIR1,2          ; Check for Capture
001D 2822       00089         goto    chk_done        ; Jump if Capture
001E 1C0C       00090         btfss   PIR1,0          ; Check for TMR1 Overflow
001F 281C       00091         goto    chk_t1          ; Loop if nothing happened
0020 1010       00092         bcf     T1CON,0         ; Turn off TMR1
0021 2833       00093         goto    ovr_flo         ; Capture event did not occur
0022            00094 chk_done
                00095 ;
                00096 ; Calculate distance to 0.5 inch resolution
                00097 ;
0022 1010       00098         bcf     T1CON,0         ; Turn off TMR1
0023 0815       00099         movf    CCPR1L,W        ; Move LSB into W
0024 00A2       00100         movwf   ACCbLO          ; Move LSB into ACCbLO
0025 0816       00101         movf    CCPR1H,W        ; Move MSB into W
0026 00A3       00102         movwf   ACCbHI          ; Move MSB into ACCbHI
0027 304A       00103         movlw   0x4A            ; Move 75usec/0.50in into W
0028 00A0       00104         movwf   ACCaLO          ; Move LSB into ACCaLO
0029 01A1       00105         clrf    ACCaHI          ; Clear MSB (ACCaHI)
002A 208F       00106         call    D_divF          ; Call 16-bit/8-bit routine
                00107                                 ; which is described in
                00108                                 ; Application Note 544
002B 3025       00109         movlw   0x25            ; Check remainder to see if
002C 0224       00110         subwf   ACCcLO,W        ; we should round up...
002D 1803       00111         btfsc   STATUS,C        ; If Remainder < (0.5 * Divisor), skip
002E 0AA2       00112         incf    ACCbLO,F        ; Round up
002F 1903       00113         btfsc   STATUS,Z        ; Check low byte for wrap around
0030 0AA3       00114         incf    ACCbHI,F        ; If LSB wrapped, increment high byte
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```
0031 1D03       00115         btfss   STATUS,Z        ; Check high byte for wrap around
0032 2835       00116         goto    done            ; High byte didn't wrap
0033            00117 ovr_flo
0033 01A2       00118         clrf    ACCbLO
0034 01A3       00119         clrf    ACCbHI
0035            00120 done
0035 21FD       00121         call    DEL_100         ; Wait 100 msec before clearing HW.
0036 1009       00122         bcf     PORTE,0         ; Disable INIT
0037 1089       00123         bcf     PORTE,1         ; Disable BINH
0038 21FD       00124         call    DEL_100         ; Wait 100 msec before enabling HW.
0039 2812       00125         goto    Xdcr
                00126
                00319         LIST
                00320
                00636         LIST
                00044
  00000001      00045 TRUE    equ     1h
  00000000      00046 FALSE   equ     0h
                00047
0080            00048         org     0x080
                00049 ;*****************************************************************
  00000000      00050 SIGNED  equ     FALSE           ; Set This To 'TRUE' if the routines
                00051 ;                               ; for Multiplication & Division needs
                00052 ;                               ; to be assembled as Signed Integer
                00053 ;                               ; Routines. If 'FALSE' the above two
                00054 ;                               ; routines ( D_mpy & D_div ) use
                00055 ;                               ; unsigned arithmetic.
                00056 ;*****************************************************************;
                00057 ;       division macro
                00058 ;
                00059 divMac  MACRO
                00060         LOCAL   NOCHK
                00061         LOCAL   NOGO
                00062 ;
                00063         bcf     STATUS,C
                00064         rlf     ACCdLO, F
                00065         rlf     ACCdHI, F
                00066         rlf     ACCcLO, F
                00067         rlf     ACCcHI, F
                00068         movf    ACCaHI,W
                00069         subwf   ACCcHI,W        ;check if a>c
                00070         btfss   STATUS,Z
                00071         goto    NOCHK
                00072         movf    ACCaLO,W
                00073         subwf   ACCcLO,W        ;if msb equal then check lsb
                00074 NOCHK   btfss   STATUS,C        ;carry set if c>a
                00075         goto    NOGO
                00076         movf    ACCaLO,W        ;c-a into c
                00077         subwf   ACCcLO, F
                00078         btfss   STATUS,C
                00079         decf    ACCcHI, F
                00080         movf    ACCaHI,W
                00081         subwf   ACCcHI, F
                00082         bsf     STATUS,C        ;shift a 1 into b (result)
                00083 NOGO    rlf     ACCbLO, F
                00084         rlf     ACCbHI, F
                00085 ;
                00086         ENDM
                00087 ;
                00088 ;*****************************************************************
                00089 ;       Double Precision Divide ( 16/16 -> 16 )
                00090 ;
                00091 ; ( ACCb/ACCa -> ACCb with remainder in ACCc ) : 16 bit output
                00092 ; with Quotiont in ACCb (ACCbHI,ACCbLO) and Remainder in ACCc
                00093 ; (ACCcHI,ACCcLO).
