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AN52678

PSoC® 1 Interface with Triaxial Analog Accelerometer for Measuring Tilt

Author: Archana Yarlagadda

Associated Part Family: CY8C21x34/21x24/24x33/24x34A/24x94/27x43/29x66

Associated Code Examples: None

Related Application Notes: AN2010, AN2099

AN52678 describes how to measure orientation and tilt with PSoC® 1 using the KXSC7/KXTC9 triaxial analog accelerometer. Additional information is provided to help you interface other triaxial accelerometers to PSoC 1 devices.

Contents

1 Introduction

Accelerometers are electromechanical devices that change output based on dynamic (force from an external source) and static acceleration (earth's gravitational force: "g"). This facilitates measurement of orientation, tilt, inclination, vibration, rotation, and other parameters. Different types of accelerometers and algorithms are suited for each of these parameters. This application note shows the interface with Programmable System-on-Chip™ (PSoC) to obtain the orientation and tilt with respect to earth (static acceleration). You can use this interface technique with other accelerometers and algorithms to suit your application.

2 PSoC Resources

Cypress provides a wealth of data at www.cypress.com to help you to select the right PSoC device for your design, and quickly and effectively integrate the device into your design. In this document, PSoC refers to the PSoC 1 family of devices. To learn more about PSoC 1, refer to the application note AN75320 - *Getting Started with PSoC 1*.

The following is an abbreviated list for PSoC 1:

- **Overview:** PSoC Portfolio, PSoC Roadmap
- **Product Selectors:** PSoC 1, PSoC 3, PSoC 4, or PSoC 5LP. In addition, PSoC Designer includes a device selection tool.
- **Datasheets:** Describe and provide electrical specifications for the PSoC 1 device family.
- **Application Notes and Code Examples:** Cover a broad range of topics, from basic to advanced level. Many of the application notes include code examples.
- **Technical Reference Manuals (TRM):** Provide detailed descriptions of the internal architecture of the PSoC 1 devices.
- **Development Kits:**
  - CY3215A-DK In-Circuit Emulation Lite Development Kit includes an in-circuit emulator (ICE). While the ICE-Cube is primarily used to debug PSoC 1 devices, it can also program PSoC 1 devices using ISSP.
  - CY3210-PSOCEVAL1 Kit enables you to evaluate and experiment Cypress's PSoC 1 programmable system-on-chip design methodology and architecture.
  - CY8CKIT-001 is a common development platform for all PSoC family devices.
- The MiniProg1 and MiniProg3 devices provide an interface for flash programming.

3 Types of Accelerometers

Accelerometers are divided based on their output type, sensing method, manufacturing technology, and other properties. Appendix A provides the types of accelerometers based on different parameters. One of the parameters considered for differentiating accelerometers is its output type. Accelerometers can have either analog or digital output. The analog output accelerometers often have voltage as the output, while digital output accelerometers have PWM waveform, I^2C, or SPI. Analog accelerometers output the most raw data form and data processing is highly flexible. Digital PWM output accelerometers involve computation and timing analysis to get the acceleration. Accelerometers with digital communication output (I^2C/SPI) have ADCs and digital communication modules integrated into the chip along with the basic analog output accelerometer. This added hardware increases the cost of the accelerometer. PSoC, with its programmability and analog capability, can interface with all three types.

As analog output type provides raw data and is cost effective, this application note focuses on the interface of analog accelerometers with PSoC.

Appendix A gives details of the analog output accelerometers for different applications. Examples of triaxial analog accelerometers are KXTC9, MMA7360L, MMA7260Q, ADXL330, BMA140, and LIS344AL. The KXSC7/KXTC9 series accelerometer is selected to show the interface in this application note; the same technique can be applied to other accelerometers.

4 Interface with PSoC

This document assumes that you are familiar with the PSoC User Modules (UM). If you are new to PSoC, refer to the PSoC 1 training modules on the Cypress website. The projects accompanying this application note use the CY8C24533 device. The accelerometer interface can also be implemented with other PSoC families, based on the same technique. The resources required in different PSoC families are provided in a later section.

