AN715

Measure Tilt Using PIC16F84A & ADXL202

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INTRODUCTION

Recent advances in accelerometer sensor technology, especially with silicon micromachined types, have driven the cost of these devices down significantly. As of today, you could obtain an accelerometer for less than $5 per axis. Measurement of acceleration or one of the derivative properties such as vibration, shock, or tilt has become very commonplace in a wide range of products. At first you might think of seismic activity or machinery performance monitoring, but would automotive airbags, sports training products, or computer peripherals ever cross your mind? The technology behind acceleration sensors has advanced to provide a very cost effective and user friendly solution for almost any application.

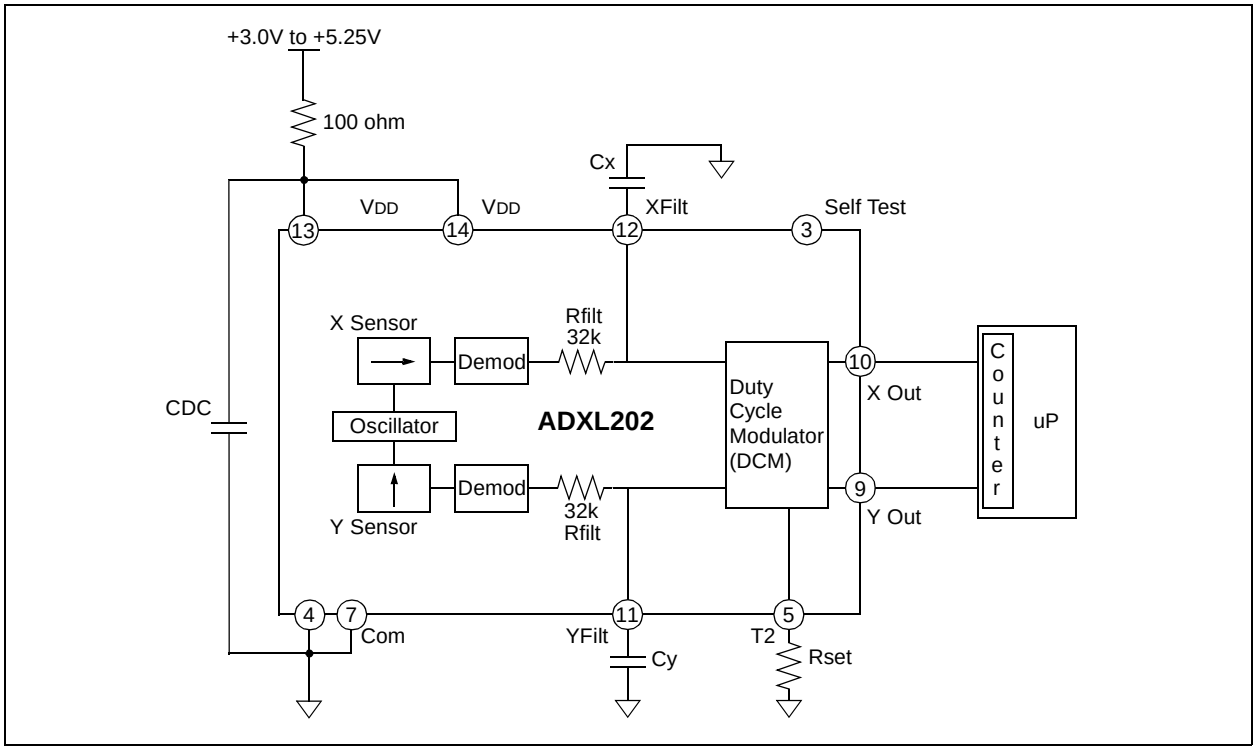
There are many types of sensors that measure acceleration, vibration, shock, or tilt. These sensors include piezo-film, electromechanical servo, piezoelectric, liquid tilt, bulk micromachined piezo resistive and capacitive sensors, as well as surface micromachined capacitive. Each of these sensors has distinct characteristics in the output signal of the sensor, cost to develop, and type of operating environment. Measurement of acceleration can also provide velocity by single integration and position by double integration. Vibration and shock can be used for machine health determination as well as motion and shock detection for car alarms. Static acceleration due to gravity can be used to determine tilt and inclination provided that the sensor is responsive to static acceleration.

This application note will focus on the surface micromachined capacitive ADXL accelerometers from Analog Devices, in particular the ADXL202. The example application will use the ADXL202 accelerometer with the PIC16F84A in a tilt meter. The PIC16F84A is a good match with the ADXL202 because all acceleration measurements are digital only. Secondly, the Data EEPROM can be used to store the calibration constants and restore on reset. The external interface can also be changed easily to accommodate a LCD display (as shown in this application note) or a serial interface to the outside world.

MEMs SENSOR: THEORY OF OPERATION

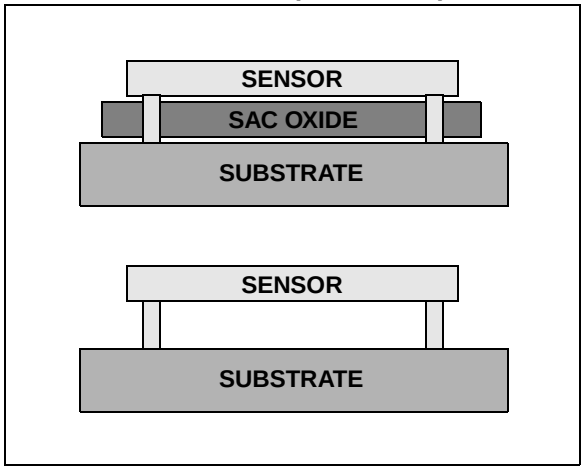
In recent years the silicon micromachined sensor has made tremendous advancements in terms of cost and level of on-chip integration for acceleration and/or vibration measurements. By implementing additional BiMOS circuitry on-chip, these products not only provide sensor but also signal conditioning in a single package that requires a few external components to complete the circuit. Some manufacturers have taken this approach one step further by converting the analog output of the sensor to a digital format such as duty cycle. This method not only lifts the burden of designing fairly complex analog circuitry for the sensor but also reduces cost and board area. Because of these advances, the micromachined accelerometer is finding its way into such products as joysticks and airbags that were previously impossible due to price or size limitations of the sensor. Figure 1 shows the block diagram of the ADXL202.

FIGURE 1: ADXL202 BLOCK DIAGRAM



A surface micromachined device is composed of springs, masses and motion sensing components. These sensors use standard integrated circuit processing techniques in standard wafer fabs, i.e., no additional cost to the user for special processes or fabs. As shown in Figure 2, normal IC processes take place by applying layers of oxide and polysilicon. Then using IC photolithography and selective etching the sensor is created as a 3-dimensional structure suspended above the substrate free to move in all directions. The surrounding area becomes the signal conditioning and output circuitry.

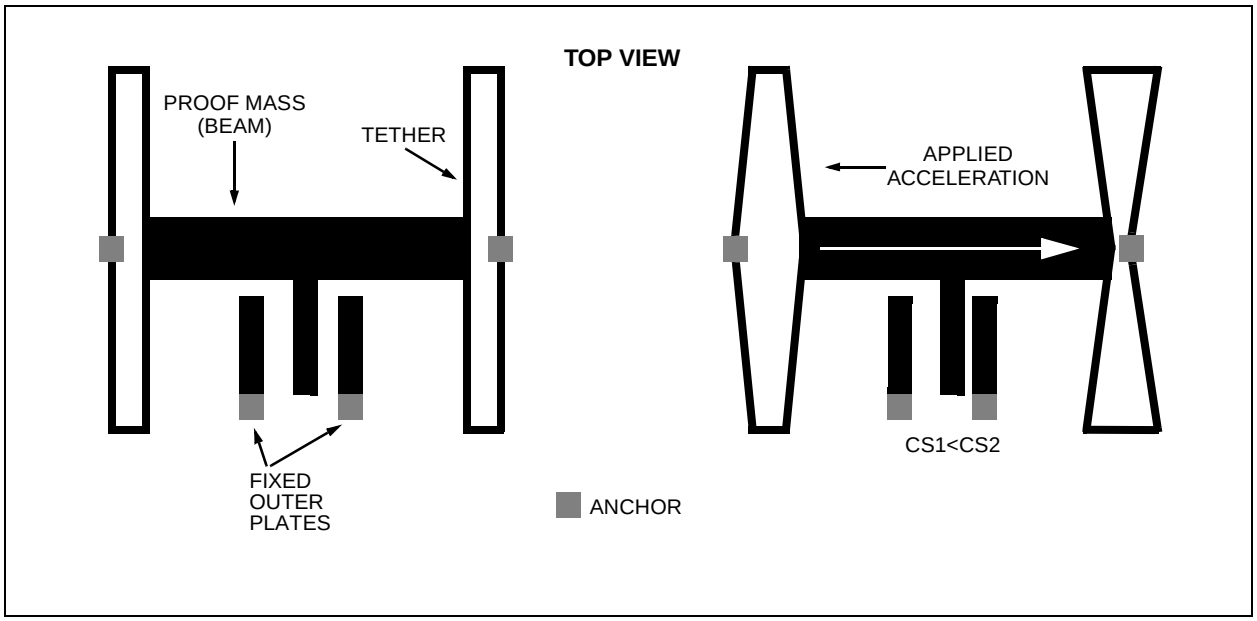
FIGURE 2: SILICON STRUCTURE OF ADXL202 (SIDE VIEW)



The core of the sensor is a surface micromachined polysilicon structure or mass that is suspended on top of the silicon wafer for each axis. The polysilicon "springs" hold the mass and provides resistance to movement due to acceleration forces. Both the mass and the substrate have plates that form a differential capacitor where the fixed plates on the substrate are driven 180° out of phase. Figure 3 shows an exaggerated diagram of the sensor. Any movement of the mass unbalances the differential capacitor resulting in a square wave output with the amplitude proportional to the acceleration. Each axis has a demodulator that rectifies the signal and determines the direction of the acceleration. This output is fed to a duty cycle modulator (DCM) that incorporates external capacitors to set the bandwidth of each axis. The analog signal is filtered and converted to a duty cycle output by the DCM. An external resistor sets the period of the duty cycle output. A 0g acceleration produces a 50% duty cycle output. A low-cost, all digital, microcontroller can be used to measure acceleration by timing both the duty cycle and the period of each axis. Refer to Figure 1 for interaction and connections between the various circuits inside the device as described above.

Some of the advantages with micromachined sensors are that they are low cost and most have on-chip signal conditioning.

FIGURE 3: SENSOR MECHANICAL OPERATION



CONFIGURING THE ADXL202

The end application for our ADXL202 is a simple tilt meter that shows X-axis and Y-axis tilt (or pitch and roll for you aeronautical buffs). The design procedure is somewhat iterative since the bandwidth, period, and microcontroller counter resolution play important roles in the minimum resolution of the measurement. Analog Devices has simplified the design procedure by providing an Excel spreadsheet entitled "The XL202 Interactive Designer" that can be downloaded off their website at www.analog.com and is shown in Appendix A. The specifications for our system are +5VDC operation, +/-1.0 degree tilt resolution, 25 samples per channel per second, and the microcontroller should operate at 4MHz or less.

Through the use of an iterative process, the designer can determine the external component values and the noise and resolution of the acceleration measurement without having to prototype a single circuit.

In Step 1of the spreadsheet shown in Appendix A, the designer will enter the supply voltage which should be between 3.0V and 5.25V. We will enter 5.0V. Analog bandwidth is entered in Step 2, which calculates the values for the external capacitors. The bandwidth directly determines the noise floor and resolution of the accelerometer and therefore may have to be adjusted to provide the desired results based on calculations later in the spreadsheet. Enter 10Hz and the resulting capacitance is 0.50µF. Since 0.50µF is not a standard, we can modify the bandwidth to get a standard value. Using 10.5Hz yields a capacitor of 0.47µF.

In Step 3, the spreadsheet calculates the RMS and peak-to-peak (P-P) noise of the acceleration measurements. The designer must estimate the amount of time that the actual signal will be above the P-P noise using a multiplier. At this step enter 4, which in turn reveals that the peak-to-peak noise will be 0.46 degrees of tilt. Now the designer must evaluate the P-P noise estimation because this noise determines the smallest acceleration resolution that the accelerometer can have. If this noise estimation is not acceptable, then the bandwidth must be lowered to reduce the P-P noise. This example is well within the 1.0 degree specification and so we will continue.

The next few steps set the period of the duty cycle output and the measurement resolution due to the counter on the microcontroller. Both the sample rate per channel and the percentage of time the ADXL202 will be powered are entered in Step 4. The designer also enters the time required to calculate the acceleration for two channels and the spreadsheet then calculates the period of the duty cycle output and the corresponding external resistor. We will use 25 samples per second per channel and the part will be powered up 100% of the time. Analog Devices has already calculated the time to acquire two channels and perform the calculations as 20ms. Of this time, it takes 3ms for calculations based on a previous application note, leaving 17ms for signal acquisition. This relates to 17,000 instruction cycles on the PICmicro® running at 4MHz.

