INTRODUCTION

One very common and relatively quick method for finding the square root of a number is the Newton-Raphson method. Although this method is quick in terms of mathematics, it also requires extensive use of division to produce results, usually iterating many times. In the PIC18CXX2 microcontroller family, though not difficult, division does require several basic operations. However, with the help of the single cycle hardware multiplier and the use of a technique different from the Newton-Raphson method, division is avoided. The following algorithm demonstrates how the single cycle multiplier is useful in calculating a square root and at the same time, save processor time.

THE ALGORITHM

Using the binary nature of the microcontroller, the square root of a fixed precision number can be found quickly. Each digit in a binary number represents a power of two. By successively rotating through each bit, or power of two and testing the result against the desired value, i.e. squaring the guess and checking if it is greater than the original argument, the approximate root gets closer and closer to the actual value. In conjunction with this, the value is achieved quickly. This is because each bit is tested rather than every possible 8-bit combination. The general technique is outlined in Figure 1. For a 16-bit integer, only nine program loops are required to completely test and produce a result. Example 1 is a demonstration of this procedure:

FIGURE 1:  SQUARE ROOT FLOW CHART
EXAMPLE 1: 8-BIT EXAMPLE

\[ A = \sqrt{0xCF48} \]

or

\[ A^2 = 0xCF48 \]

<table>
<thead>
<tr>
<th>Step</th>
<th>A</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1000 0000 (0x80)</td>
<td>this squared is less than 0xCF48, start next cycle with a new bit</td>
</tr>
<tr>
<td></td>
<td>new bit</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1100 0000 (0xC0)</td>
<td>this squared is less than 0xCF48, start next cycle with a new bit</td>
</tr>
<tr>
<td></td>
<td>new bit</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1110 0000 (0xE0)</td>
<td>this squared is less than 0xCF48, start next cycle with a new bit</td>
</tr>
<tr>
<td></td>
<td>new bit</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1111 0000 (0xF0)</td>
<td>this is greater than 0xCF48, shift bit right</td>
</tr>
<tr>
<td></td>
<td>new bit</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1110 1000 (0xE8)</td>
<td>this is greater than 0xCF48, shift bit right</td>
</tr>
<tr>
<td></td>
<td>shifted bit</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1110 0100 (0xE4)</td>
<td>this squared is less than 0xCF48, start next cycle with a new bit</td>
</tr>
<tr>
<td></td>
<td>new bit</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1110 0110 (0xE6)</td>
<td>this squared is less than 0xCF48, start next cycle with a new bit</td>
</tr>
<tr>
<td></td>
<td>new bit</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1110 0111 (0xE7)</td>
<td>this is greater than 0xCF48, shift right</td>
</tr>
<tr>
<td></td>
<td>bit shifted out</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1110 0110 (0xE6)</td>
<td>right-most bit is thrown away for the integer approximation and the process is finished; otherwise, this could keep going for more accurate fractional approximation</td>
</tr>
</tbody>
</table>
ANALYSIS

Following the flow of this algorithm, there are only nine loops for an 8-bit number. And summing all the mathematics involved, there is only one multiplication and one conditional test for each step; a conditional test is most likely a subtraction with some bit testing. Plus, there are some logical operations to perform the bit manipulations, again one per loop. This means there are three basic operations per loop, totaling to 27 operations for the complete routine. Of course, the actual number of operations goes up some when applied to a specific microcontroller, but subjectively speaking, this is still not bad when compared to the large number of steps required to perform any number of divisions as required by the Newton-Raphson method.

The program in Appendix A is a functioning demonstration of the algorithm described above for 16-bit and 32-bit numbers. Table 1 gives the simulation results for these code examples. Also, the code is written specifically for the PIC18CXX2 series microcontrollers, but it can be modified to run on PIC17C microcontrollers that have a hardware multiplier.

TABLE 1: PERFORMANCE

<table>
<thead>
<tr>
<th></th>
<th>Max Cycles</th>
<th>40MHz</th>
<th>10MHz</th>
<th>4MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-bit</td>
<td>149</td>
<td>14.9us</td>
<td>59.6us</td>
<td>149us</td>
</tr>
<tr>
<td>Square Root</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32-bit</td>
<td>1002</td>
<td>100.2us</td>
<td>400.8us</td>
<td>1002us</td>
</tr>
<tr>
<td>Square Root</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CONCLUSION

This algorithm is just one possible way to compute the square root of a number. Its advantage is in the use of multiplication, a function easily performed on the PIC18CXX2 microcontroller, rather than division, an operation requiring a number of basic operations. In addition, the method and coding are extremely simple, requiring very little program and data memory. The end result is a fast and compact method to calculate the integer square root of a number.