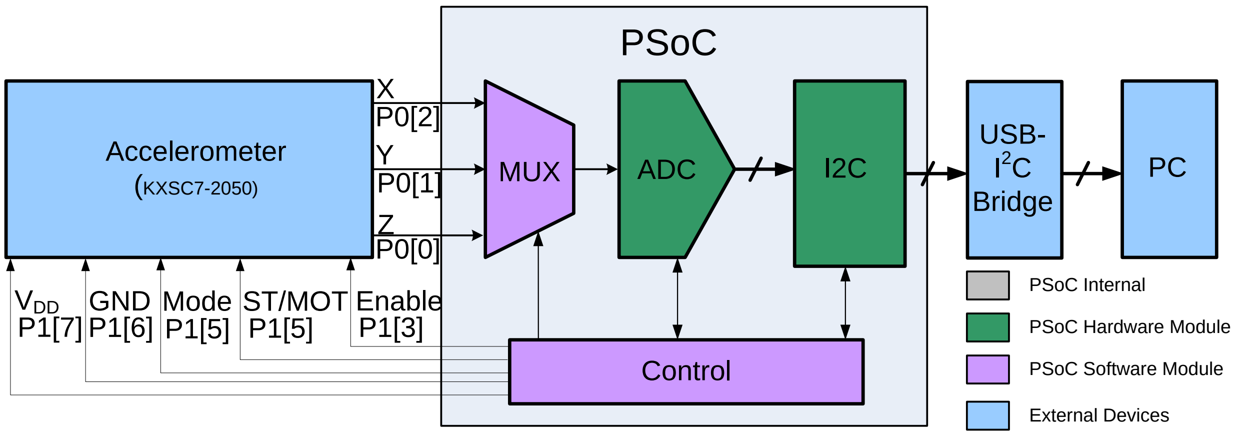
Figure 1 shows the block diagram of the system. The voltages on the accelerometer outputs (X, Y, and Z) change based on the acceleration. These inputs are multiplexed into ADC and converted into a digital value. The measured voltage on the three axes can be processed based on your application. For example, the output voltages V_x, V_y, and V_z on X, Y, and Z outputs can be used to measure tilt.

The voltages measured are converted into acceleration in the respective axes. The voltage to acceleration conversion is based on the sensitivity index and offset of the accelerometers, as shown in the following equation.

$$Acceleration\ (g_x) = (V_x - Offset) \times Sensitivity$$

The acceleration in Y and Z directions are obtained using the above equation based on the respective output voltages. These values are used to measure tilt.

Figure 1. Block Diagram of Accelerometer with PSoC



Tilt of an element is given by its angle of X, Y, and Z axes relative to ground. These angles of tilt: pitch (φ), roll (ρ), and theta (θ) can be calculated in firmware from the measured voltages with the following equations:

$$\rho = \tan^{-1}\left(\frac{g_X}{\sqrt{g_Y^2 + g_Z^2}}\right)$$

$$\phi = \tan^{-1}\left(\frac{g_Y}{\sqrt{g_X^2 + g_Z^2}}\right)$$

$$\theta = \tan^{-1}\left(\frac{\sqrt{g_Y^2 + g_X^2}}{g_Z}\right)$$

The example project converts the ADC counts into the corresponding voltages, and obtains the acceleration in each axis by considering the offset and sensitivity of the considered accelerometer. If you want to interface with any other triaxial accelerometer, change the offset and sensitivity values to values provided in the accelerometer datasheet. The example project makes use of the I^2C UM and transfers data via the external I^2C-USB Bridge hardware. The output is then plotted using the Bridge Control Panel software for graphical interface. Instead of transmitting to a graphical interface, you can use the orientation/tilt of the device to implement other functions in your project.

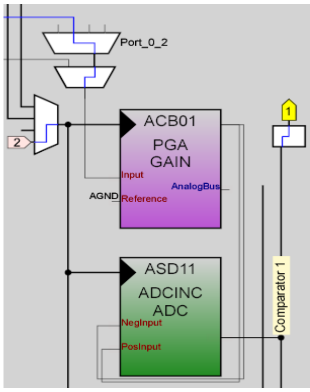
4.1 User Modules and Routing

The modules required to implement the accelerometer interface are an analog multiplexer and an ADC. The value obtained from the ADC can be processed as desired for your application. Thus all other modules such as the EzI2Cs (I^2C communication) UM, used in the example project for GUI interface, are optional.