In Step 5, the counter rate of the microcontroller is used to calculate the measurement resolution due to the counter in g's and degrees of tilt. The spreadsheet also determines the size of the counter on the microcontroller to prevent an overflow. Per our specifications, the microcontroller is clocked at 4MHz resulting in a 1MHz timer frequency (Timer0). With this timer rate, the resolution of the digital section of the ADXL202 is 0.06 degrees of tilt. The counter required to acquire the digital output must be 15-bits. We can easily implement a 15-bit counter using the Timer0 as the low byte of the count and for each Timer0 overflow increment an upper byte counter. The designer must again determine if this

resolution is acceptable. To increase the resolution, either increase the counter rate (Step 5) or decrease the number of samples per second (Step 4).

Step 6 checks for aliasing errors due to the sample rate. Nyquist requirements specify that the sample rate needs to be faster than the bandwidth by a factor of 2. Analog Devices recommends that at least a factor of 10 is used to minimize dynamic errors from the PWM sampling technique. For our case the, the ratio is 11.2 which according to Nyquist and Analog Devices is more than sufficient. If the spreadsheet calculates that the ratio is low, the designer must increase the sample rate in Step 4 or decrease the bandwidth in Step 2.

The results are in! The spreadsheet calculates the minimum resolution of the acceleration measurement due to RMS P-P noise and resolution of the counter in Step 7. It also provides a minimum resolution of a tilt measurement. Our calculated minimum resolution is 0.5 degrees of tilt which is acceptable according to the specification. If this resolution was not acceptable, then the bandwidth (Step 2), acquisition rate (Step 4), or the counter rate (Step 5) would have to be adjusted to reduce noise.

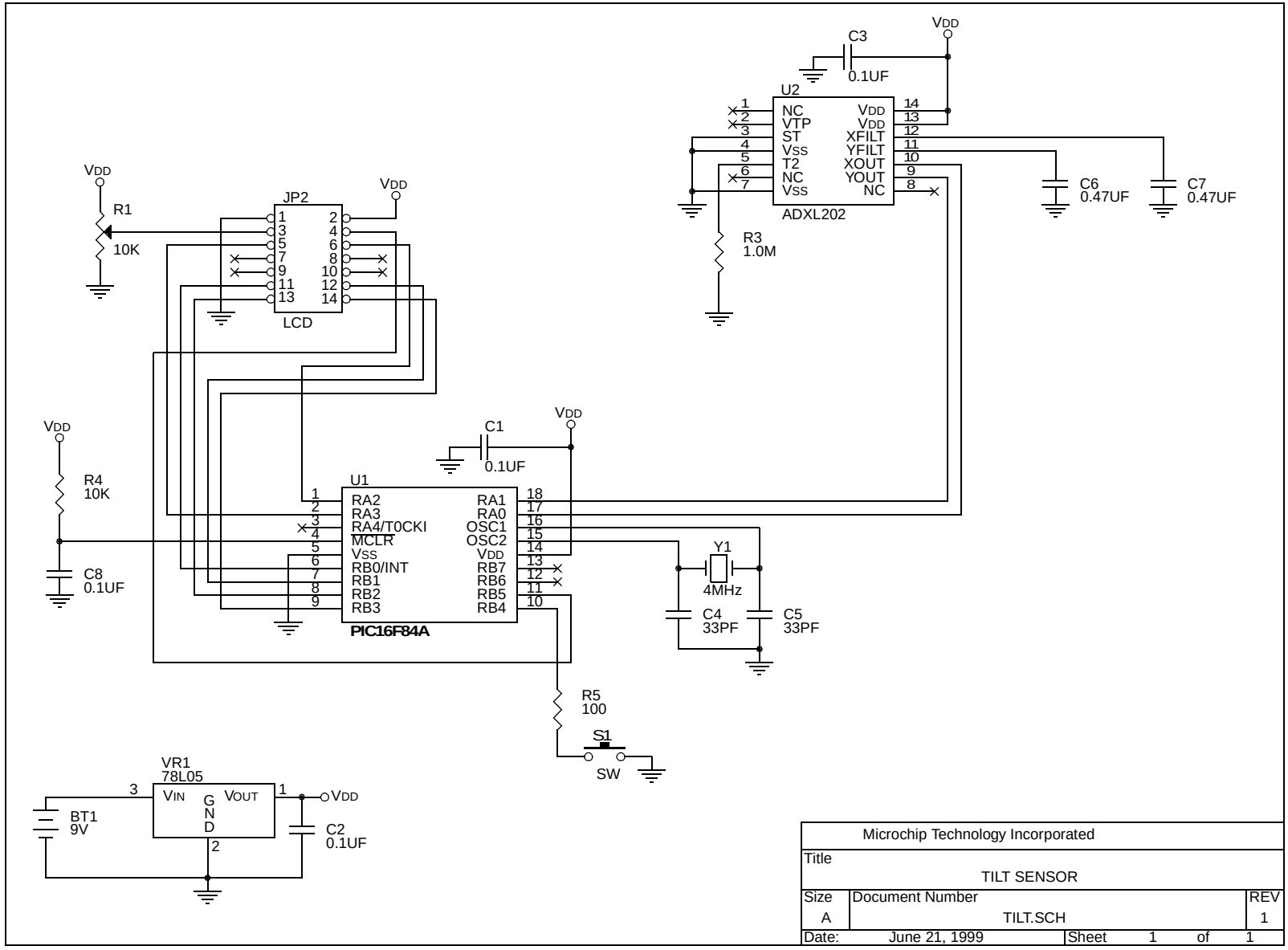
The spreadsheet also offers the designer the ability to explore how oversampling the PWM signal affects noise at the expense of sacrificing bandwidth in Step 8. Finally, Step 9 provides the estimated drift of the 0 g point due to temperature effects.

TILT METER APPLICATION

In the tilt meter application, the value of tilt in the X-axis and Y-axis is displayed on a 2-line by 8-character dot matrix LCD display. The only other function is a push button switch to perform a simple calibration cycle. The PIC16F84A makes an ideal companion to the ADXL202 because calibration parameters for the sensor can be stored in on-chip Data EEPROM memory for retrieval and usage in later calculations. Using the ADXL202 in conjunction with a PICmicro® not only reduces the time to market for the product but also overall system cost and power consumption.

Figure 4 shows the schematic for the simple tilt meter. For convenience, a 9V battery is used with a LM78L05 +5V regulator to provide power to the circuit. The ADXL202 is configured as shown in the ADXL202 Interactive Designer spreadsheet with 0.47µF capacitors on the XFILT and YFILT pins. A resistor of 1.0625MΩ is called out by the spreadsheet to connect to the RSET pin. Since the duty cycle generator's current source that determines the PWM frequency is only accurate to approximately 10%, a 1.0 MΩ, 5% resistor can be used. The 6% error between the two resistors will get corrected by the measurement of T2. The duty cycle output pins from the ADXL202 XOUT and YOUT are connected to RA0 and RA1 respectively.

FIGURE 4: TILT METER SCHEMATIC



The microcontroller circuit is also very simple. The 4MHz crystal uses two 33pF capacitors to complete the oscillator circuit. The push button switch is connected to RB4. This pin has internal pull-up resistors reducing the need for any external circuitry. The LCD display is driven using the 4-bit MPU mode which only requires 3 I/O pins for control and 4 I/O pins for data. Refer to the specifications for the Hitachi HD44780 LCD controller or the application note, AN587, "Interfacing PICmicros® to an LCD Module", for more interface information. The controls lines RS, R/W, and E connect to RB5, RA3, and RA2. The data lines are connected to RB<0:3>. There is also a 10KΩ potentiometer connected to pin 3 of the LCD display to control the contrast.

Acceleration is a vector quantity with both a direction and magnitude. The acceleration vector can be broken up into two vectors on the ADXL202, the X-axis and Y-axis. The ADXL202 is responsive to both static acceleration due to gravity as well as acceleration due to motion. The main problem with using this type of accelerometer to measure degrees tilt is not that it is sensitive to motion but that it can't distinguish between gravity and motion. The user must implement some type of time weighted filter to remove the effects of motion from the measurement (not implemented in this design). When the tilt angle is varied along the sensitive X- and Y-axis, the acceleration vector changes and the ADXL202 responds by changing the duty cycle outputs. The angle of tilt is defined by the following equation:

$\theta = \arcsin[(V(out)-V(zero\ g)) / (1g \times Scale\ factor(V/g))]$

This is a difficult calculation on an 8-bit microcontroller, therefore the calculation will be simplified. In spite of this, we still yield very good results (shown later in the firmware section).

The firmware is centered around the duty cycle measurement. The technical note from Analog Devices titled "Using the ADXL202 Duty Cycle Output" shows a very efficient method of measuring the period and duty cycle of the PWM waveforms. Figure 5 shows the waveforms from XOUT and YOUT. The most obvious method of measuring these waveforms is to measure the time from rising edge to falling edge to next rising edge for each of the waveforms. While very simple, this method takes 3 complete cycles to complete the process. If you take a closer look at Figure 5, you will see that the high time of XOUT and YOUT are centered about each other. We can use this to our advantage.

Figure 6 shows the waveform and measurement points for the improved measurement scheme. At Ta the counter is started. The program then records the times at Tb, Tc, and Td. By looking at the points of Figure 6, we can say that:

T1x = Tb - Ta = Tb (counter was 0 at Ta)

T1y = Td - Tc

T2x = T2y = T2 = Te - Ta = Tg - Tf

Since we have already established that the center of T1 is aligned with the center of T2, the equation for T2 reduces to:

T2 = Td - T1y/2 - T1x/2

T2 = Td - (Td - Tc)/2 - Tb/2

This technique not only reduces the measurement time to two cycles, it also only calculates T2 once.

FIGURE 5: ADXL202 DUTY CYCLE OUTPUT

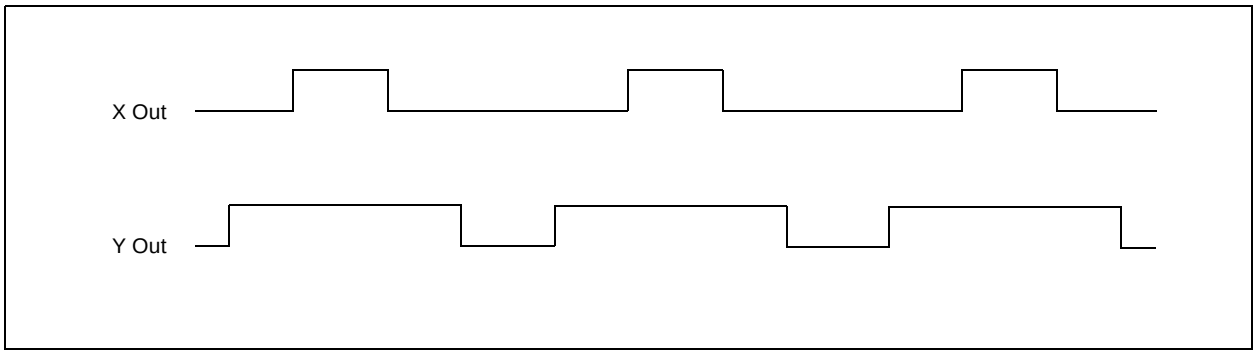
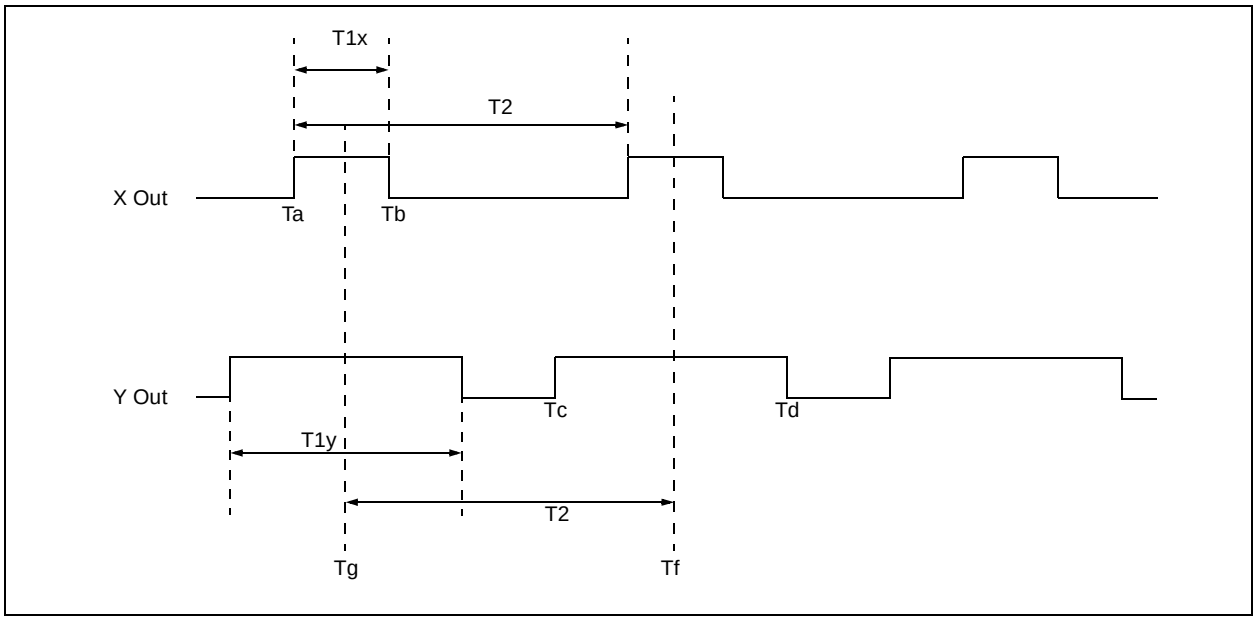