                00094 ;   NOTE  :  Before calling this routine, the user should make sure that
```

```
                00095 ;            the Numerator(ACCb) is greater than Denominator(ACCa). If
                00096 ;            the case is not true, the user should scale either Numerator
                00097 ;            or Denominator or both such that Numerator is greater than
                00098 ;            the Denominator.
                00099 ;
                00100 ;
0080 3010       00101 setup   movlw   .16             ; for 16 shifts
0081 00A8       00102         movwf   temp
0082 0823       00103         movf    ACCbHI,W       ;move ACCb to ACCd
0083 00A7       00104         movwf   ACCdHI
0084 0822       00105         movf    ACCbLO,W
0085 00A6       00106         movwf   ACCdLO
0086 01A3       00107         clrf    ACCbHI
0087 01A2       00108         clrf    ACCbLO
0088 3400       00109         retlw   0
                00110 ;
                00111 ;*****************************************************************
                00112 ;
0089 09A0       00113 neg_A   comf    ACCaLO, F       ; negate ACCa ( -ACCa -> ACCa )
008A 0AA0       00114         incf    ACCaLO, F
008B 1903       00115         btfsc   STATUS,Z
008C 03A1       00116         decf    ACCaHI, F
008D 09A1       00117         comf    ACCaHI, F
008E 3400       00118         retlw   0
                00119 ;
                00120 ;*****************************************************************
                00121
                00122 ;
008F            00123 D_divF
                00124 ;
                00125      IF   SIGNED
                00126      CALL    S_SIGN
                00127      ENDIF
                00128 ;
008F 2080       00129         call    setup
0090 01A5       00130         clrf    ACCcHI
0091 01A4       00131         clrf    ACCcLO
                00132 ;
                00133 ; use the mulMac macro 16 times
                00134 ;
                00135         divMac
  0000              M         LOCAL   NOCHK
  0000              M         LOCAL   NOGO
                    M ;
0092 1003           M         bcf     STATUS,C
0093 0DA6           M         rlf     ACCdLO, F
0094 0DA7           M         rlf     ACCdHI, F
0095 0DA4           M         rlf     ACCcLO, F
0096 0DA5           M         rlf     ACCcHI, F
0097 0821           M         movf    ACCaHI,W
0098 0225           M         subwf   ACCcHI,W        ;check if a>c
0099 1D03           M         btfss   STATUS,Z
009A 289D           M         goto    NOCHK
009B 0820           M         movf    ACCaLO,W
009C 0224           M         subwf   ACCcLO,W        ;if msb equal then check lsb
009D 1C03           M NOCHK   btfss   STATUS,C        ;carry set if c>a
009E 28A6           M         goto    NOGO
009F 0820           M         movf    ACCaLO,W        ;c-a into c
00A0 02A4           M         subwf   ACCcLO, F
00A1 1C03           M         btfss   STATUS,C
00A2 03A5           M         decf    ACCcHI, F
00A3 0821           M         movf    ACCaHI,W
00A4 02A5           M         subwf   ACCcHI, F
00A5 1403           M         bsf     STATUS,C        ;shift a 1 into b (result)
00A6 0DA2           M NOGO    rlf     ACCbLO, F
00A7 0DA3           M         rlf     ACCbHI, F
                        M ;
```

```
                  00136         divMac
  0000                M         LOCAL   NOCHK
  0000                M         LOCAL   NOGO
                      M ;
00A8 1003             M         bcf     STATUS,C
00A9 0DA6             M         rlf     ACCdLO, F
00AA 0DA7             M         rlf     ACCdHI, F
00AB 0DA4             M         rlf     ACCcLO, F
00AC 0DA5             M         rlf     ACCcHI, F
00AD 0821             M         movf    ACCaHI,W
00AE 0225             M         subwf   ACCcHI,W          ;check if a>c
00AF 1D03             M         btfss   STATUS,Z
00B0 28B3             M         goto    NOCHK
00B1 0820             M         movf    ACCaLO,W
00B2 0224             M         subwf   ACCcLO,W          ;if msb equal then check lsb
00B3 1C03             M NOCHK   btfss   STATUS,C          ;carry set if c>a
00B4 28BC             M         goto    NOGO