4.1.1 Implementation with ADCINC

The Accelarometer_Project_ADCINC example provided with this application note uses an incremental ADC for the analog to digital conversion of the accelerometer data. The incremental ADC, ADCINC UM, is built using the programmable analog blocks present in PSoC. The ADCINC UM is available in all PSoC families and is thus chosen to show the accelerometer interface. The UM placement and routing is shown in Figure 2.

Figure 2. Routing in PSoC with ADCINC as ADC



Because the ADCINC UM is a switched capacitor block, an additional buffer is required between the pin and ADC, as shown in Figure 2. This is to avoid impedance loading on the SC circuit when connected to a high-impedance node.

The three inputs from the triaxial accelerometer are multiplexed to the ADC UM with analog multiplexers. The port and pin numbers are changed to match the port and pin numbers to which X, Y, and Z inputs are connected.

```
AMUX8_InputSelect(AMUX8_PORT0_2);
```

The resolution in ADCINC can be set from 6 bit to 14 bit, as shown in Figure 3. For the accelerometer chosen (KXSC7), the typical supply voltage is 2.8 V and its sensitivity is 560 mV/g. The resolution of acceleration due to gravity that can be achieved with a 14-bit ADC is as follows:

$$\text{“g” per ADC count} = \left(\frac{2.8}{560 * 10^{-3} * (2^{14} - 1)} \right) = 0.3\ mg$$

Figure 3. ADCINC Configuration

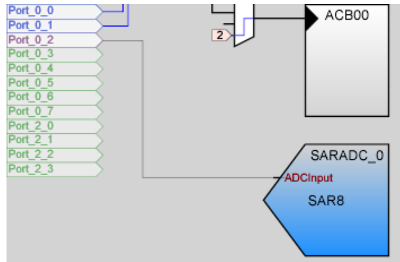
Parameters - ADCINC	
Name	ADCINC
User Module	ADCINC
Version	1.1
DataFormat	Unsigned
Resolution	14 Bit
Data Clock	VC2
PosInput	ACB01
NegInput	ACB01
NegInputGain	Disconnected
ClockPhase	Normal
PulseWidth	1
PWM Output	None

4.1.2 Implementation with SAR ADC

The Accelerometer_SAR8_Project example provided with this application note uses SAR ADC to convert the analog output from the accelerometer to digital data for processing. The project is implemented using the CY8C24x33 device family. This PSoC family has an additional SAR ADC along with ADCs such as ADCINC. This ADC only has 8-bit resolution, but is a standalone UM. It does not need any additional digital or analog blocks for its implementation. Unlike the ADCINC UM, SAR8 does not need buffer between the pins and ADC. Thus, when you are using the CY8C24x33 device and have limited resources, you can use the SAR ADC as shown in this section. The routing in PSoC Designer for SAR ADC implementation is shown in Figure 4. Multiplexing ports into the SAR8 block is done in firmware, by changing the contents of registers, as follows.

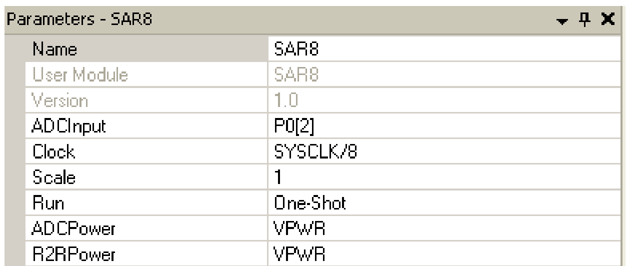
```
SAR8_SelectADCChannel(SAR8_P0_2);
```

Figure 4. Routing in PSoC with SAR8 as ADC



The SAR8 is an 8-bit ADC, and the configuration for the ADC is shown in Figure 5.