FIGURE 6: ADXL202 DUTY CYCLE MEASUREMENT



Now that our system is reading the duty cycle outputs of the ADXL202 and displaying the results on the LCD display, we need to consider how the system is calibrated. The first calibration step is the initial calibration of the tilt sensor with respect to gravity. The simplest method is to position the system such that the X-axis and Y-axis are both level. When instructed to calibrate, the PIC16F84A will calculate the duty cycle output T1 for both axis and the period T2. Several readings may be taken and averaged to improve the accuracy of the measurements. These values are now stored in both RAM as well as EEPROM as calibration constants. A scale factor is also used in the calibration process to create an n-bit result. These constants are defined as:

- T2cal, the value of T2 during the calibration phase. T2 must be stored because it can vary over temperature and has jitter from one measurement to another.
- ZXcal, the value of T1x during the calibration phase.
- ZYcal, the value of T1y during the calibration phase.
- K, the scale factor and is equal to *[4 * (T2cal * bit_scale_factor) / T2cal]*

K needs to be calculated only once. Since each axis will use this factor it is hard coded in the firmware. The bit_scale_factor is used to determine the size of the result. Since we are looking for a result of +/- 90 (1 degree of tilt per count), the bit scale factor would be 180. Therefore, K is assigned a value of 720. This is the simplification that was mentioned earlier.

Once we have calculated the calibration constants we can apply them to the duty cycle measurements to get degree of tilt. The following formulas give the degree of tilt for each axis:

*ZXactual = (ZXcal * T2actual) / T2cal (1)*

*ZYactual = (ZYcal * T2actual) / T2cal (2)*

T2actual is the current measurement of T2. This formula adjusts the 0g value for changes in T2 due to temperature or jitter.

*XAcceleration = [K * (T1x - ZXactual)] / T2actual (3)*

*YAcceleration = [K * (T1y - ZYactual)] / T2actual (4)*

The values of T1x and T1y are the current measurements of T1 for each axis. The results in XAcceleration and YAcceleration are the degrees to tilt in the X-axis and Y-axis directions properly scaled for 1 degree per count. This method of calibration is very simple yet will suffer from small errors due to variance in duty cycle % per g (which was assumed to be 12.5%) from one part to the next.

The order of the math operations is deliberate to preserve the accuracy of the result. All math operations are done in fixed point math. Several variables are used in the math operations. The following table shows the two inputs to each routine and the location of the result of the routine.

TABLE 1: MATH OPERATIONS VARIABLE USAGE

Operation	Operand #1	Operand #2	Result
16 x 16 Addition	ACCHI, ACCLO	ARGH, ARGL	ACCHI, ACCLO
16 x 16 Subtraction	ACCHI, ACCLO	ARGH, ARGL	ACCHI, ACCLO
16 x 16 Multiply	ACCHI, ACCLO	ARGH, ARGL	PRODW3, PRODW2, PRODW1, PRODW0
32 x 16 Divide	PRODW3, PRODW2, PRODW1, PRODW0	DIV1, DIV0	ANS1, ANS0

For calculating Zactuals in formula (1) and (2), the 16 x 16 multiply of Zcal * T2actual takes place first followed by the division of the result by T2cal. When calculating tilt (really is scaled acceleration) in the formulas (3) and (4), the subtraction of Zactual from T1 takes place first, followed by multiplication of the result by K, and finally the division of the result by T2actual.

Finally, the last two pieces of the code are for the LCD display and the Data EEPROM access. The LCD code is a derivative of that found in the application note, AN587, "Interfacing PICmicro® Microcontrollers to an LCD Module". Most of the changes were related to the different I/O pins used for data and control. The Data EEPROM routines use code directly from the PIC16F84A data sheet DS35007 for reads and writes. The WriteCal routine takes the calibration constants and writes them to the Data EEPROM. This routine is only called when a calibration cycle is performed. The RestoreCal routine is called when the PIC16F84A is reset. The calibration constants are grouped sequentially in memory so that these routines can use indirect addressing and shorten the length of code.

CONCLUSION

As in all applications, the type of acceleration sensor depends on the system requirements as well as the property being measured. Some accelerometers are better suited towards measuring vibration and shock such as the piezo-film and piezoelectric. Others are used for tilt measurements such as liquid tilt and micromachined types. The type of sensor selected then dictates the signal conditioning circuitry requirements. Some accelerometers have AC response, some DC. Some sensors have analog outputs, others digital. In other words, one accelerometer does not fit into all applications. This application note has shown that a designer can quickly and easily complete an accelerometer based design using the ADXL sensors from Analog Devices. The use of a microcontroller further simplifies the design by giving the designer a more integrated, lower cost solution for the data measurement application.

REFERENCES

Data Sheets

- *ADXL202 Data Sheet,* Analog Devices Inc., Rev. 0
- *ADXL210 Data Sheet,* Analog Devices Inc., Rev. Pr.A
- *PIC16F84A Data Sheet,* Microchip Technology Inc., DS35007A

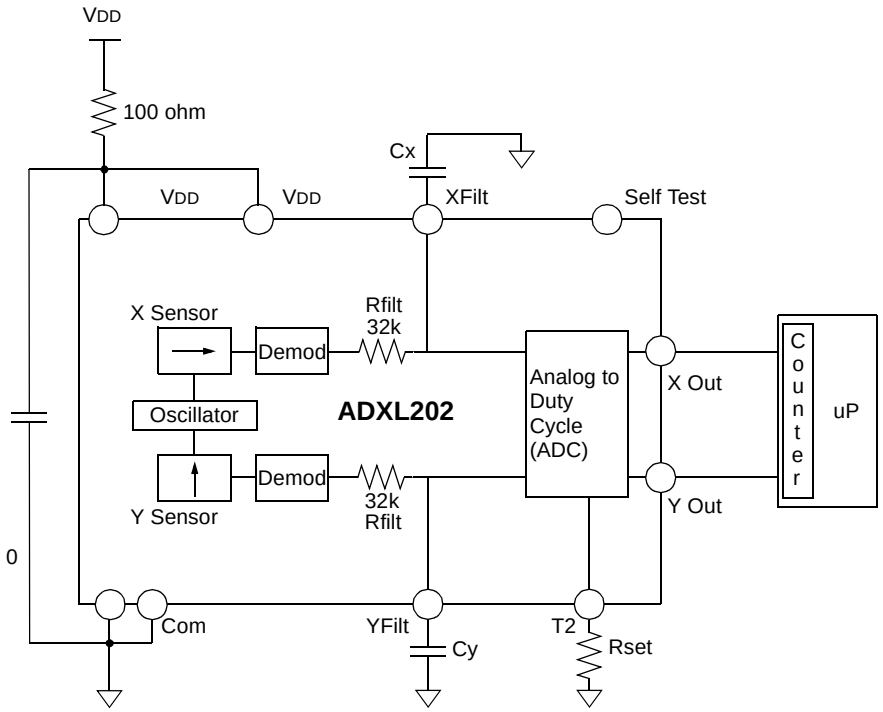
Technical Notes From Analog Devices

- *Using the ADXL202 Duty Cycle Output*
- *Accelerometer Design and Applications*
- *A Compact Algorithm Using The ADXL202 Duty Cycle Output*
- *The Interactive Designer ADXL202*

APPENDIX A: ADXL202 INTERACTIVE DESIGNER

The XL202 Interactive Designer

Enter values below. When your design is complete the values for your design will print out on this page.



Parameters

Supply voltage	5.0	V
Analog Bandwidth	10.5	Hz
Acquisition Rate	25	readings per second
Resolution (g's)	0.008	g
Resolution (deg of tilt)	0.47	deg of tilt
Microcontroller counter rate	1	MHz
T2	8.5	mS
Power cycling %	100%	on time
Tmax	35	deg C
Tmin	15	deg C
Zero g drift Tmax	0.02	g
Zero g drift Tmin	0.02	g

Component Values

Supply Decoupling	0.1	uF
Xcap, Ycap	0.47	uF
Rset	1062.5	kohm

You will be asked to enter variety of design parameters important to your applications. This will include such issues as how fast is the signal you need to measure, what is the required update or acquisition rate, what is the counter speed on your microcontroller. After entering target values (inputs) the spreadsheet will calculate outputs such as the resolution of the accelerometer. You can then iterate the input values and trade off parameters as necessary to meet your design goals. Only enter values that are in **bold**.

1. Enter your nominal supply voltage

The XL202 will operate from 3.0V to 5.25V. Enter your nominal supply voltage here.

Vdd **5.0** **V**

2. What is the fastest signal you want to be able to observe?

In this step you will determine the bandwidth for the analog stage of the accelerometer. The bandwidth generally determines the noise floor and thus the resolution of the accelerometer. In a later section you will also calculate digital noise sources from the PWM stage; the combination of these two noise sources determines the total noise floor. You will be measuring a real world acceleration, such as human or vehicle motion. What part of the signal content is important? If the signals are transient, such as shock or impulse, you may want to set a higher bandwidth. Human motion can often be measured at 10Hz or less. Don't forget to consider filter delays that could result in a lag between a stimulus and a response by the accelerometer, (dominated by the filter). Component values for the Xfilt and Yfilt capacitor are calculated below. You will probably want to iterate to a standard capacitor value.

Enter desired Bandwidth **10.5** Hz Value for Cx, Cy 0.47 uF Component Value!

3. Estimate P-P noise

The peak to peak noise of the accelerometer is the best indicator of resolution of the accelerometer. Noise is a statistical process, and is best described by an RMS measurement, (available on the datasheet). P-P noise is then estimated using a statistical estimation. You need to select a RMS to P-P estimation. The table below tells you how various RMS to P-P noise multipliers, predict the amount of time the actual signal will EXCEED the estimated P-P noise. The lower the multiplier, the more likely it is that a noise event will exceed the P-P limit.

Enter RMS to P-P multiplier **4** X of RMS

RMS Multiplier	% of time a signal will exceed the P-P estimate
2X	32.00%
4X	4.60%
6X	0.27%
8X	0.01%

Calculated noise at the analog output Xfilt and Yfilt

Noise(rms) at Xfilt, Yfilt	0.002 g (max RMS)	
Noise(P-P) at Xfilt, Yfilt	0.008 g (max P-P) @4X RMS	
Noise(P-P) at Xfilt, Yfilt	0.47 Deg of tilt (max P-P)	At 17mg/deg of tilt

Note: Noise level is inversely proportional to supply voltage

Note Decrease Noise (increase resolution) by decreasing BW.

3A. Iterate

Look at the P-P noise estimate; this is the noise limited resolution, (the smallest signal you can resolve). Is this acceptable for your application? If not you should consider adjusting the bandwidth down to reduce P-P noise and improve resolution.

4. How fast would you like to acquire the signals?

In this section we will begin the design of the digital output, and the microcontroller interface. You will input an acquisition rate, i.e. how many times per second you want a new reading from the accelerometer. You are also asked how long the part should be powered each second. Note that if you only want a few samples per second, but intend to keep the part powered all of the time, then you will need to set a faster acquisition rate in order to get reasonable values for the PWM output. The program requests that you input the time required to do the multiplies and divides to calculate the acceleration. 3.0ms is the time required for a Microchip 16C63 running at 4 Mhz. This section generates a component value for the Rset resistor.

Enter desired acquistion rate **25** Each Channel per second

% of time part will be powered per second **100%**

Calculate Acquisition Time

Maximum time available to acquire 2 channels	20.0	ms
Time required to calculate two channels	**3.0**	ms
Time left for signal acquisition	17.0	ms (two channels)

This implies a requirement for the value of the PWM period T2

Thus, T2 =	8.5	mS or	118 Hz	This is the Sample Rate
Value for Rset	1062.5	kohm		Component Value!