00B5 0820             M         movf    ACCaLO,W          ;c-a into c
00B6 02A4             M         subwf   ACCcLO, F
00B7 1C03             M         btfss   STATUS,C
00B8 03A5             M         decf    ACCcHI, F
00B9 0821             M         movf    ACCaHI,W
00BA 02A5             M         subwf   ACCcHI, F
00BB 1403             M         bsf     STATUS,C          ;shift a 1 into b (result)
00BC 0DA2             M NOGO    rlf     ACCbLO, F
00BD 0DA3             M         rlf     ACCbHI, F
                      M ;
                  00137         divMac
  0000                M         LOCAL   NOCHK
  0000                M         LOCAL   NOGO
                      M ;
00BE 1003             M         bcf     STATUS,C
00BF 0DA6             M         rlf     ACCdLO, F
00C0 0DA7             M         rlf     ACCdHI, F
00C1 0DA4             M         rlf     ACCcLO, F
00C2 0DA5             M         rlf     ACCcHI, F
00C3 0821             M         movf    ACCaHI,W
00C4 0225             M         subwf   ACCcHI,W          ;check if a>c
00C5 1D03             M         btfss   STATUS,Z
00C6 28C9             M         goto    NOCHK
00C7 0820             M         movf    ACCaLO,W
00C8 0224             M         subwf   ACCcLO,W          ;if msb equal then check lsb
00C9 1C03             M NOCHK   btfss   STATUS,C          ;carry set if c>a
00CA 28D2             M         goto    NOGO
00CB 0820             M         movf    ACCaLO,W          ;c-a into c
00CC 02A4             M         subwf   ACCcLO, F
00CD 1C03             M         btfss   STATUS,C
00CE 03A5             M         decf    ACCcHI, F
00CF 0821             M         movf    ACCaHI,W
00D0 02A5             M         subwf   ACCcHI, F
00D1 1403             M         bsf     STATUS,C          ;shift a 1 into b (result)
00D2 0DA2             M NOGO    rlf     ACCbLO, F
00D3 0DA3             M         rlf     ACCbHI, F
                      M ;
                  00138         divMac
  0000                M         LOCAL   NOCHK
  0000                M         LOCAL   NOGO
                      M ;
00D4 1003             M         bcf     STATUS,C
00D5 0DA6             M         rlf     ACCdLO, F
00D6 0DA7             M         rlf     ACCdHI, F
00D7 0DA4             M         rlf     ACCcLO, F
00D8 0DA5             M         rlf     ACCcHI, F
00D9 0821             M         movf    ACCaHI,W
00DA 0225             M         subwf   ACCcHI,W          ;check if a>c
00DB 1D03             M         btfss   STATUS,Z
00DC 28DF             M         goto    NOCHK
```

```
00DD 0820               M         movf    ACCaLO,W
00DE 0224               M         subwf   ACCcLO,W          ;if msb equal then check lsb
00DF 1C03               M NOCHK   btfss   STATUS,C          ;carry set if c>a
00E0 28E8               M         goto    NOGO
00E1 0820               M         movf    ACCaLO,W          ;c-a into c
00E2 02A4               M         subwf   ACCcLO, F
00E3 1C03               M         btfss   STATUS,C
00E4 03A5               M         decf    ACCcHI, F
00E5 0821               M         movf    ACCaHI,W
00E6 02A5               M         subwf   ACCcHI, F
00E7 1403               M         bsf     STATUS,C          ;shift a 1 into b (result)
00E8 0DA2               M NOGO    rlf     ACCbLO, F
00E9 0DA3               M         rlf     ACCbHI, F
                        M ;
                    00139         divMac
  0000                  M         LOCAL   NOCHK
  0000                  M         LOCAL   NOGO
                        M ;
00EA 1003               M         bcf     STATUS,C
00EB 0DA6               M         rlf     ACCdLO, F
00EC 0DA7               M         rlf     ACCdHI, F
00ED 0DA4               M         rlf     ACCcLO, F
00EE 0DA5               M         rlf     ACCcHI, F
00EF 0821               M         movf    ACCaHI,W
00F0 0225               M         subwf   ACCcHI,W          ;check if a>c
00F1 1D03               M         btfss   STATUS,Z
00F2 28F5               M         goto    NOCHK
00F3 0820               M         movf    ACCaLO,W
00F4 0224               M         subwf   ACCcLO,W          ;if msb equal then check lsb