Figure 5. Configuration of SAR ADC



4.2 Resources Used in Different PSoC Families

Different UMs can be used to implement the same project in different PSoC families.

Table 1 shows the resources required when you use other PSoC families.

Table 1. Resources Used for Accelerometer Project

Part Number CY8C	Digital Bocks		Analog Blocks		Flash (KB)		SRAM (Bytes)		Decimator		I^2C Controller		User Modules
	A	**U**	**A**	**U**	**A**	**U**	**A**	**U**	**A**	**U**	**A**	**U**	**A=Available, U=Used**
24x33	4	0	4	0	8	0.5	256	6	1	0	1	1	SAR8, EzI2C
29x66	16	1	12	2	32	0.5	2048	14	1	1	1	1	ADCINC, PGA, EzI2C
27x43	8	1	12	2	16	0.5	256	14	1	1	1	1	ADCINC, PGA, EzI2C
24x94	4	1	6	2	16	0.5	1024	14	1	1	1	1	ADCINC, PGA, EzI2C
24x23A	4	1	6	2	4	0.5	256	14	1	1	1	1	ADCINC, PGA, EzI2C
21x34	4	1	4	2	8	0.8	512	17	0	0	1	1	ADC8, EzI2C
21x23	4	1	4	2	4	0.8	256	17	0	0	1	1	ADC8, EzI2C

4.3 Firmware Code and Control

All the UMs are started and the appropriate inputs are connected to the ADC in firmware. The output of the ADC can then be processed based on the end application. In the example project, the acceleration and tilt in each axis is calculated and transmitted through an I^2C bridge and plotted on a GUI.

4.3.1 Measure Acceleration

For each axis connection, the ADC input is sampled and the ADC counts are converted to the voltage equivalent value in this function. The KXSC7-2050 has an offset voltage of 1.65 V and this is subtracted from the voltage measured. Then, voltage is converted to the "g" equivalent based on the sensitivity of the accelerometer. When other accelerometers are used, the offset and sensitivity parameters must be changed to the respective accelerometer values. The code change required is provided in the Interface with Other Analog Accelerometers section.

The results are plotted as acceleration in each direction, but they can also be plotted as the angle of tilt in each direction. Similarly, other data processing can also be done in firmware.

4.3.2 Measure Tilt

The tilt in each axis is obtained from the acceleration on each axis, using the equations provided earlier.

4.3.3 IIR Filter

The acceleration obtained is filtered using the software IIR method by taking a part of the old value and adding to a part of the new value. This method is explained in application note AN2099, *PSoC 1, PSoC 3, PSoC 4, and PSoC 5LP - Single-Pole Infinite Impulse Response (IIR) Filters*.

4.3.4 I^{2}C Communication

The acceleration on each axis after converting to "g" is stored in the I^{2}C RAM buffer. The PSoC is configured as an I^{2}C slave using the EzI2Cs UM. These values are transferred over the I^{2}C-USB Bridge and displayed using the Bridge Control Panel software.

4.4 Interface with Other Analog Accelerometers

The project provided with this application note can be adapted to interface with other triaxial accelerometers by changing the following parameters in the "*main.c"* code:

```
//Volts per count=(3.3V/2^8)=0.0128
#define ADC_VOLTS_PER_COUNT 0.0128
//KXSC7-2050 1/sensitivity=1.515 g/V
#define ACCL_SENSITIVITY 1.515
//KXSC7-2050  Offset = 1.65 V
#define ACCL_OFFSET 1.65
```

When other triaxial accelerometers are used, the sensitivity and offset corresponding to the accelerometer, should be modified. If a different ADC resolution or supply voltage is used, "ADC_VOLTS_PER_COUNT" should be changed.

5 Setup for Testing and Graphical Interface

The Kionix KXSC7-2050 is interfaced with PSoC using the CY3210-PSoCEval1 board as shown in Figure 6. Table 2 shows the PSoC connections. The KXTC9-2050 accelerometer can also be interfaced with PSoC using the same project. The PSoC port pins and the accelerometer pins are connected. The results are observed using the I^{2}C-USB bridge. Refer to AN50987 - *Getting Started with I2C in PSoC 1* for details on using the I^{2}C-USB Bridge. Either the acceleration or tilt on each axis can be displayed on the GUI. The Results section displays the acceleration.