5. Enter the counter rate of your Microcontroller and calculate the resolution of the digital output.

In Section 2, we calculated the resolution of the analog section. In this section we will calculate the resolution of the digital output; a fuction of the PWM rate T2 (calculated in section 4), and the counting rate of your microcontroller. Please note that the counting rate is different, and usually slower than the microcontroller clock rate. The output of this calculation is a measure of the quantization error of the counter. In some cases it may limit the ultimate resolution; we will explore this in

Counter Rate **1 Mhz**

Note: you will need a counter of size 17000 counts or 15 bits
To avoid overflowing the counter

Resolution	1062.5	Counts per g	
Resolution	0.001	g	Quantization bit size
Resolution	0.06	Deg of Tilt	Based on 17mg/deg of tilt

Note: Increase resolution by increasing counter rate or decreasing samples per second

6. Check for aliasing and other errors in sampling:

In all cases the sample rate (1/T2) needs to be faster than the bandwidth of the analog section by a factor of at least 2 in order to meet the requirements of Nyquist. Nyquist notwithstanding, a ratio of at least 10 is recommend to minimize dynamic errors that are endemic to PWM sampling techniques. If your ratio is low, you can improve it by either increasing the sample rate (by increasing the acquistion rate in section 4) or decreasing the analog bandwidth (in section 2).

Ratio of sample rate (1/T2) to analog BW: 11.2 Good!

7. Estimate of total resolution (iterate to meet design objective)

We are now in a position to bring together the various calculation above to determine the resolution of the complete analog and digital design. The ultimate resolution is determined by both the noise at the analog output (Xcap and Ycap) and the quantization bit size of the PWM + counter system. At this point check the total system resolution to see if it meets your requirements. If it does not, then revisit bandwidth at Xfilt and Yfilt, acquistion rate or counting rate to reduce noise. You may also want to consider digital filtering, (oversampling) to reduce noise at the expense of sampling rate as discussed in the next section.

Noise due to analog section	0.008 g (max P-P) @4X RMS	This is the noise contribution at the analog output Xcap, Ycap
Resolution of digital output- counter	0.001 g	This is the quantization noise of the digital output
Estimated Total Noise (resolution):	0.008 g P-P	This is the total P-P noise, which is the root sum square of the analog and digital noise.
Estimated Total Noise (resolution):	0.5 deg of tilt @ 17mg/deg	
Noise (Resolution) is limited by:	Bandwidth at Xfilt, Yfilt; reduce bandwidth if lower noise desired (section 2)	

8. Option: Reduce noise by oversampling (at expense of bandwidth)

Another design option is to use digital filtering (averaging) in order to reduce noise, at the expense of bandwidth. By averaging several samples you are in effect filtering the signal. Implementing averages of 2,4 8, 16 samples are simple right shifts in microcontroller code (very efficient). For oversampling to work, samples need to be taken at a rate no faster than 10 times the analog bandwidth. Note: make sure oversampling is set to 1 sample if you don't want to use oversampling!

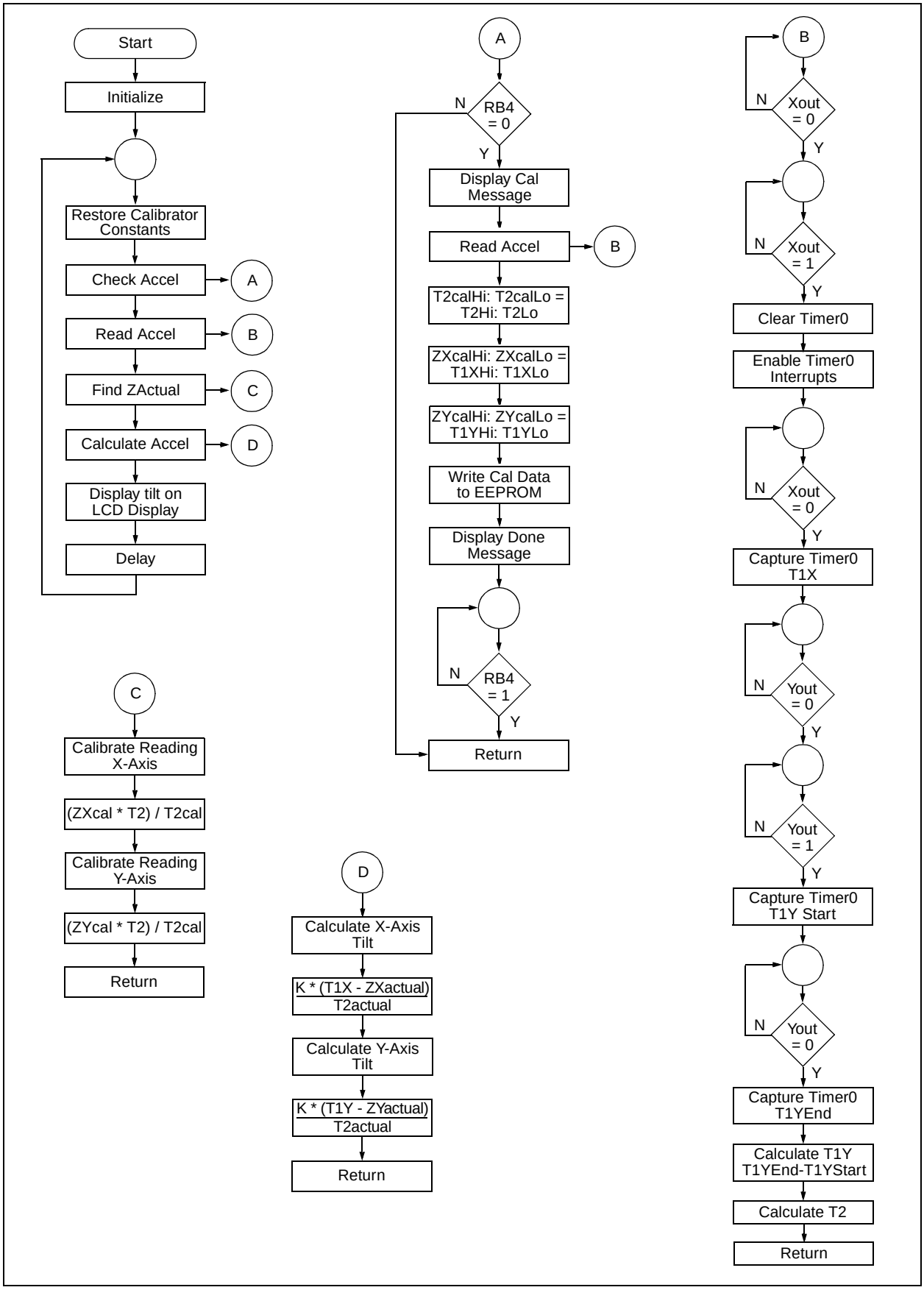
Estimated Noise (resolution) with average of:	**1** Samples	Noise before oversampling	0.008 g P-P	
Note: Samples should be taken about:	95.2381 mS apart	Noise after oversampling	0.008 g P-P	0% Reduction
		Bandwidth before oversamplin	10.5 Hz	
		Bandwidth after oversampling	10.5 Hz	

9. Estimated Drift of Zero g point

You can estimate the zero g temperature shift by entering your expected temperature range below and an estimate of the drift in mg/C (from the data sheet). Note that zero g drift can be positive or negative, but in general is very linear. X axis and Yaxis drift are uncorrelated.

			Drift from 25C Value		
			Drift in mG	Drift in deg of tilt	
Drift in mG per degree C	**0.002** g/C				
Max Temp	**35** C	at Tmax	0.02 mg	1.2 deg of tilt	at 17mg/deg C
Min Temp	**15** C	at Tmin	0.02 mg	1.2 deg of tilt	at 17mg/deg C

APPENDIX B: TILT SENSOR FIRMWARE FLOWCHART



APPENDIX C: TILT MOTOR SOURCE CODE LISTING

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        00001         list    p=16f84a
        00002         include <p16f84a.inc>
        00001         LIST
        00002 ; P16F84A.INC Standard Header File,Version 2.00 Microchip Technology
        00134         LIST
        00003
2007 3FF1  00004         __config    _CP_OFF&_WDT_OFF&_XT_OSC&_PWRTE_ON
        00005 ;Assembled using MPASM V2.30
        00006 ;PORTA defines
        00007 #define XOUT    0
        00008 #define YOUT    1
        00009 #define E       2
        00010 #define RW      3
        00011
        00012 ;PORTB defines
        00013 #define CAL     4
        00014 #define RS      5
        00015
        00016 ;=================================================================
        00017 ;       RAM EQUATES
        00018 ;=================================================================
        00019         cblock  0x0c
 0000000C  00020               T1XHi
 0000000D  00021               T1XLo
 0000000E  00022               ArgL
 0000000F  00023               ArgH
 00000010  00024               AccHi
 00000011  00025               AccLo
 00000012  00026               DivCnt
 00000013  00027               PRODW3
 00000014  00028               PRODW2
 00000015  00029               PRODW1
 00000016  00030               PRODW0
 00000017  00031               DIV0
 00000018  00032               DIV1
 00000019  00033               ANS0
 0000001A  00034               ANS1
 0000001B  00035               T2Hi
 0000001C  00036               T2Lo
 0000001D  00037               T1YStartLo
 0000001E  00038               T1YStartHi
 0000001F  00039               T1YEndLo
 00000020  00040               T1YEndHi
 00000021  00041               T1YHi
 00000022  00042               T1YLo
 00000023  00043               ZXcalHi
 00000024  00044               ZXcalLo
 00000025  00045               ZYcalHi
 00000026  00046               ZYcalLo
 00000027  00047               T2calHi
 00000028  00048               T2calLo
 00000029  00049               ZXActualHi
 0000002A  00050               ZXActualLo
 0000002B  00051               ZYActualHi
 0000002C  00052               ZYActualLo
 0000002D  00053               XAccel
 0000002E  00054               YAccel
```

```
0000002F  00055               Temp0
00000030  00056               Temp1
00000031  00057               Temp2
00000032  00058               Temp3
00000033  00059               Timer0H
00000034  00060               EADR
00000035  00061               EDATA
          00062         endc
          00063
0000000E  00064 Count1  equ     ArgL
0000000F  00065 Count2  equ     ArgH
0000002F  00066 Temp    equ     Temp0
00000019  00067 CMD     equ     ANS0
00000019  00068 LDATA   equ     CMD
00000017  00069 Digit0  equ     DIV0
00000018  00070 Digit1  equ     DIV1
          00071
00000002  00072 KHi     equ     0x02
000000D0  00073 KLo     equ     0xd0
          00074
0000      00075         org     0x0000
0000 2808 00076         goto    Start           ;Go to start of program
          00077
0004      00078         org     0x0004
0004 0AB3 00079         incf    Timer0H,F
0005 110B 00080         bcf     INTCON,T0IF
0006 118B 00081         bcf     INTCON,RBIE
0007 0009 00082         retfie
          00083
0008      00084 Start
0008 1283 00085         bcf     STATUS,RP0
0009 0185 00086         clrf    PORTA
000A 0186 00087         clrf    PORTB
000B 1683 00088         bsf     STATUS,RP0      ;Bank1
000C 3003 00089         movlw   B'00000011'     ;Set up the I/O ports
000D 0085 00090         movwf   TRISA
000E 3010 00091         movlw   B'00010000'
000F 0086 00092         movwf   TRISB
0010 300F 00093         movlw   B'00001111'
0011 0081 00094         movwf   OPTION_REG
0012 1283 00095         bcf     STATUS,RP0      ;Bank0
0013 21E1 00096         call    OpenXLCD        ;Initialize LCD
0014 22C6 00097         call    RestoreCal      ;Restore calibration constants
0015 178B 00098         bsf     INTCON,GIE
          00099
0016      00100 Main
0016 20F2 00101         call    CheckCal        ;Check if need to calibrate
0017 2020 00102         call    ReadAccel       ;Read the acceleration
0018 2060 00103         call    FindZActual     ;Calibrate readings
0019 2085 00104         call    CalculateAccel  ;Calculate tilt (acceleration)
001A 2194 00105         call    DisplayAccel    ;Display results
001B 30FF 00106         movlw   0xff            ;Delay for a while
001C 22A2 00107         call    Delay_Ms_4MHz
001D 30FF 00108         movlw   0xff
001E 22A2 00109         call    Delay_Ms_4MHz
001F 2816 00110         goto    Main            ;Do it again
          00111 ;*****************************************************************
          00112
          00113 ;=================================================================
          00114 ;=========== Acceleration Measurement/Calculation Routines ==========
```