MEMORY REQUIREMENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Type</th>
<th>Address</th>
<th>Location</th>
<th>Size(Bytes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_Vctr</td>
<td>code</td>
<td>0x000000</td>
<td>program</td>
<td>0x000004</td>
</tr>
<tr>
<td>.cinit</td>
<td>romdata</td>
<td>0x00002a</td>
<td>program</td>
<td>0x000002</td>
</tr>
<tr>
<td>S_ROOT</td>
<td>code</td>
<td>0x00002c</td>
<td>program</td>
<td>0x000014</td>
</tr>
<tr>
<td>SRoot</td>
<td>code</td>
<td>0x000120</td>
<td>program</td>
<td>0x000022</td>
</tr>
<tr>
<td>SimpMth</td>
<td>udata</td>
<td>0x000000</td>
<td>data</td>
<td>0x000014</td>
</tr>
</tbody>
</table>

Program Memory Usage

<table>
<thead>
<tr>
<th>Start</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x000000</td>
<td>0x000003</td>
</tr>
<tr>
<td>0x00002a</td>
<td>0x000141</td>
</tr>
</tbody>
</table>

284 out of 32766 program addresses used, program memory utilization is 0%
APPENDIX A: MAIN.ASM

; *******************************************************************
; Title "Square Root Calling Routine Demo"
; *******************************************************************

; *******************************************************************
; *** Author: Ross Fosler ***
; *** Applications Engineer ***
; *** Microchip Technology Inc. ***
; ***
; *** Program: main.asm ***
; *** This routine calls the square root function ***
; *** to find the root of two arbitrary numbers. ***
; ***
; *** Last Rev: August 10, 2000 ***
; *** Ver 1.00 ***
; ***
; *******************************************************************

listp=18C252
#include P18C252.INC

EXTERN ARGA0, ARGA1, ARGA2, ARGA3
EXTERN RES0, RES1
EXTERN Sqrt

W equ 0 ; Standard constants
F equ 1
a equ 0

R_Vctr CODE 0x0000
    goto Main
; *******************************************************************

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; Calling Routine
SRoot    CODE

Main
movlw 0xCF
movwf ARGA1, a
movlw 0x48
movwf ARGA0, a

call Sqrt   ; Sqrt(0xCF48)
    ; RES0 should now contain 0xE6

movlw 0xE0
movwf ARGA3, a
movlw 0x12
movwf ARGA2, a
movlw 0xA1
movwf ARGA1, a
movlw 0x40
movwf ARGA0, a

call Sqrt   ; Sqrt(0xE012A140)
    ; RES1:RES0 should now contain 0xEF81

bra Main

; **********************************************************

END
APPENDIX B: SQRT.ASM

;********************************************************************************
; Title:"16/32 bit Integer Square Root"
;********************************************************************************

;********************************************************************************
; ***
; *** Author: Ross Fosler
; *** Applications Engineer
; *** Microchip Technology Inc.
; ***
; Program:sqrt.asm
;*** This module contains code to perform fast integer
;*** square root functions on either 16 or 32 bit
;*** values.
;***
;*** Last Rev:August 10, 2000
;*** Ver 1.00
;***
;********************************************************************************

#include P18C252.INC

;********************************************************************************
; MSB equ 7 ; general literal constants
LSB equ 0
W equ 0
F equ 1
a equ 0

;********************************************************************************

SimpMth UDATA_ACS

ARGA0 res 1 ; various argument registers
ARGA1 res 1
ARGA2 res 1
ARGA3 res 1

GLOBAL ARGA0, ARGA1, ARGA2, ARGA3

ARG1H res 1
ARG1L res 1
ARG2H res 1
ARG2L res 1

GLOBAL ARG1H, ARG1L, ARG2H, ARG2L

SARG1 res 1 ; signed arguments
SARG2 res 1

GLOBAL SARG1, SARG2

RES1 res 1 ; result registers
RES0 res 1

GLOBAL RES0, RES1

SQRES0 res 1
SQRES1 res 1
SQRES2 res 1
GLOBAL SQRES0, SQRES1, SQRES2, SQRES3

BITLOC0 res 1 ; temporary registers
BITLOC1 res 1
TEMP0 res 1
TEMP1 res 1

; The function of this square root routine is to determine the root
to the nearest integer. At the same time the root is found at the
best possible speed; therefore, the root is found a little differently
for the two basic sizes of numbers, 16-bit and 32-bit. The following
differentiates the two and jumps to the appropriate function.