Figure 6. Board Setup to Test Accelerometer Interface

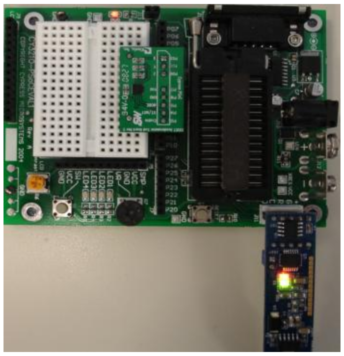


Table 2. CY3210 Evaluation Board Setup

PSoC 1 Pins	CY3210 Connections	Description
P0[2]	-	X-axis output from KXSC7-2050/KXTC9-2050
P0[1]	-	Y-axis output from KXSC7-2050/KXTC9-2050
P0[0]	-	Z-axis output from KXSC7-2050/KXTC9-2050
P1[3]	-	Enable signal for KXSC7-2050/KXTC9-2050
P1[4]	-	ST/MOT signal for KXSC7-2050/KXTC9-2050
P1[5]	-	Mode signal for KXSC7-2050
-	ISSP header (J11)	Connect MiniProg1 or MiniProg3 for programming
-	ISSP header (J11)	Connect MiniProg3 for I2C communication to PC; P1[0] and P1[1] are routed in CY3210

6 Results

The acceleration on each axis is displayed in the graph and is expressed in terms of “g”. KXSC7-2050/KXTC9-2050 is a three-axis, 2g accelerometer, the g values for the X, Y, and Z axes are between –1 and +1.

Different orientation of the board leads to different “g” values on the output. Figure 7 through Figure 12 show some combinations. The board orientation is changed manually; therefore, the outputs vary slightly from the expected values.