```
        00115 ;=======================================================================
        00116 ;***********************************************************************
        00117 ;ReadAccel
        00118 ;       This subroutine acquires and calculates T1X, T1Y, and T2.
        00119 ;               T1X is in registers T1XHi,T1XLo
        00120 ;               T1Y is in registers T1YHi,T1YLo
        00121 ;               T2 is in registers T2Hi,T2Lo
        00122 ;***********************************************************************
0020      00123 ReadAccel
0020      00124 EDGE1
0020 1805  00125        btfsc   PORTA,XOUT      ;Wait for low on XOUT
0021 2820  00126        goto    EDGE1
0022      00127 EDGE2
0022 1C05  00128        btfss   PORTA,XOUT      ;Wait for high on XOUT
0023 2822  00129        goto    EDGE2
0024 0181  00130        clrf    TMR0            ;Clear Timer
0025 01B3  00131        clrf    Timer0H
0026 110B  00132        bcf     INTCON,T0IF     ;Enable Timer0 overflow interrupt
0027 168B  00133        bsf     INTCON,T0IE
0028      00134 EDGE3
0028 1805  00135        btfsc   PORTA,XOUT      ;Look for falling edge on XOUT
0029 2828  00136        goto    EDGE3
002A 0801  00137        movf    TMR0,W          ;Save Timer0H:TMR0 as T1X
002B 008D  00138        movwf   T1XLo
002C 0833  00139        movf    Timer0H,W
002D 008C  00140        movwf   T1XHi
002E      00141 EDGE4
002E 1885  00142        btfsc   PORTA,YOUT      ;Look a low level on YOUT
002F 282E  00143        goto    EDGE4
0030      00144 EDGE5
0030 1C85  00145        btfss   PORTA,YOUT      ;Look for rising edge on YOUT
0031 2830  00146        goto    EDGE5
0032 0801  00147        movf    TMR0,W          ;Save Timer0H:TMR0 for start
0033 009D  00148        movwf   T1YStartLo      ;of T1Y
0034 0833  00149        movf    Timer0H,W
0035 009E  00150        movwf   T1YStartHi
0036      00151 EDGE6
0036 1885  00152        btfsc   PORTA,YOUT      ;Look for falling edge on YOUT
0037 2836  00153        goto    EDGE6
0038 0801  00154        movf    TMR0,W          ;Save Timer0H:TMR0 as the end
0039 009F  00155        movwf   T1YEndLo        ;of T1Y
003A 0833  00156        movf    Timer0H,W
003B 00A0  00157        movwf   T1YEndHi
003C 128B  00158        bcf     INTCON,T0IE
        00159
003D 0820  00160        movf    T1YEndHi,W      ;Calculate T1Y
003E 0090  00161        movwf   AccHi
003F 081F  00162        movf    T1YEndLo,W
0040 0091  00163        movwf   AccLo
0041 081E  00164        movf    T1YStartHi,W
0042 008F  00165        movwf   ArgH
0043 081D  00166        movf    T1YStartLo,W
0044 008E  00167        movwf   ArgL
0045 210E  00168        call    Sub16x16
0046 0810  00169        movf    AccHi,W
0047 00A1  00170        movwf   T1YHi
0048 0811  00171        movf    AccLo,W
0049 00A2  00172        movwf   T1YLo
004A 0820  00173        movf    T1YEndHi,W      ;CALCULATE T2
004B 0090  00174        movwf   AccHi           ;2*(T2Hi,T2Lo) = (T1YEndHi:T1YEndLo)+
```

```
004C 081F  00175        movf    T1YEndLo,W      ;(T1YStartHi:T1YStartLo)-(T1XHi:T1XLo)
004D 0091  00176        movwf   AccLo
004E 081E  00177        movf    T1YStartHi,W
004F 008F  00178        movwf   ArgH
0050 081D  00179        movf    T1YStartLo,W
0051 008E  00180        movwf   ArgL
0052 2107  00181        call    Add16x16        ;ACCHI,ACCLO=(T1YEndHi:T1YEendLo)+
0053 080C  00182        movf    T1XHi,W         ;       (T1YStartHi:T1YStartLo)
0054 008F  00183        movwf   ArgH
0055 080D  00184        movf    T1XLo,W
0056 008E  00185        movwf   ArgL
0057 210E  00186        call    Sub16x16        ;ACCHI,ACCLO = 2*T2
0058 1003  00187        bcf     STATUS,C
0059 0C90  00188        rrf     AccHi,F
005A 0C91  00189        rrf     AccLo,F
005B 0810  00190        movf    AccHi,W
005C 009B  00191        movwf   T2Hi
005D 0811  00192        movf    AccLo,W
005E 009C  00193        movwf   T2Lo
005F 0008  00194        return
           00195
           00196
           00197 ;*****************************************************************
0060       00198 FindZActual
           00199 ;       This subroutine finds the value of ZActual for the X and Y
           00200 ;       axis.
           00201 ;       Output is ZXActualHi & ZXActualLo for the X-axis and
           00202 ;       ZYActualHi & ZXActualLo for the Y-axis.
           00203 ;*****************************************************************
0060       00204 FindZActual
0060 0823  00205        movf    ZXcalHi,W       ;First the X-axis
0061 0090  00206        movwf   AccHi
0062 0824  00207        movf    ZXcalLo,W
0063 0091  00208        movwf   AccLo
0064 081B  00209        movf    T2Hi,W
0065 008F  00210        movwf   ArgH
0066 081C  00211        movf    T2Lo,W
0067 008E  00212        movwf   ArgL            ;PRODW3,PRODW2,PRODW1,PRODW0 =
0068 211A  00213        call    Mul16x16        ;(ZXCAL_HI,ZXCAL_LO)*(T2HI,T2LO)
0069 0827  00214        movf    T2calHi,W
006A 0098  00215        movwf   DIV1
006B 0828  00216        movf    T2calLo,W
006C 0097  00217        movwf   DIV0
006D 2165  00218        call    Div32x16        ;ANS1,ANS0 = (ZXcal * T2) / T2cal
006E 081A  00219        movf    ANS1,W
006F 00A9  00220        movwf   ZXActualHi
0070 0819  00221        movf    ANS0,W
0071 00AA  00222        movwf   ZXActualLo
0072 0825  00223        movf    ZYcalHi,W       ;Same thing for the Y-axis
0073 0090  00224        movwf   AccHi
0074 0826  00225        movf    ZYcalLo,W
0075 0091  00226        movwf   AccLo
0076 081B  00227        movf    T2Hi,W
0077 008F  00228        movwf   ArgH
0078 081C  00229        movf    T2Lo,W
0079 008E  00230        movwf   ArgL            ;PRODW3,PRODW2,PRODW1,PRODW0 =
007A 211A  00231        call    Mul16x16        ;(ZYCAL_HI,ZYCAL_LO)*(T2HI,T2LO)
007B 0827  00232        movf    T2calHi,W
007C 0098  00233        movwf   DIV1
007D 0828  00234        movf    T2calLo,W
```

```
007E 0097  00235        movwf   DIV0
007F 2165  00236        call    Div32x16        ;ANS1,ANS0 = (ZYcal * T2) / T2cal
0080 081A  00237        movf    ANS1,W
0081 00AB  00238        movwf   ZYActualHi
0082 0819  00239        movf    ANS0,W
0083 00AC  00240        movwf   ZYActualLo
0084 0008  00241        return
           00242
           00243
           00244 ;*************************************************************************
           00245 ;CalculateAccel
           00246 ;       This subroutine performs the acceleration calculation for
           00247 ;       each axis.  The formula is:
           00248 ;               ACCEL = [K * (T1-Zactual) / T2actual]
           00249 ;       Output is XAccel and YAccel
           00250 ;*************************************************************************
0085       00251 CalculateAccel
0085 0829  00252        movf    ZXActualHi,W    ;Check if acceleration is positive
0086 020C  00253        subwf   T1XHi,W         ;or negative by comparing
0087 1C03  00254        btfss   STATUS,C        ;T1X and ZXactual
0088 28A5  00255        goto    CA1             ;Jump if T1X < ZXactual
0089 1D03  00256        btfss   STATUS,Z        ;Test if T1XHI=ZX_ACTUAL_HI
008A 288F  00257        goto    CA2             ;Jump if T1X > ZXactual
008B 082A  00258        movf    ZXActualLo,W
008C 020D  00259        subwf   T1XLo,W
008D 1C03  00260        btfss   STATUS,C
008E 28A5  00261        goto    CA1             ;Jump if TX1 < ZXactual
008F       00262 CA2
008F 080C  00263        movf    T1XHi,W         ;T1X - ZXactual
0090 0090  00264        movwf   AccHi
0091 080D  00265        movf    T1XLo,W
0092 0091  00266        movwf   AccLo
0093 0829  00267        movf    ZXActualHi,W
0094 008F  00268        movwf   ArgH
0095 082A  00269        movf    ZXActualLo,W
0096 008E  00270        movwf   ArgL
0097 210E  00271        call    Sub16x16
0098 3002  00272        movlw   KHi
0099 008F  00273        movwf   ArgH
009A 30D0  00274        movlw   KLo
009B 008E  00275        movwf   ArgL
009C 211A  00276        call    Mul16x16        ;PRODW3,PRODW2,PRODW1,PRODW0 =
           00277                                ;K * (T1X - ZXactual)
009D 081B  00278        movf    T2Hi,W
009E 0098  00279        movwf   DIV1
009F 081C  00280        movf    T2Lo,W
00A0 0097  00281        movwf   DIV0
00A1 2165  00282        call    Div32x16        ;ANS1:ANS0=
00A2 0819  00283        movf    ANS0,W          ;  [K*(T1X-ZXactual)]/T2actual
00A3 00AD  00284        movwf   XAccel          ;The result will be a signed 8-bit #
00A4 28BB  00285        goto    DoYCalc
00A5       00286 CA1
00A5 0829  00287        movf    ZXActualHi,W    ;ZXactual - T1X
00A6 0090  00288        movwf   AccHi
00A7 082A  00289        movf    ZXActualLo,W
00A8 0091  00290        movwf   AccLo
00A9 080C  00291        movf    T1XHi,W
00AA 008F  00292        movwf   ArgH
00AB 080D  00293        movf    T1XLo,W
00AC 008E  00294        movwf   ArgL
```

```
00AD 210E  00295        call    Sub16x16
00AE 3002  00296        movlw   KHi
00AF 008F  00297        movwf   ArgH
00B0 30D0  00298        movlw   KLo
00B1 008E  00299        movwf   ArgL
00B2 211A  00300        call    Mul16x16        ;PRODW3,PRODW2,PRODW1,PRODW0 =
         00301                                  ;K * (ZXactual - T1X)
00B3 081B  00302        movf    T2Hi,W
00B4 0098  00303        movwf   DIV1
00B5 081C  00304        movf    T2Lo,W
00B6 0097  00305        movwf   DIV0
00B7 2165  00306        call    Div32x16        ;ANS1,ANS0 =
00B8 0919  00307        comf    ANS0,W          ;  [K*(ZXactual-T1X)]/T2actual
00B9 3E01  00308        addlw   0x01            ;The result will be a signed 8-bit #
00BA 00AD  00309        movwf   XAccel
00BB       00310 DoYCalc
00BB 082B  00311        movf    ZYActualHi,W    ;Check if acceleration is positive
00BC 0221  00312        subwf   T1YHi,W         ;or negative by comparing
00BD 1C03  00313        btfss   STATUS,C        ;T1Y and ZYactual
00BE 28DB  00314        goto    CA3             ;Jump if T1Y < ZYactual
00BF 1D03  00315        btfss   STATUS,Z        ;Test if T1YHI=ZY_ACTUAL_HI
00C0 28C5  00316        goto    CA4             ;Jump if T1Y > ZYactual
00C1 082C  00317        movf    ZYActualLo,W
00C2 0222  00318        subwf   T1YLo,W
00C3 1C03  00319        btfss   STATUS,C
00C4 28DB  00320        goto    CA3             ;Jump if TY1 < ZYactual
00C5       00321 CA4
00C5 0821  00322        movf    T1YHi,W         ;T1Y - ZYactual
00C6 0090  00323        movwf   AccHi
00C7 0822  00324        movf    T1YLo,W
00C8 0091  00325        movwf   AccLo
00C9 082B  00326        movf    ZYActualHi,W
00CA 008F  00327        movwf   ArgH
00CB 082C  00328        movf    ZYActualLo,W
00CC 008E  00329        movwf   ArgL
00CD 210E  00330        call    Sub16x16
00CE 3002  00331        movlw   KHi
00CF 008F  00332        movwf   ArgH
00D0 30D0  00333        movlw   KLo
00D1 008E  00334        movwf   ArgL
00D2 211A  00335        call    Mul16x16        ;PRODW3,PRODW2,PRODW1,PRODW0 =
         00336                                  ;K * (T1Y - ZYactual)
00D3 081B  00337        movf    T2Hi,W
00D4 0098  00338        movwf   DIV1
00D5 081C  00339        movf    T2Lo,W
00D6 0097  00340        movwf   DIV0
00D7 2165  00341        call    Div32x16        ;ANS1,ANS0 =
00D8 0819  00342        movf    ANS0,W          ;  [K*(T1Y-ZYactual)]/T2actual
00D9 00AE  00343        movwf   YAccel          ;The result will be a signed 8-bit #
00DA 0008  00344        return
00DB       00345 CA3
00DB 082B  00346        movf    ZYActualHi,W    ;ZYactual - T1Y
00DC 0090  00347        movwf   AccHi
00DD 082C  00348        movf    ZYActualLo,W
00DE 0091  00349        movwf   AccLo
00DF 0821  00350        movf    T1YHi,W
00E0 008F  00351        movwf   ArgH
00E1 0822  00352        movf    T1YLo,W
00E2 008E  00353        movwf   ArgL
00E3 210E  00354        call    Sub16x16
```