00F5 1C03               M NOCHK   btfss   STATUS,C          ;carry set if c>a
00F6 28FE               M         goto    NOGO
00F7 0820               M         movf    ACCaLO,W          ;c-a into c
00F8 02A4               M         subwf   ACCcLO, F
00F9 1C03               M         btfss   STATUS,C
00FA 03A5               M         decf    ACCcHI, F
00FB 0821               M         movf    ACCaHI,W
00FC 02A5               M         subwf   ACCcHI, F
00FD 1403               M         bsf     STATUS,C          ;shift a 1 into b (result)
00FE 0DA2               M NOGO    rlf     ACCbLO, F
00FF 0DA3               M         rlf     ACCbHI, F
                        M ;
                    00140         divMac
  0000                  M         LOCAL   NOCHK
  0000                  M         LOCAL   NOGO
                        M ;
0100 1003               M         bcf     STATUS,C
0101 0DA6               M         rlf     ACCdLO, F
0102 0DA7               M         rlf     ACCdHI, F
0103 0DA4               M         rlf     ACCcLO, F
0104 0DA5               M         rlf     ACCcHI, F
0105 0821               M         movf    ACCaHI,W
0106 0225               M         subwf   ACCcHI,W          ;check if a>c
0107 1D03               M         btfss   STATUS,Z
0108 290B               M         goto    NOCHK
0109 0820               M         movf    ACCaLO,W
010A 0224               M         subwf   ACCcLO,W          ;if msb equal then check lsb
010B 1C03               M NOCHK   btfss   STATUS,C          ;carry set if c>a
010C 2914               M         goto    NOGO
010D 0820               M         movf    ACCaLO,W          ;c-a into c
010E 02A4               M         subwf   ACCcLO, F
010F 1C03               M         btfss   STATUS,C
0110 03A5               M         decf    ACCcHI, F
0111 0821               M         movf    ACCaHI,W
0112 02A5               M         subwf   ACCcHI, F
0113 1403               M         bsf     STATUS,C          ;shift a 1 into b (result)
0114 0DA2               M NOGO    rlf     ACCbLO, F
0115 0DA3               M         rlf     ACCbHI, F
```

```
                      M ;
                    00141         divMac
  0000                M         LOCAL   NOCHK
  0000                M         LOCAL   NOGO
                      M ;
0116 1003             M         bcf     STATUS,C
0117 0DA6             M         rlf     ACCdLO, F
0118 0DA7             M         rlf     ACCdHI, F
0119 0DA4             M         rlf     ACCcLO, F
011A 0DA5             M         rlf     ACCcHI, F
011B 0821             M         movf    ACCaHI,W
011C 0225             M         subwf   ACCcHI,W          ;check if a>c
011D 1D03             M         btfss   STATUS,Z
011E 2921             M         goto    NOCHK
011F 0820             M         movf    ACCaLO,W
0120 0224             M         subwf   ACCcLO,W          ;if msb equal then check lsb
0121 1C03             M NOCHK   btfss   STATUS,C          ;carry set if c>a
0122 292A             M         goto    NOGO
0123 0820             M         movf    ACCaLO,W          ;c-a into c
0124 02A4             M         subwf   ACCcLO, F
0125 1C03             M         btfss   STATUS,C
0126 03A5             M         decf    ACCcHI, F
0127 0821             M         movf    ACCaHI,W
0128 02A5             M         subwf   ACCcHI, F
0129 1403             M         bsf     STATUS,C          ;shift a 1 into b (result)
012A 0DA2             M NOGO    rlf     ACCbLO, F
012B 0DA3             M         rlf     ACCbHI, F
                      M ;
                    00142         divMac
  0000                M         LOCAL   NOCHK
  0000                M         LOCAL   NOGO
                      M ;
012C 1003             M         bcf     STATUS,C
012D 0DA6             M         rlf     ACCdLO, F
012E 0DA7             M         rlf     ACCdHI, F
012F 0DA4             M         rlf     ACCcLO, F
0130 0DA5             M         rlf     ACCcHI, F
0131 0821             M         movf    ACCaHI,W
0132 0225             M         subwf   ACCcHI,W          ;check if a>c
0133 1D03             M         btfss   STATUS,Z
0134 2937             M         goto    NOCHK
0135 0820             M         movf    ACCaLO,W