Figure 7. Board Inline with “g” and X = 0g, Y = 1g, and Z = 0g

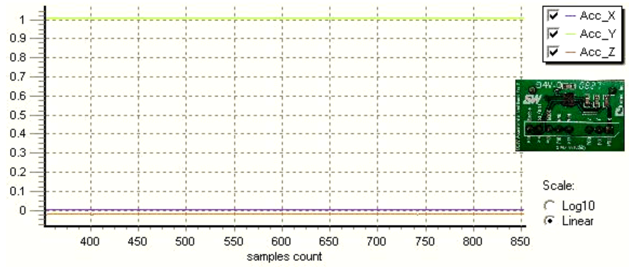


Figure 8. Board Inline with “g” and X = 1g, Y = 0g, and Z = 0g

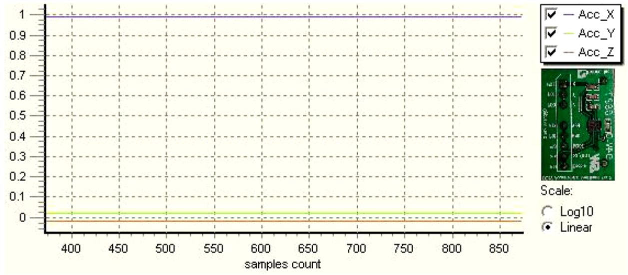


Figure 9. Board Inline with “g” and X = 0g, Y = –1g, and Z = 0g

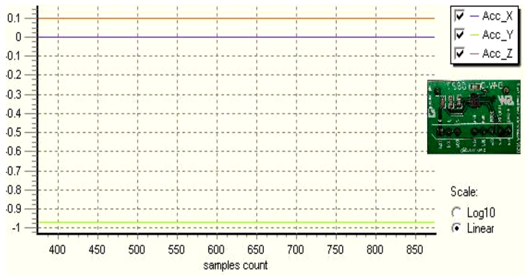


Figure 10. Board Inline with “g” and X = –1g, Y = 0g, and Z = 0g

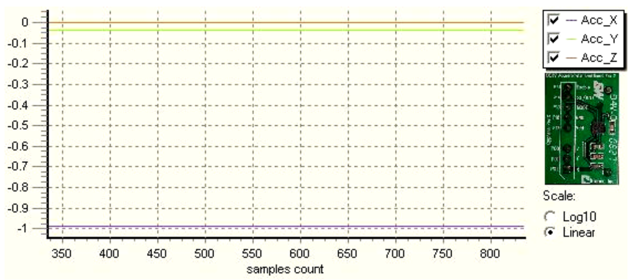


Figure 11. Accelerometer Chip Perpendicular to Earth and on Top

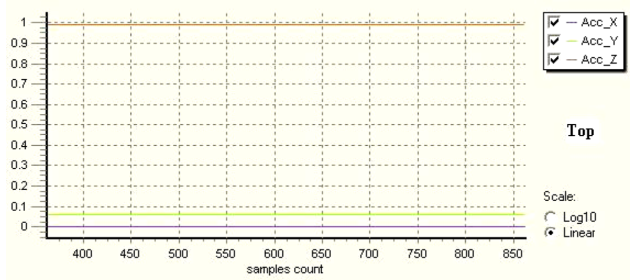
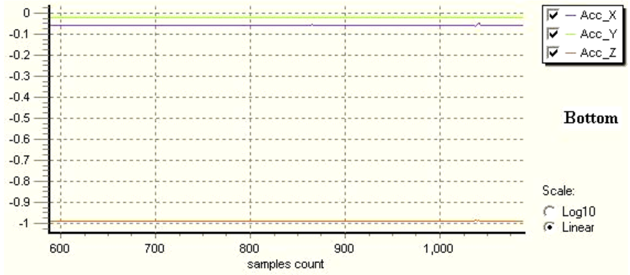
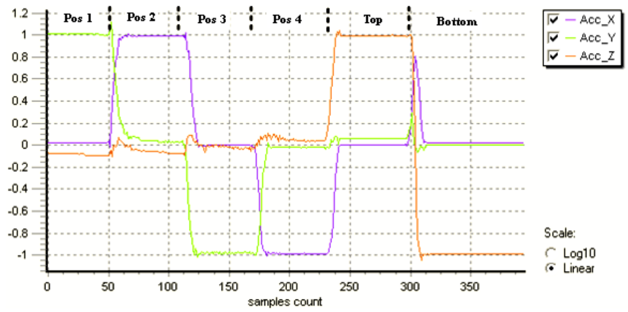


Figure 12. Accelerometer Chip Perpendicular to Earth and on Bottom



The graph obtained when the board is changed from one position to another is shown in Figure 13.

Figure 13. Accelerometer Moved Along Different Axes



When there is a free fall, X, Y, and Z have 0g acceleration.

7 Summary

An accelerometer type can be selected based on your application. It is possible to interface both digital and analog output accelerometers with PSoC. This application note demonstrates the interface of a triaxial analog output accelerometer to obtain acceleration and tilt. This application note also provides the simple changes required to interface other triaxial accelerometers.

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A Appendix A

A.1 Accelerometer Types and Applications

All accelerometers have a mechanical mass that converts vibration into displacement. This displacement is sensed using a sensor. The classification of accelerometers based on sensor type is listed in Table 3.

Table 3. Accelerometer Types and Properties

Accelerator Type	Properties	Measurement
Capacitive	Good DC accuracy, low noise, good temperature performance	Tilt, Vibration
Piezoelectric	AC response only	Vibration, Shock
Piezoresistive	Good DC accuracy, poor temperature performance	Tilt, Vibration
Electromechanical Servo	Good DC accuracy, low frequency only, fragile	Tilt

The choice of accelerometer depends on the type of application in which it is used.