```
00E4 3002  00355        movlw   KHi
00E5 008F  00356        movwf   ArgH
00E6 30D0  00357        movlw   KLo
00E7 008E  00358        movwf   ArgL
00E8 211A  00359        call    Mul16x16        ;PRODW3,PRODW2,PRODW1,PRODW0 =
        00360                           ;K * (ZYactual - T1Y)
00E9 081B  00361        movf    T2Hi,W
00EA 0098  00362        movwf   DIV1
00EB 081C  00363        movf    T2Lo,W
00EC 0097  00364        movwf   DIV0
00ED 2165  00365        call    Div32x16        ;ANS1,ANS0 =
00EE 0919  00366        comf    ANS0,W          ;[K*(ZYactual-T1Y)]/T2actual
00EF 3E01  00367        addlw   0x01            ;The result will be a signed 8-bit #
00F0 00AE  00368        movwf   YAccel
00F1 0008  00369        return
        00370
        00371
        00372 ;***************************************************************************
        00373 ;CheckCal
        00374 ;       This subroutine reads the CAL pushbutton switch (RB4) and if
        00375 ;       it is low, performs a simple calibration routine.
        00376 ;***************************************************************************
00F2        00377 CheckCal
00F2 1A06  00378        btfsc   PORTB,CAL       ;Is RB4 low?
00F3 0008  00379        return                  ;If not then exit routine
00F4 2276  00380        call    DisplayCal
00F5 2020  00381        call    ReadAccel       ;If yes then perform a read cycle
00F6 081B  00382        movf    T2Hi,W          ;Save the measured values in the
00F7 00A7  00383        movwf   T2calHi         ;calibration registers
00F8 081C  00384        movf    T2Lo,W
00F9 00A8  00385        movwf   T2calLo
00FA 080C  00386        movf    T1XHi,W
00FB 00A3  00387        movwf   ZXcalHi
00FC 080D  00388        movf    T1XLo,W
00FD 00A4  00389        movwf   ZXcalLo
00FE 0821  00390        movf    T1YHi,W
00FF 00A5  00391        movwf   ZYcalHi
0100 0822  00392        movf    T1YLo,W
0101 00A6  00393        movwf   ZYcalLo
0102 22B9  00394        call    WriteCal        ;Write the calibration data to EEPROM
0103 2292  00395        call    DisplayDone     ;Write message to LCD display
0104        00396 CCLoop
0104 1E06  00397        btfss   PORTB,CAL       ;Wait for pushbutton switch to be
0105 2904  00398        goto    CCLoop          ;released
0106 0008  00399        return
        00400 ;***************************************************************************
        00401
        00402
        00403 ;=========================================================================
        00404 ;=================== Mathematical Operations =============================
        00405 ;=========================================================================
        00406 ;*************************************************************************
        00407 ;Add16x16
        00408 ;       This subroutine performs a 16-bit by 16-bit addition.
        00409 ;       Note that this routine does not check for possible overflow
        00410 ;       results i.e., 17-bit sum.
        00411 ;       Inputs are AccHi:AccLo and ArgH:ArgL
        00412 ;       Result is in AccHi:AccLo
        00413 ;               (AccHi:AccLo) = (AccHi:AccLo)+(ArgH:ArgL)
        00414 ;*************************************************************************
```

```
0107      00415 Add16x16
0107 080E  00416        movf    ArgL,W          ;Add low bytes together
0108 0791  00417        addwf   AccLo,F
0109 1803  00418        btfsc   STATUS,C        ;Check for carry out of addtion
010A 0A90  00419        incf    AccHi,F         ;If yes, increment AccHi
010B 080F  00420        movf    ArgH,W          ;Add high bytes together
010C 0790  00421        addwf   AccHi,F
010D 0008  00422        return
           00423
           00424 ;*****************************************************************
           00425 ;Sub16x16
           00426 ;       This subroutine performs a 16-bit by 16-bit subtraction.
           00427 ;       Inputs are AccHi:AccLo and ArgH:ArgL
           00428 ;       Result is in AccHi:AccLo
           00429 ;               (AccHi:AccLo) = (AccHi:AccLo)-(ArgH:ArgL)
           00430 ;*****************************************************************
010E       00431 Sub16x16
010E 098E  00432        comf    ArgL,F          ;2's complement ArgH:ArgL
010F 0A8E  00433        incf    ArgL,F
0110 1903  00434        btfsc   STATUS,2
0111 038F  00435        decf    ArgH,F
0112 098F  00436        comf    ArgH,F
0113 080E  00437        movf    ArgL,W          ;Now perform a 16-bit addition
0114 0791  00438        addwf   AccLo,F
0115 1803  00439        btfsc   STATUS,W
0116 0A90  00440        incf    AccHi,F
0117 080F  00441        movf    ArgH,W
0118 0790  00442        addwf   AccHi,F
0119 0008  00443        return
           00444
           00445 ;*****************************************************************
           00446 ;Mul16x16
           00447 ;       This subroutine performs a 16-bit by 16-bit multiplication.
           00448 ;       It produces a 32-bit number. Multiplication by 0 is checked
           00449 ;       and performed correctly, ie, A * 0 = 0.
           00450 ;       Inputs are (AccHi:AccLo) and (ArgH:ArgL)
           00451 ;       Output is (PRODW3:PRODW2:PRODW1:PRODW0)
           00452 ;         (PRODW3:PRODW2:PRODW1:PRODW0) = (AccHi:AccLo) * (Argh:ArgL)
           00453 ;*****************************************************************
011A       00454 Mul16x16
011A 01AF  00455        clrf    Temp0           ;Clear the temporary variables used
011B 01B0  00456        clrf    Temp1           ;in this routine
011C 01B1  00457        clrf    Temp2
011D 01B2  00458        clrf    Temp3
011E 0196  00459        clrf    PRODW0
011F 0195  00460        clrf    PRODW1
0120 0194  00461        clrf    PRODW2
0121 0193  00462        clrf    PRODW3
0122 0811  00463        movf    AccLo,W
0123 00AF  00464        movwf   Temp0           ;Move contents of AccHi:AccLo
0124 0810  00465        movf    AccHi,W         ;into Temp1:Temp0
0125 00B0  00466        movwf   Temp1
0126 0890  00467        movf    AccHi,F         ;Test if AccHi:AccLo = 0000
0127 1D03  00468        btfss   STATUS,Z
0128 292C  00469        goto    CheckNext       ;AccHi:AccLo not zero
0129 0891  00470        movf    AccLo,F
012A 1903  00471        btfsc   STATUS,Z
012B 2960  00472        goto    Equal0          ;AccHi:AccLo = 0000
012C       00473 CheckNext
012C 088F  00474        movf    ArgH,F          ;Test if ArgH:ArgL = 0000
```

```
012D 1D03  00475        btfss   STATUS,Z
012E 2932  00476        goto    DoMultiply      ;ArgH:ArgL not zero
012F 088E  00477        movf    ArgL,F
0130 1903  00478        btfsc   STATUS,Z
0131 2960  00479        goto    Equal0          ;ArgH:ArgL = 0000
0132       00480 DoMultiply
0132 088F  00481        movf    ArgH,F          ;Test if ArgH:ArgL has been reduced
0133 1D03  00482        btfss   STATUS,Z        ;to 0
0134 2938  00483        goto    TestLSB         ;ArgH:ArgL has not been reduced to 0
0135 088E  00484        movf    ArgL,F
0136 1903  00485        btfsc   STATUS,Z
0137 0008  00486        return                  ;ArgH:ArgL has been reduced to zero
           00487                                ;so multiplication isdone
0138       00488 TestLSB
0138 1003  00489        bcf     STATUS,C        ;Shift ArgH:ArgL right
0139 0C8F  00490        rrf     ArgH,F
013A 0C8E  00491        rrf     ArgL,F
013B 1C03  00492        btfss   STATUS,C        ;Is LSb of ArgH:ArgL = 1
013C 295A  00493        goto    DoShift         ;Jump if LSb = 0
013D 082F  00494        movf    Temp0,W         ;If LSb = 1 then
013E 0796  00495        addwf   PRODW0,F        ;PRODW3:PRODW2:PRODW1:PRODW0 =
013F 1C03  00496        btfss   STATUS,C        ;PRODW3:PRODW2:PRODW1:PRODW0 +
0140 294A  00497        goto    ADD2            ;Temp3:Temp2:Temp1:Temp0
0141 3001  00498        movlw   0x01            ;Add carry bit if necessary
0142 0795  00499        addwf   PRODW1,F
0143 1C03  00500        btfss   STATUS,C
0144 294A  00501        goto    ADD2
0145 3001  00502        movlw   0x01            ;Add carry bit if PRODW1 overflows
0146 0794  00503        addwf   PRODW2,F        ;as a result of the addition of the
0147 1C03  00504        btfss   STATUS,C        ;previous carry
0148 294A  00505        goto    ADD2
0149 0A93  00506        incf    PRODW3,F
014A       00507 ADD2
014A 0830  00508        movf    Temp1,W
014B 0795  00509        addwf   PRODW1,F
014C 1C03  00510        btfss   STATUS,C
014D 2953  00511        goto    ADD3
014E 3001  00512        movlw   0x01
014F 0794  00513        addwf   PRODW2,F
0150 1C03  00514        btfss   STATUS,C
0151 2953  00515        goto    ADD3
0152 0A93  00516        incf    PRODW3,F
0153       00517 ADD3
0153 0831  00518        movf    Temp2,W
0154 0794  00519        addwf   PRODW2,F
0155 1C03  00520        btfss   STATUS,C
0156 2958  00521        goto    ADD4
0157 0A93  00522        incf    PRODW3,F
0158       00523 ADD4
0158 0832  00524        movf    Temp3,W
0159 0793  00525        addwf   PRODW3,F
015A       00526 DoShift
015A 1003  00527        bcf     STATUS,C        ;Shift temp registers left
015B 0DAF  00528        rlf     Temp0,F
015C 0DB0  00529        rlf     Temp1,F
015D 0DB1  00530        rlf     Temp2,F
015E 0DB2  00531        rlf     Temp3,F
015F 2932  00532        goto    DoMultiply
0160       00533 Equal0
0160 0196  00534        clrf    PRODW0          ;Since one arguement equals zero
```

```
0161 0195  00535        clrf    PRODW1          ;PRODW3,PRODW2,PRODW1,PRODW0 = 0
0162 0194  00536        clrf    PRODW2
0163 0193  00537        clrf    PRODW3
0164 0008  00538        return
           00539
           00540 ;*****************************************************************
           00541 ;Div32x16
           00542 ;       This subroutine performs a 32-bit x 16-bit division.
           00543 ;       Division is performed by binary long division.
           00544 ;       Inputs are (PRODW3:PRODW2:PRODW1:PRODW0) and (DIV1:DIV0).
           00545 ;       Output is (ANS1:ANS0)
           00546 ;         (ANS1:ANS0) = (PRODW3:PRODW2:PRODW1:PRODW0) / (DIV1:DIV0)
           00547 ;*****************************************************************
0165       00548 Div32x16
0165 019A  00549        clrf    ANS1            ;Clear the result registers
0166 0199  00550        clrf    ANS0
0167 3011  00551        movlw   0x11            ;DivCnt = 17d
0168 0092  00552        movwf   DivCnt
0169       00553 DA1
0169 0818  00554        movf    DIV1,W
016A 0213  00555        subwf   PRODW3,W        ;Is DIV1 > PRODW3
016B 1C03  00556        btfss   STATUS,C
016C 2973  00557        goto    NoSub           ;Jump if DIV1 > PRODW3
016D 1D03  00558        btfss   STATUS,2        ;Is DIV1 = PRODW3
016E 297C  00559        goto    DoSubs          ;Jump if DIV1 < PRODW3
016F 0817  00560        movf    DIV0,W          ;Is DIV0 > PRODW2
0170 0214  00561        subwf   PRODW2,W
0171 1803  00562        btfsc   STATUS,C
0172 297C  00563        goto    DoSubs          ;Jump if DIV0 < PRODW2
0173       00564 NoSub
0173 1003  00565        bcf     STATUS,C        ;Clear the carry bit
0174 0D99  00566        rlf     ANS0,F          ;Add 0 to LSb of ANS1,ANS0
0175 0D9A  00567        rlf     ANS1,F
0176 1003  00568        bcf     STATUS,C        ;Clear the carry bit
0177 0D96  00569        rlf     PRODW0,F        ;Shift PRODW3,2,1,0 left
0178 0D95  00570        rlf     PRODW1,F
0179 0D94  00571        rlf     PRODW2,F
017A 0D93  00572        rlf     PRODW3,F
017B 2991  00573        goto    ChkCnt
017C       00574 DoSubs
017C 0813  00575        movf    PRODW3,W
017D 0090  00576        movwf   AccHi
017E 0814  00577        movf    PRODW2,W
017F 0091  00578        movwf   AccLo
0180 0818  00579        movf    DIV1,W
0181 008F  00580        movwf   ArgH
0182 0817  00581        movf    DIV0,W
0183 008E  00582        movwf   ArgL
0184 210E  00583        call    Sub16x16        ;(PRODW3:2) = (PRODW3:2)-(DIV1:0)
0185 0810  00584        movf    AccHi,W
0186 0093  00585        movwf   PRODW3
0187 0811  00586        movf    AccLo,W
0188 0094  00587        movwf   PRODW2
0189 1403  00588        bsf     STATUS,C
018A 0D99  00589        rlf     ANS0,F
018B 0D9A  00590        rlf     ANS1,F          ;Add 1 to LSb of ANS1:ANS0
018C 1003  00591        bcf     STATUS,C
018D 0D96  00592        rlf     PRODW0,F        ;Shift PRODW3,2,1,0, left
018E 0D95  00593        rlf     PRODW1,F
018F 0D94  00594        rlf     PRODW2,F
```