0136 0224             M         subwf   ACCcLO,W          ;if msb equal then check lsb
0137 1C03             M NOCHK   btfss   STATUS,C          ;carry set if c>a
0138 2940             M         goto    NOGO
0139 0820             M         movf    ACCaLO,W          ;c-a into c
013A 02A4             M         subwf   ACCcLO, F
013B 1C03             M         btfss   STATUS,C
013C 03A5             M         decf    ACCcHI, F
013D 0821             M         movf    ACCaHI,W
013E 02A5             M         subwf   ACCcHI, F
013F 1403             M         bsf     STATUS,C          ;shift a 1 into b (result)
0140 0DA2             M NOGO    rlf     ACCbLO, F
0141 0DA3             M         rlf     ACCbHI, F
                      M ;
                    00143         divMac
  0000                M         LOCAL   NOCHK
  0000                M         LOCAL   NOGO
                      M ;
0142 1003             M         bcf     STATUS,C
0143 0DA6             M         rlf     ACCdLO, F
0144 0DA7             M         rlf     ACCdHI, F
0145 0DA4             M         rlf     ACCcLO, F
0146 0DA5             M         rlf     ACCcHI, F
0147 0821             M         movf    ACCaHI,W
0148 0225             M         subwf   ACCcHI,W          ;check if a>c
0149 1D03             M         btfss   STATUS,Z
```

```
014A 294D               M         goto    NOCHK
014B 0820               M         movf    ACCaLO,W
014C 0224               M         subwf   ACCcLO,W         ;if msb equal then check lsb
014D 1C03               M NOCHK   btfss   STATUS,C         ;carry set if c>a
014E 2956               M         goto    NOGO
014F 0820               M         movf    ACCaLO,W         ;c-a into c
0150 02A4               M         subwf   ACCcLO, F
0151 1C03               M         btfss   STATUS,C
0152 03A5               M         decf    ACCcHI, F
0153 0821               M         movf    ACCaHI,W
0154 02A5               M         subwf   ACCcHI, F
0155 1403               M         bsf     STATUS,C         ;shift a 1 into b (result)
0156 0DA2               M NOGO    rlf     ACCbLO, F
0157 0DA3               M         rlf     ACCbHI, F
                        M ;
                    00144         divMac
  0000                  M         LOCAL   NOCHK
  0000                  M         LOCAL   NOGO
                        M ;
0158 1003               M         bcf     STATUS,C
0159 0DA6               M         rlf     ACCdLO, F
015A 0DA7               M         rlf     ACCdHI, F
015B 0DA4               M         rlf     ACCcLO, F
015C 0DA5               M         rlf     ACCcHI, F
015D 0821               M         movf    ACCaHI,W
015E 0225               M         subwf   ACCcHI,W         ;check if a>c
015F 1D03               M         btfss   STATUS,Z
0160 2963               M         goto    NOCHK
0161 0820               M         movf    ACCaLO,W
0162 0224               M         subwf   ACCcLO,W         ;if msb equal then check lsb
0163 1C03               M NOCHK   btfss   STATUS,C         ;carry set if c>a
0164 296C               M         goto    NOGO
0165 0820               M         movf    ACCaLO,W         ;c-a into c
0166 02A4               M         subwf   ACCcLO, F
0167 1C03               M         btfss   STATUS,C
0168 03A5               M         decf    ACCcHI, F
0169 0821               M         movf    ACCaHI,W
016A 02A5               M         subwf   ACCcHI, F
016B 1403               M         bsf     STATUS,C         ;shift a 1 into b (result)
016C 0DA2               M NOGO    rlf     ACCbLO, F
016D 0DA3               M         rlf     ACCbHI, F
                        M ;
                    00145         divMac
  0000                  M         LOCAL   NOCHK
  0000                  M         LOCAL   NOGO
                        M ;
016E 1003               M         bcf     STATUS,C
016F 0DA6               M         rlf     ACCdLO, F
0170 0DA7               M         rlf     ACCdHI, F
0171 0DA4               M         rlf     ACCcLO, F
0172 0DA5               M         rlf     ACCcHI, F
0173 0821               M         movf    ACCaHI,W
0174 0225               M         subwf   ACCcHI,W         ;check if a>c
0175 1D03               M         btfss   STATUS,Z