A.2 Applications

Some applications in which accelerometers are used are as follows:

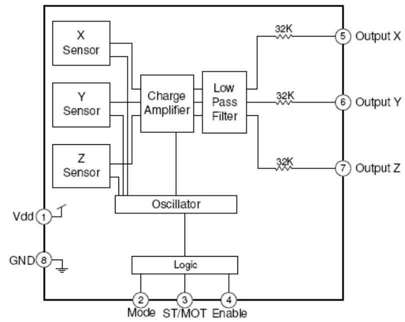
- Mobile Phones: Used for motion activated functions, gaming, free-fall detection, and vibration control.
- Vehicles: Used for crash testing, robotics, motion control, and skid detection.
- Computers: Used in computers and computer peripherals such as mouse, for motion activated functions, gaming, and tilt sensing.
- Medical Appliances: Used in pacemaker and blood pressure measurement applications.
- Home Appliances: Used in appliances such as washing machines for spin and vibration measurement.

B Appendix B

B.1 KXSC7-2050 Accelerometer

KXSC7-2050 is a tri-axis, analog voltage output device. The output range of this device is ±2g, or 19.9 m/s^2. The voltage on the three outputs change based on the static and dynamic acceleration of the device. The functional block diagram of the accelerometer is shown in Figure 14. This diagram is reproduced from the datasheet of the KXSC7 accelerometer.

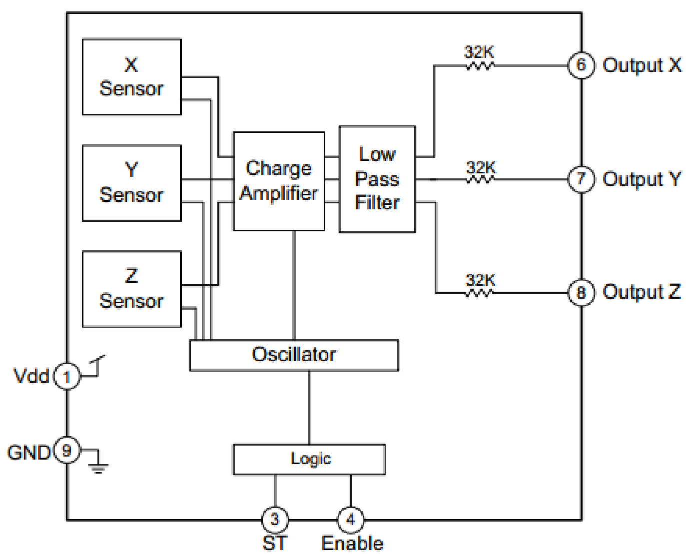
Figure 14. Functional Block Diagram of KXSC7-2050



The sensor element in the accelerometer works on the principle of differential capacitance. Here, the acceleration causes displacement in the silicon structure, resulting in a change in capacitance. The ASIC is included inside the package to convert change in capacitance into analog voltage, which is proportional to acceleration. It also features a programmable low-pass filter. Thus the output voltages can be read directly by the ADC and processed accordingly.

The KXTC9 is a high-performance, tri-axis accelerometer with analog outputs, a factory-programmable low-pass filter, and g-range from ±1.5g to ±6g. The functional block diagram of the KXTC9-2050 accelerometer is provided in Figure 15.

Figure 15. Functional Block Diagram of KXTC9-2050



Document History

Document Title: AN52678 - PSoC® 1 Interface with Triaxial Analog Accelerometer for Measuring Tilt

Document Number: 001-52678

Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	2683340	YARA	04/03/2009	New application note.
*A	3170736	YARA	02/15/2011	1. Change of title, abstract, and introduction. 2. Figure and description about ADC configurations, as per customer feedback. 3. Information required for interfacing with other three-axis analog accelerometers. 4. Update of projects from PSoC Designer 5.0 to 5.1.
*B	3271365	YARA	06/01/2011	Updated title as per template.
*C	4368577	MSUR	05/02/2014	Updated in new template. Completing Sunset Review.
*D	4635405	DIMA	01/22/2015	Updated the document as per new template. Updated the Software Version to “PSoC Designer™ 5.4 CP1” in page 1. Removed reference to obsolete AN2352 in Interface with PSoC. Updated the hyperlink AN2352 to AN2099 in IIR Filter. Included support for KXTC9-2050 accelerometer in Appendix B.
*E	4756504	MSUR	05/06/2015	Added the PSoC Resources section. Updated Figure 1 and added Table 2.

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