```
0190 0D93  00595        rlf     PRODW3,F
0191       00596 ChkCnt
0191 0B92  00597        decfsz  DivCnt,F       ;Check for 17 operations
0192 2969  00598        goto    DA1             ;If not then loop
0193 0008  00599        return
           00600 ;*****************************************************************
           00601
           00602
           00603 ;=================================================================
           00604 ;====================== Display Routines =========================
           00605 ;=================================================================
           00606 ;*****************************************************************
           00607 ;DisplayAccel
           00608 ;       This subroutine takes the values int XAccel and YAccel and
           00609 ;       displays the ASCII equivalent on the LCD display.
           00610 ;*****************************************************************
0194       00611 DisplayAccel
0194 223E  00612        call    BusyXLCD        ;Wait for LCD to not be busy
0195 3001  00613        movlw   0x01            ;Reset cursor to home position
0196 221C  00614        call    WriteCmdXLCD    ;of line 1
           00615
0197 1FAD  00616        btfss   XAccel,7        ;Check if XAccel is negative
0198 29A0  00617        goto    XSpace
0199 223E  00618        call    BusyXLCD        ;Is negative
019A 302D  00619        movlw   '-'             ;Print a '-' to the display
019B 2254  00620        call    WriteDataXLCD
019C 092D  00621        comf    XAccel,W        ;2's complement XAccel
019D 3E01  00622        addlw   0x01
019E 00AD  00623        movwf   XAccel
019F 29A3  00624        goto    DispX
01A0       00625 XSpace                         ;Not negative
01A0 223E  00626        call    BusyXLCD
01A1 3020  00627        movlw   ' '             ;Print a space to the display
01A2 2254  00628        call    WriteDataXLCD
01A3       00629 DispX
01A3 082D  00630        movf    XAccel,W        ;Convert XAccel to 2-digit ASCII
01A4 22AC  00631        call    Bin2Ascii
01A5 223E  00632        call    BusyXLCD
01A6 0818  00633        movf    Digit1,W        ;Write the upper digit to the LCD
01A7 2254  00634        call    WriteDataXLCD
01A8 223E  00635        call    BusyXLCD
01A9 0817  00636        movf    Digit0,W        ;Write the lower digit to the LCD
01AA 2254  00637        call    WriteDataXLCD
01AB 223E  00638        call    BusyXLCD
01AC 30DF  00639        movlw   0xdf            ;Write a degrees symbol to the LCD
01AD 2254  00640        call    WriteDataXLCD
01AE 223E  00641        call    BusyXLCD
01AF 3020  00642        movlw   ' '             ;Write " Pit" to the LCD
01B0 2254  00643        call    WriteDataXLCD   ;for the word pitch which refers
01B1 223E  00644        call    BusyXLCD        ;to the X-axis
01B2 3050  00645        movlw   'P'
01B3 2254  00646        call    WriteDataXLCD
01B4 223E  00647        call    BusyXLCD
01B5 3069  00648        movlw   'i'
01B6 2254  00649        call    WriteDataXLCD
01B7 223E  00650        call    BusyXLCD
01B8 3074  00651        movlw   't'
01B9 2254  00652        call    WriteDataXLCD
01BA 223E  00653        call    BusyXLCD
01BB 30A8  00654        movlw   0xa8            ;Change the cursor position to home
```

```
01BC 221C  00655        call    WriteCmdXLCD    ;of line 2
         00656
01BD 1FAE  00657        btfss   YAccel,7        ;Check if YAccel is negative
01BE 29C6  00658        goto    YSpace
01BF 223E  00659        call    BusyXLCD        ;Is negative
01C0 302D  00660        movlw   '-'             ;Print a '-' to the display
01C1 2254  00661        call    WriteDataXLCD
01C2 092E  00662        comf    YAccel,W        ;2's complement YAccel
01C3 3E01  00663        addlw   0x01
01C4 00AE  00664        movwf   YAccel
01C5 29C9  00665        goto    DispY
01C6       00666 YSpace                         ;Not negative
01C6 223E  00667        call    BusyXLCD
01C7 3020  00668        movlw   ' '             ;Print a space to the display
01C8 2254  00669        call    WriteDataXLCD
01C9       00670 DispY
01C9 082E  00671        movf    YAccel,W        ;Convert YAccel to 2-digit ASCII
01CA 22AC  00672        call    Bin2Ascii
01CB 223E  00673        call    BusyXLCD
01CC 0818  00674        movf    Digit1,W        ;Write the upper digit to the LCD
01CD 2254  00675        call    WriteDataXLCD
01CE 223E  00676        call    BusyXLCD
01CF 0817  00677        movf    Digit0,W        ;Write the lower digit t the LCD
01D0 2254  00678        call    WriteDataXLCD
01D1 223E  00679        call    BusyXLCD
01D2 30DF  00680        movlw   0xdf            ;Write a degrees symbol to the LCD
01D3 2254  00681        call    WriteDataXLCD
01D4 223E  00682        call    BusyXLCD
01D5 3020  00683        movlw   ' '             ;Write " Rol" to the LCD
01D6 2254  00684        call    WriteDataXLCD   ;for the word roll which refers
01D7 223E  00685        call    BusyXLCD        ;to the Y-axis
01D8 3052  00686        movlw   'R'
01D9 2254  00687        call    WriteDataXLCD
01DA 223E  00688        call    BusyXLCD
01DB 306F  00689        movlw   'o'
01DC 2254  00690        call    WriteDataXLCD
01DD 223E  00691        call    BusyXLCD
01DE 306C  00692        movlw   'l'
01DF 2254  00693        call    WriteDataXLCD
01E0 0008  00694        return
         00695
         00696 ;*****************************************************************
         00697 ;OpenXLCD
         00698 ;       This subroutine initializes the LCD display. It is
         00699 ;       cleared and blank upon exit of this routine
         00700 ;*****************************************************************
01E1       00701 OpenXLCD
01E1 301E  00702        movlw   0x1e            ;Delay for POR
01E2 22A2  00703        call    Delay_Ms_4MHz
         00704
01E3 30F0  00705        movlw   0xf0            ;Write upper byte of configuration
01E4 1683  00706        bsf     STATUS,RP0      ;value to the LCD three times
01E5 0586  00707        andwf   TRISB,F         ;After this the LCD can be read
01E6 1283  00708        bcf     STATUS,RP0
01E7 0586  00709        andwf   PORTB,F
01E8 3003  00710        movlw   0x03
01E9 0486  00711        iorwf   PORTB,F         ;Output data to the port, 8-bit mode
01EA 1505  00712        bsf     PORTA,E         ;Clock the data in
01EB 0000  00713        nop
01EC 1105  00714        bcf     PORTA,E
```

```
                00715
01ED 300A  00716        movlw   0x0a            ;Wait for ~5ms
01EE 22A2  00717        call    Delay_Ms_4MHz
                00718
01EF 30F0  00719        movlw   0xf0
01F0 0586  00720        andwf   PORTB,F
01F1 3003  00721        movlw   0x03
01F2 0486  00722        iorwf   PORTB,F         ;Output data to the port, 8-bit mode
01F3 1505  00723        bsf     PORTA,E         ;Clock the data in
01F4 0000  00724        nop
01F5 1105  00725        bcf     PORTA,E
                00726
01F6 300A  00727        movlw   0x0a            ;Wait for ~5ms
01F7 22A2  00728        call    Delay_Ms_4MHz
                00729
01F8 30F0  00730        movlw   0xf0
01F9 0586  00731        andwf   PORTB,F
01FA 3003  00732        movlw   0x03
01FB 0486  00733        iorwf   PORTB,F         ;Output data to the port, 8-bit mode
01FC 1505  00734        bsf     PORTA,E         ;Clock the data in
01FD 0000  00735        nop
01FE 1105  00736        bcf     PORTA,E
                00737
01FF 30F0  00738        movlw   0xf0
0200 0586  00739        andwf   PORTB,F
0201 1486  00740        bsf     PORTB,1         ;Output data to the port, 4-bit mode
0202 1505  00741        bsf     PORTA,E
0203 0000  00742        nop
0204 1105  00743        bcf     PORTA,E
                00744
0205 300F  00745        movlw   0x0f
0206 1683  00746        bsf     STATUS,RP0
0207 0486  00747        iorwf   TRISB,F
0208 1283  00748        bcf     STATUS,RP0
                00749
0209 223E  00750        call    BusyXLCD        ;Function Set: 4-bit mode, 2 lines,
020A 302F  00751        movlw   0x2f            ;5x8 dots
020B 221C  00752        call    WriteCmdXLCD
                00753
020C 223E  00754        call    BusyXLCD        ;Display Cntrl: display, cursor off
020D 3008  00755        movlw   0x08
020E 221C  00756        call    WriteCmdXLCD
                00757
020F 223E  00758        call    BusyXLCD        ;Display Cntrl: display & cursor on,
0210 300F  00759        movlw   0x0f            ;blinking on
0211 221C  00760        call    WriteCmdXLCD
                00761
0212 223E  00762        call    BusyXLCD        ;Clear Display
0213 3001  00763        movlw   0x01
0214 221C  00764        call    WriteCmdXLCD
                00765
0215 223E  00766        call    BusyXLCD        ;Shift Cntrl: cursor moves to left
0216 3013  00767        movlw   0x13
0217 221C  00768        call    WriteCmdXLCD
                00769
0218 223E  00770        call    BusyXLCD        ;Set DDRAM address to 0
0219 3080  00771        movlw   0x80
021A 221C  00772        call    WriteCmdXLCD
021B 0008  00773        return
                00774
```

```
        00775
        00776 ;***********************************************************************
        00777 ;WriteCmdXLCD
        00778 ;       This subroutine writes a command to the LCD display using
        00779 ;       a 4-bit interface.
        00780 ;***********************************************************************
021C    00781 WriteCmdXLCD
021C 1283  00782        bcf     STATUS,RP0
021D 0099  00783        movwf   CMD             ;Save command in WREG to CMD
021E 30F0  00784        movlw   0xf0            ;Setup up data port for write
021F 1683  00785        bsf     STATUS,RP0
0220 0586  00786        andwf   TRISB,F
0221 1283  00787        bcf     STATUS,RP0
0222 0586  00788        andwf   PORTB,F
0223 0819  00789        movf    CMD,W           ;Write upper 4-bits to data port
0224 00AF  00790        movwf   Temp
0225 0EAF  00791        swapf   Temp,F
0226 300F  00792        movlw   0x0f
0227 052F  00793        andwf   Temp,W
0228 390F  00794        andlw   0x0f
0229 0486  00795        iorwf   PORTB,F
022A 1185  00796        bcf     PORTA,RW        ;Set the control bits for write
022B 1286  00797        bcf     PORTB,RS        ;and command
022C 0000  00798        nop
022D 1505  00799        bsf     PORTA,E         ;Clock the upper nibble in
022E 0000  00800        nop
022F 1105  00801        bcf     PORTA,E
0230 30F0  00802        movlw   0xf0
0231 0586  00803        andwf   PORTB,F
0232 300F  00804        movlw   0x0f
0233 0519  00805        andwf   CMD,W           ;Output the lower 4-bits to data port
0234 0486  00806        iorwf   PORTB,F
0235 0000  00807        nop
0236 1505  00808        bsf     PORTA,E         ;Clock the lower nibble in
0237 0000  00809        nop
0238 1105  00810        bcf     PORTA,E
0239 300F  00811        movlw   0x0f
023A 1683  00812        bsf     STATUS,RP0
023B 0486  00813        iorwf   TRISB,F
023C 1283  00814        bcf     STATUS,RP0
023D 0008  00815        return
        00816
        00817
        00818 ;***********************************************************************
        00819 ;BusyXLCD
        00820 ;       This subroutine monitors the busy bit from the LCD display
        00821 ;       It returns when the LCD is no longer busy.
        00822 ;***********************************************************************
023E    00823 BusyXLCD
023E 1283  00824        bcf     STATUS,RP0
023F 1585  00825        bsf     PORTA,RW        ;Set up for a read
0240 1286  00826        bcf     PORTB,RS        ;Read the busy bit/address
0241 0000  00827        nop
0242 1505  00828        bsf     PORTA,E         ;Clock the data out
0243 0000  00829        nop
0244 1D86  00830        btfss   PORTB,3         ;Read the busy bit
0245 2A4D  00831        goto    BNHI
0246 1105  00832        bcf     PORTA,E         ;Still busy
0247 0000  00833        nop
0248 1505  00834        bsf     PORTA,E         ;Clock out the lower nibble
```