Sqrt(ARGA3:ARGA2:ARGA1:ARGA0) = RES1:RES0

S_ROOT CODE

Sqrt tstfsz ARGA3, a ; determine if the number is 16-bit
bra Sqrt32 ; or 32-bit and call the best function
tstfsz ARGA2, a
bra Sqrt32
clf RES1, a
bra Sqrt16

GLOBAL Sqrt

; ******************** Square Root ****************************
Sqrt16 clrf TEMP0, a ; clear the temp solution
movlw 0x80 ; setup the first bit
movwf BITLOC0, a
movwf RES0, a
Square8 movf RES0, W, a ; square the guess
mulwf RES0, a
movf PRODL, W, a ; ARGA - PROD test
subwf ARG0, W, a
movf PRODH, W, a
subwfb ARG1, W, a
btfsc STATUS, C, a
bra NextBit ; if positive then next bit
movff TEMP0, RES0 ; if negative then rotate right
rrncf BITLOC0, F, a
movf BITLOC0, W, a ; back into RES0
iorwf RES0, F, a
btfsc BITLOC0, 7, a
bra Done ; if last value was tested then get
bra NextBit ; out
bra Square8 ; else go back for another test

NextBit movff RES0, TEMP0 ; copy the last good approximation
rrncf BITLOC0, F, a ; rotate the bit location register
movf BITLOC0, W, a
iorwf RES0, F, a
GLOBAL Sqrt16

;*******************************************************************
;********************* Square Root *******************************
; Sqrt16(ARGA3:ARGA2:ARGA1:ARGA0) = RES1:RES0

Sqrt16 clrff TEMP0, a  ; clear the temp solution
clrff TEMP1, a
clrff BITLOC0, a  ; setup the first bit
clrff RES0, a
movlw 0x80
movwf BITLOC1, a  ; BitLoc = 0x8000
movwf RES1, a  ; RES = 0x8000

Squar16 movff RES0, ARG1L  ; square the guess
movff RES1, ARG1H
call Sq16

movf SQRES0, W, a  ; ARGA - PROD test
subwf ARG0, W, a
movf SQRES1, W, a
subwf ARG1, W, a
movf SQRES2, W, a
subwf ARG2, W, a
movf SQRES3, W, a
subwf ARG3, W, a

btfsc STATUS, C, a  ; if positive then next bit
bra NxtBt16
; if negative then rotate right
addlw 0x00
movff TEMP0, RES0  ; move last good value back into RES0
movff TEMP1, RES1
rrcf BITLOC1, F, a  ; then rotate the bit and put it
rrcf BITLOC0, F, a
movf BITLOC1, W, a  ; back into RES1:RES0
iorwf RES1, F, a
movf BITLOC0, W, a
iorwf RES0, F, a

btfsc STATUS, C, a  ; if last value was tested then get
bra NxtBt16
; else go back for another test

NxtBt16 addlw 0x00  ; clear carry
movff RES0, TEMP0  ; copy the last good approximation
movff RES1, TEMP1
rrcf BITLOC1, F, a  ; rotate the bit location register
rrcf BITLOC0, F, a
movf BITLOC1, W, a  ; and put back into RES1:RES0
iorwf RES1, F, a
movf BITLOC0, W, a
iorwf RES0, F, a
btfsc STATUS, C, a ; if last value was tested then get
bra Done32 ; out
bra Squar16

Done32 movff TEMP0,RES0 ; put the final result in RES1:RES0
movff TEMP1,RES1
return

GLOBAL Sqrt32

; *******************************************************************
; *********** 16 X 16 Unsigned Square ****************************
; SQRES3:SQRES0 = ARG1H:ARG1L ^ 2

Sq16 movf ARG1L, W, a
mulwf ARG1L ; ARG1L * ARG2L ->
; PRODH:PRODL
movff PRODH, SQRES1 ;
movff PRODL, SQRES0 ;

movf ARG1H, W, a
mulwf ARG1H ; ARG1H * ARG2H ->
; PRODH:PRODL
movff PRODH, SQRES3 ;
movff PRODL, SQRES2 ;

movf ARG1L, W, a
mulwf ARG1H ; ARG1L * ARG2H ->
; PRODH:PRODL
movf PRODL, W, a ; Add cross
addwfc SQRES1, F, a ; products
movf PRODH, W, a ; Add cross
addwfc SQRES2, F, a ; products
clr WREG, a ;
addwfc SQRES3, F, a ;

movf ARG1H, W, a ;
mulwf ARG1L ; ARG1H * ARG2L ->
; PRODH:PRODL
movf PRODL, W, a ; Add cross
movf PRODH, W, a ; Add cross
addwfc SQRES2, F, a ; products
clr WREG, W ;
addwfc SQRES3, F, a ;

return

GLOBAL Sq16

; *******************************************************************
end
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