0176 2979               M         goto    NOCHK
0177 0820               M         movf    ACCaLO,W
0178 0224               M         subwf   ACCcLO,W         ;if msb equal then check lsb
0179 1C03               M NOCHK   btfss   STATUS,C         ;carry set if c>a
017A 2982               M         goto    NOGO
017B 0820               M         movf    ACCaLO,W         ;c-a into c
017C 02A4               M         subwf   ACCcLO, F
017D 1C03               M         btfss   STATUS,C
017E 03A5               M         decf    ACCcHI, F
017F 0821               M         movf    ACCaHI,W
0180 02A5               M         subwf   ACCcHI, F
0181 1403               M         bsf     STATUS,C         ;shift a 1 into b (result)
0182 0DA2               M NOGO    rlf     ACCbLO, F
```

```
0183 0DA3               M         rlf     ACCbHI, F
                        M ;
                    00146         divMac
  0000                  M         LOCAL   NOCHK
  0000                  M         LOCAL   NOGO
                        M ;
0184 1003               M         bcf     STATUS,C
0185 0DA6               M         rlf     ACCdLO, F
0186 0DA7               M         rlf     ACCdHI, F
0187 0DA4               M         rlf     ACCcLO, F
0188 0DA5               M         rlf     ACCcHI, F
0189 0821               M         movf    ACCaHI,W
018A 0225               M         subwf   ACCcHI,W         ;check if a>c
018B 1D03               M         btfss   STATUS,Z
018C 298F               M         goto    NOCHK
018D 0820               M         movf    ACCaLO,W
018E 0224               M         subwf   ACCcLO,W         ;if msb equal then check lsb
018F 1C03               M NOCHK   btfss   STATUS,C         ;carry set if c>a
0190 2998               M         goto    NOGO
0191 0820               M         movf    ACCaLO,W         ;c-a into c
0192 02A4               M         subwf   ACCcLO, F
0193 1C03               M         btfss   STATUS,C
0194 03A5               M         decf    ACCcHI, F
0195 0821               M         movf    ACCaHI,W
0196 02A5               M         subwf   ACCcHI, F
0197 1403               M         bsf     STATUS,C         ;shift a 1 into b (result)
0198 0DA2               M NOGO    rlf     ACCbLO, F
0199 0DA3               M         rlf     ACCbHI, F
                        M ;
                    00147         divMac
  0000                  M         LOCAL   NOCHK
  0000                  M         LOCAL   NOGO
                        M ;
019A 1003               M         bcf     STATUS,C
019B 0DA6               M         rlf
ACCdLO, F
019C 0DA7               M         rlf     ACCdHI, F
019D 0DA4               M         rlf     ACCcLO, F
019E 0DA5               M         rlf     ACCcHI, F
019F 0821               M         movf    ACCaHI,W
01A0 0225               M         subwf   ACCHI,W          ;check if a>c
01A1 1D03               M         btfss   STAUS,Z
01A2 29A5               M         goto    NOCHK
01A3 0820               M         movf    ACCaLO,W
01A4 0224               M         subwf   ACCcLO,W         ;if msb equal then check lsb
01A5 1C03               M NOCHK   btfss   STAUS,C          ;carry set if c>a
01A6 29AE               M         goto    NOGO
01A7 0820               M         movf    ACCaLO,W         ;c-a into c
01A8 02A4               M         subwf   ACCcLO, F
01A9 1C03               M         btfss   STAUS,C
01AA 03A5               M         decf    ACCHI, F
01AB 0821               M         movf    ACCaHI,W
01AC 02A5               M         subwf   ACCHI, F
01AD 1403               M         bsf     STAUS,C         ;shift a 1 into b (result)
01AE 0DA2               M NOGO    rlf     ACCbLO, F
01AF 0DA3               M         rlf     ACCbHI, F
                        M ;
                    00148         divMac
  0000                  M         LOCAL   NOCHK
  0000                  M         LOCAL   NOGO
                        M ;
01B0 1003               M         bcf     STATUS,C
01B1 0DA6               M         rlf     ACCdLO, F
01B2 0DA7               M         rlf     ACCHI, F
01B3 0DA4               M         rlf     ACCcLO, F
01B4 0DA5               M         rlf     ACCcHI, F