```
0249 0000  00835        nop
024A 1105  00836        bcf     PORTA,E
024B 1185  00837        bcf     PORTA,RW
024C 2A3E  00838         goto    BusyXLCD        ;Try again
024D       00839 BNHI
024D 1105  00840        bcf     PORTA,E         ;LCD not busy
024E 0000  00841        nop
024F 1505  00842        bsf     PORTA,E         ;Clock out the lower nibble
0250 0000  00843        nop
0251 1105  00844        bcf     PORTA,E
0252 1185  00845        bcf     PORTA,RW
0253 0008  00846        return
           00847
           00848
           00849 ;*************************************************************************
           00850 ;WriteDataXLCD
           00851 ;       This subroutine writes a byte of data to the LCD display
           00852 ;       using the 4-bit interface.
           00853 ;*************************************************************************
0254       00854 WriteDataXLCD
0254 1283  00855        bcf     STATUS,RP0
0255 0099  00856        movwf   LDATA           ;Save the data in LDATA
0256 30F0  00857        movlw   0xf0            ;Setup the data port
0257 1683  00858        bsf     STATUS,RP0
0258 0586  00859        andwf   TRISB,F
0259 1283  00860        bcf     STATUS,RP0
025A 0586  00861        andwf   PORTB,F
025B 0819  00862        movf    LDATA,W         ;Write the upper nibble of data
025C 00AF  00863        movwf   Temp            ;to the data port
025D 0EAF  00864        swapf   Temp,F
025E 300F  00865        movlw   0x0f
025F 052F  00866        andwf   Temp,W
0260 390F  00867        andlw   0x0f
0261 0486  00868        iorwf   PORTB,F
0262 1686  00869        bsf     PORTB,RS        ;Set control signals for write
0263 1185  00870        bcf     PORTA,RW        ;to data registers
0264 0000  00871        nop
0265 1505  00872        bsf     PORTA,E         ;Clock the upper nibble in
0266 0000  00873        nop
0267 1105  00874        bcf     PORTA,E
0268 30F0  00875        movlw   0xf0
0269 0586  00876        andwf   PORTB,F
026A 300F  00877        movlw   0x0f
026B 0519  00878        andwf   LDATA,W         ;Write the lower nibble to data port
026C 0486  00879        iorwf   PORTB,F
026D 0000  00880        nop
026E 1505  00881        bsf     PORTA,E         ;Clock the lower nibble in
026F 0000  00882        nop
0270 1105  00883        bcf     PORTA,E
0271 300F  00884        movlw   0x0f
0272 1683  00885        bsf     STATUS,RP0
0273 0486  00886        iorwf   TRISB,F
0274 1283  00887        bcf     STATUS,RP0
0275 0008  00888        return
           00889
           00890 ;*************************************************************************
           00891 ;DisplayCal
           00892 ;       This subroutine displays a message to the LCD display
           00893 ;       indicating that a calibration cycle is in progress.
           00894 ;*************************************************************************
```

```
0276       00895 DisplayCal
0276 223E  00896         call    BusyXLCD
0277 3001  00897         movlw   0x01
0278 221C  00898         call    WriteCmdXLCD
0279 223E  00899         call    BusyXLCD
027A 3043  00900         movlw   'C'
027B 2254  00901         call    WriteDataXLCD
027C 223E  00902         call    BusyXLCD
027D 3061  00903         movlw   'a'
027E 2254  00904         call    WriteDataXLCD
027F 223E  00905         call    BusyXLCD
0280 306C  00906         movlw   'l'
0281 2254  00907         call    WriteDataXLCD
0282 223E  00908         call    BusyXLCD
0283 3069  00909         movlw   'i'
0284 2254  00910         call    WriteDataXLCD
0285 223E  00911         call    BusyXLCD
0286 3062  00912         movlw   'b'
0287 2254  00913         call    WriteDataXLCD
0288 223E  00914         call    BusyXLCD
0289 3072  00915         movlw   'r'
028A 2254  00916         call    WriteDataXLCD
028B 223E  00917         call    BusyXLCD
028C 3061  00918         movlw   'a'
028D 2254  00919         call    WriteDataXLCD
028E 223E  00920         call    BusyXLCD
028F 3074  00921         movlw   't'
0290 2254  00922         call    WriteDataXLCD
0291 0008  00923         return
           00924
           00925
           00926 ;*****************************************************************
           00927 ;DisplayDone
           00928 ;       This subroutine displays a message to the LCD display
           00929 ;       indicating that a calibration cycle has completed.
           00930 ;*****************************************************************
0292       00931 DisplayDone
0292 223E  00932         call    BusyXLCD
0293 30A8  00933         movlw   0xa8
0294 221C  00934         call    WriteCmdXLCD
0295 223E  00935         call    BusyXLCD
0296 3044  00936         movlw   'D'
0297 2254  00937         call    WriteDataXLCD
0298 223E  00938         call    BusyXLCD
0299 306F  00939         movlw   'o'
029A 2254  00940         call    WriteDataXLCD
029B 223E  00941         call    BusyXLCD
029C 306E  00942         movlw   'n'
029D 2254  00943         call    WriteDataXLCD
029E 223E  00944         call    BusyXLCD
029F 3065  00945         movlw   'e'
02A0 2254  00946         call    WriteDataXLCD
02A1 0008  00947         return
           00948
           00949
           00950
           00951 ;=================================================================
           00952 ;====================== Misc. Routines ===========================
           00953 ;=================================================================
           00954 ;*****************************************************************
```

```
                00955 ;Delay_Ms_4MHz
                00956 ;       Generic delay routine.  Delay length in ms is loaded
                00957 ;       into WREG before calling.
                00958 ;*****************************************************************
02A2            00959 Delay_Ms_4MHz
02A2 1283  00960        bcf     STATUS,RP0
02A3 008E  00961        movwf   Count1
02A4            00962 DLMS2M1
02A4 307C  00963        movlw   0x7c
02A5 008F  00964        movwf   Count2
02A6            00965 DLMS2M2
02A6 0000  00966        nop
02A7 0B8F  00967        decfsz  Count2,F
02A8 2AA6  00968        goto    DLMS2M2
02A9 0B8E  00969        decfsz  Count1,F
02AA 2AA4  00970        goto    DLMS2M1
02AB 0008  00971        return
                00972
                00973
                00974 ;*****************************************************************
                00975 ;Bin2Ascii
                00976 ;       This routine converts a binary number to a 2-digit ASCII
                00977 ;       number.  The binary number is sent in WREG.
                00978 ;*****************************************************************
02AC            00979 Bin2Ascii
02AC 0198  00980        clrf    Digit1          ;Clear the upper digit
02AD 0097  00981        movwf   Digit0          ;Save the binary number
02AE            00982 B2A1
02AE 300A  00983        movlw   0x0a            ;Repeadedly subtract 10 from the
02AF 0217  00984        subwf   Digit0,W        ;number until the result is less
02B0 1C03  00985        btfss   STATUS,C        ;then 10
02B1 2AB5  00986        goto    B2A2
02B2 0097  00987        movwf   Digit0
02B3 0A98  00988        incf    Digit1,F
02B4 2AAE  00989        goto    B2A1
02B5            00990 B2A2
02B5 3030  00991        movlw   0x30            ;Add 0x30 to make the result
02B6 0797  00992        addwf   Digit0,F        ;ASCII
02B7 0798  00993        addwf   Digit1,F
02B8 3400  00994        retlw   0
                00995 ;*****************************************************************
                00996
                00997
                00998 ;=================================================================
                00999 ;==================== Data EEPROM Routines ========================
                01000 ;=================================================================
                01001 ;*****************************************************************
                01002 ;WriteCal
                01003 ;       This subroutine takes 6 bytes starting with address
                01004 ;       ZXcalHi and writes them to the internal Data EEPROM.
                01005 ;       Calls to WriteEE perform the actual write sequence.
                01006 ;*****************************************************************
02B9            01007 WriteCal
02B9 3006  01008        movlw   0x06            ;Load byte counter with 6
02BA 008E  01009        movwf   Count1
02BB 3023  01010        movlw   ZXcalHi         ;Load the starting address into FSR
02BC 0084  01011        movwf   FSR
02BD 01B4  01012        clrf    EADR            ;Start writing data to EE address 0
02BE            01013 WCLoop
02BE 0800  01014        movf    INDF,W          ;Load data
```

```
02BF 00B5  01015        movwf   EDATA
02C0 22D2  01016        call    WriteEE         ;Call routine to write data
02C1 0AB4  01017        incf    EADR,F          ;Increment EE address
02C2 0A84  01018        incf    FSR,F           ;Increment FSR
02C3 0B8E  01019        decfsz  Count1,F        ;Decrement count
02C4 2ABE  01020        goto    WCLoop
02C5 0008  01021        return
           01022
           01023
           01024 ;*****************************************************************
           01025 ;RestoreCal
           01026 ;       This subroutine reads 6 bytes from the Data EE starting
           01027 ;       with address 0 and saves them starting with ZXcalHi.
           01028 ;       Calls to ReadEE perform the actual read sequence.
           01029 ;*****************************************************************
02C6       01030 RestoreCal
02C6 3006  01031        movlw   0x06            ;Load byte counter
02C7 008E  01032        movwf   Count1
02C8 3023  01033        movlw   ZXcalHi         ;Load starting address into FSR
02C9 0084  01034        movwf   FSR
02CA 01B4  01035        clrf    EADR            ;Load starting EE address with 0
02CB       01036 RCLoop
02CB 22E4  01037        call    ReadEE          ;Read data from EE
02CC 0080  01038        movwf   INDF            ;Save in register
02CD 0AB4  01039        incf    EADR,F          ;Increment EE address
02CE 0A84  01040        incf    FSR,F           ;Increment FSR
02CF 0B8E  01041        decfsz  Count1,F        ;Decrement count
02D0 2ACB  01042        goto    RCLoop
02D1 0008  01043        return
           01044
           01045 ;*****************************************************************
           01046 ;WriteEE
           01047 ;       This is the subroutine to load the address and data into
           01048 ;       the special EE access registers and perform the EE write
           01049 ;       sequence.
           01050 ;*****************************************************************
02D2       01051 WriteEE
02D2 1283  01052        bcf     STATUS,RP0
02D3 0834  01053        movf    EADR,W          ;Load EE address
02D4 0089  01054        movwf   EEADR
02D5 0835  01055        movf    EDATA,W         ;Load EE data
02D6 0088  01056        movwf   EEDATA
02D7 1683  01057        bsf     STATUS,RP0
02D8 1208  01058        bcf     EECON1,EEIF
02D9 1508  01059        bsf     EECON1,WREN     ;EE write sequence
02DA 3055  01060        movlw   0x55            ;must be performed
02DB 0089  01061        movwf   EECON2          ;in this order
02DC 30AA  01062        movlw   0xaa            ;otherwise write
02DD 0089  01063        movwf   EECON2          ;does not take
02DE 1488  01064        bsf     EECON1,WR       ;place correctly
02DF       01065 eBusy
02DF 1E08  01066        btfss   EECON1,EEIF     ;Wait for write to complete
02E0 2ADF  01067        goto    eBusy
02E1 1108  01068        bcf     EECON1,WREN     ;Disable writes
02E2 1283  01069        bcf     STATUS,RP0
02E3 0008  01070        return
           01071
           01072
           01073 ;*****************************************************************
           01074 ;ReadEE
```

```
        01075 ;       This is the subroutine to read from the data EE using the
        01076 ;       special EE access registers.
        01077 ;*****************************************************************
02E4      01078 ReadEE
02E4 1283  01079        bcf     STATUS,RP0
02E5 0834  01080        movf    EADR,W          ;Load EE address
02E6 0089  01081        movwf   EEADR
02E7 1683  01082        bsf     STATUS,RP0
02E8 1408  01083        bsf     EECON1,RD       ;Perform the EE write sequence
02E9 1283  01084        bcf     STATUS,RP0
02EA 0808  01085        movf    EEDATA,W        ;Move data into WREG
02EB 0008  01086        return
        01087
        01088
        01089       end


MEMORY USAGE MAP ('X' = Used,  '-' = Unused)

0000 : X---XXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0040 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
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 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0240 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0280 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
02C0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXX---- ----------------
2000 : -------X-------- ---------------- ---------------- ----------------

All other memory blocks unused.

Program Memory Words Used:   745
Program Memory Words Free:   279

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

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