01B5 0821               M         movf    ACCaHI,W
```

```
01B6 0225               M         subwf   ACCHI,W          ;check if a>c
01B7 1D03               M         btfss   STATUS,Z
01B8 29BB               M         goto    NOCHK
01B9 0820               M         movf    ACCaLO,W
01BA 0224               M         subwf   ACCcLO,W         ;if msb equal then check lsb
01BB 1C03               M NOCHK   btfss   STATUS,C         ;carry set if c>a
01BC 29C4               M         goto    NOGO
01BD 0820               M         movf    ACCaLO,W         ;c-a into c
01BE 02A4               M         subwf   ACCcLO, F
01BF 1C03               M         btfss   STATUS,C
01C0 03A5               M         decf    ACCcHI, F
01C1 0821               M         movf    ACCaHI,W
01C2 02A5               M         subwf   ACCcHI, F
01C3 1403               M         bsf     STATUS,C         ;shift a 1 into b (result)
01C4 0DA2               M NOGO    rlf     ACCbLO, F
01C5 0DA3               M         rlf     ACCbHI, F
                        M ;
                    00149         divMac
  0000                  M         LOCAL   NOCHK
  0000                  M         LOCAL   NOGO
                        M ;
01C6 1003               M         bcf     STATUS,C
01C7 0DA6               M         rlf     ACCdLO, F
01C8 0DA7               M         rlf     ACCdHI, F
01C9 0DA4               M         rlf     ACCcLO, F
01CA 0DA5               M         rlf     ACCcHI, F
01CB 0821               M         movf    ACCaHI,W
01CC 0225               M         subwf   ACCcHI,W         ;check if a>c
01CD 1D03               M         btfss   STATUS,Z
01CE 29D1               M         goto    NOCHK
01CF 0820               M         movf    ACCaLO,W
01D0 0224               M         subwf   ACCcLO,W         ;if msb equal then check lsb
01D1 1C03               M NOCHK   btfss   STATUS,C         ;carry set if c>a
01D2 29DA               M         goto    NOGO
01D3 0820               M         movf    ACCaLO,W         ;c-a into c
01D4 02A4               M         subwf   ACCcLO, F
01D5 1C03               M         btfss   STATUS,C
01D6 03A5               M         decf    ACCcHI, F
01D7 0821               M         movf    ACCaHI,W
01D8 02A5               M         subwf   ACCcHI, F
01D9 1403               M         bsf     STATUS,C         ;shift a 1 into b (result)
01DA 0DA2               M NOGO    rlf     ACCbLO, F
01DB 0DA3               M         rlf     ACCbHI, F
                        M ;
                    00150         divMac
  0000                  M         LOCAL   NOCHK
  0000                  M         LOCAL   NOGO
                        M ;
01DC 1003               M         bcf     STATUS,C
01DD 0DA6               M         rlf     ACCdLO, F
01DE 0DA7               M         rlf     ACCdHI, F
01DF 0DA4               M         rlf     ACCcLO, F
01E0 0DA5               M         rlf     ACCcHI, F
01E1 0821               M         movf    ACCaHI,W
01E2 0225               M         subwf   ACCcHI,W         ;check if a>c
01E3 1D03               M         btfss   STATUS,Z
01E4 29E7               M         goto    NOCHK
01E5 0820               M         movf    ACCaLO,W
01E6 0224               M         subwf   ACCcLO,W         ;if msb equal then check lsb
01E7 1C03               M NOCHK   btfss   STATUS,C         ;carry set if c>a
01E8 29F0               M         goto    NOGO
01E9 0820               M         movf    ACCaLO,W         ;c-a into c
01EA 02A4               M         subwf   ACCcLO, F
01EB 1C03               M         btfss   STATUS,C
01EC 03A5               M         decf    ACCcHI, F
01ED 0821               M         movf    ACCaHI,W
01EE 02A5               M         subwf   ACCcHI, F
```

```
01EF 1403              M         bsf     STATUS,C         ;shift a 1 into b (result)
01F0 0DA2              M NOGO    rlf     ACCbLO, F
01F1 0DA3              M         rlf     ACCbHI, F
                       M ;
                    00151 ;
                    00152     IF    SIGNED
                    00153         btfss   sign,MSB         ; check sign if negative
                    00154         retlw   0
                    00155         goto    neg_B            ; negate ACCa ( -ACCa -> ACCa )
                    00156     ELSE
01F2 3400           00157         retlw   0
                    00158     ENDIF
                    00159 ;
                    00160 ;*****************************************************************
                    00161 ;  Assemble this section only if Signed Arithmetic Needed
                    00162 ;
                    00163      IF    SIGNED
                    00164 ;
                    00165 S_SIGN  movf    ACCaHI,W
                    00166         xorwf   ACCbHI,W
                    00167         movwf   sign
                    00168         btfss   ACCbHI,MSB       ; if MSB set go & negate ACCb
                    00169         goto    chek_A
                    00170 ;
                    00171         comf    ACCbLO, F        ; negate ACCb
                    00172         incf    ACCbLO, F
                    00173         btfsc   STATUS,Z
                    00174         decf    ACCbHI, F
                    00175         comf    ACCbHI, F
                    00176 ;
                    00177 chek_A  btfss   ACCaHI,MSB       ; if MSB set go & negate ACCa
                    00178         retlw   0
                    00179         goto    neg_A
                    00180 ;
                    00181      ENDIF
                    00182 ;
                    00183 ;
                    00184 ;
                    00185     ifdef XDCR
                    00186 ;
                    00187 ; This file has been included, do not have test program.
                    00188 ;
                    00189     else
                    00190 ;
                    00191 ;*****************************************************************
                    00192 ;                        Test Program
                    00193 ;*****************************************************************
                    00194 ;    Load constant values to ACCa & ACCb for testing
                    00195 ;
                    00196 main   movlw   1
                    00197        movwf   ACCaHI
                    00198        movlw   0FF              ; loads ACCa = 01FF
                    00199        movwf   ACCaLO
                    00200 ;
                    00201        movlw   07F
                    00202        movwf   ACCbHI
                    00203        movlw   0FF              ; loads ACCb = 7FFF
                    00204        movwf   ACCbLO
                    00205 ;
                    00206        call    D_divF           ; remainder in ACCc. Here ACCb =0040 &
                    00207                                 ; ACCc=003F
                    00208 self    goto    self
                    00209 ;
                    00210 ;       org     PIC54
                    00211 ;       LIST    p=16c54
                    00212 ;       goto    main
                 00213 ;*****************************************************************
```

```
                00214 ;
                00215
                00216     endif
                00217 ;
                00218 ;     END ; END directive MUST be commented out if this file is included.
                00129       LIST
                00130
                00158       LIST
                00159
                00160       end

MPASM 01.40 Released             XDCR.ASM   1-22-1997  10:55:26         PAGE 15
MEMORY USAGE MAP ('X' = Used,  '-' = Unused)

0000 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXX------
0080 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
00C0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0100 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0140 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0180 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
01C0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0200 : XXXXXX---------- ---------------- ---------------- ----------------

All other memory blocks unused.

Program Memory Words Used:   448
Program Memory Words Free:  3648


Errors   :     0
Warnings :     0 reported,     0 suppressed
Messages :     7 reported,     0 suppressed
```

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