

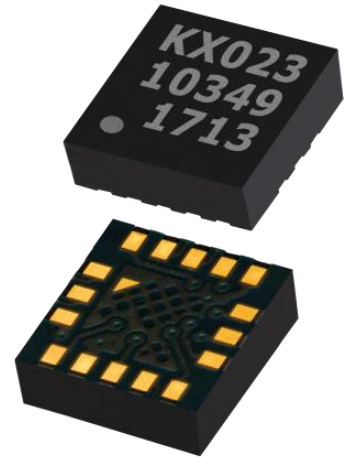


± 2g / 4g / 8g Tri-axis Digital Accelerometer Specifications

PART NUMBER:
KX023-1025
Rev. 12.0
5-Apr-16

Product Description

The KX023 is a tri-axis $\pm 2g$, $\pm 4g$ or $\pm 8g$ silicon micromachined accelerometer with integrated 256 byte buffer, orientation, tap/double tap, and activity detecting algorithms. The sense element is fabricated using Kionix's proprietary plasma micromachining process technology. Acceleration sensing is based on the principle of a differential capacitance arising from acceleration-induced motion of the sense element, which further utilizes common mode cancellation to decrease errors from process variation, temperature, and environmental stress. The sense element is hermetically sealed at the wafer level by bonding a second silicon lid wafer to the device using a glass frit. A separate ASIC device packaged with the sense element provides signal conditioning, and intelligent user-programmable application algorithms. The accelerometer is delivered in a 3 x 3 x 0.9 mm LGA plastic package operating from a 1.71 – 3.6V DC supply. Voltage regulators are used to maintain constant internal operating voltages over the range of input supply voltages. This results in stable operating characteristics over the range of input supply voltages and virtually undetectable ratiometric error. I²C or SPI digital protocol is used to communicate with the chip to configure and check for updates to the orientation, Directional Tap™ detection and activity monitoring algorithms.



Features

- 3 x 3 x 0.9 mm LGA
- User-selectable g Range and Output Data Rate
- User-selectable low power mode or high resolution mode
- Digital High-Pass Filter Outputs
- Embedded FIFO/FILO buffer
- Low Power Consumption with FlexSet™ Performance Optimization
- Internal voltage regulator
- Enhanced integrated Directional Tap/Double-Tap™, and Device-orientation Algorithms
- User-configurable wake-up function
- Digital I²C up to 3.4 MHz
- Digital 3-wire and 4-wire SPI up to 10 MHz
- Lead-free Solderability
- Excellent Temperature Performance
- High Shock Survivability
- Factory Programmed Offset and Sensitivity
- Self-test Function



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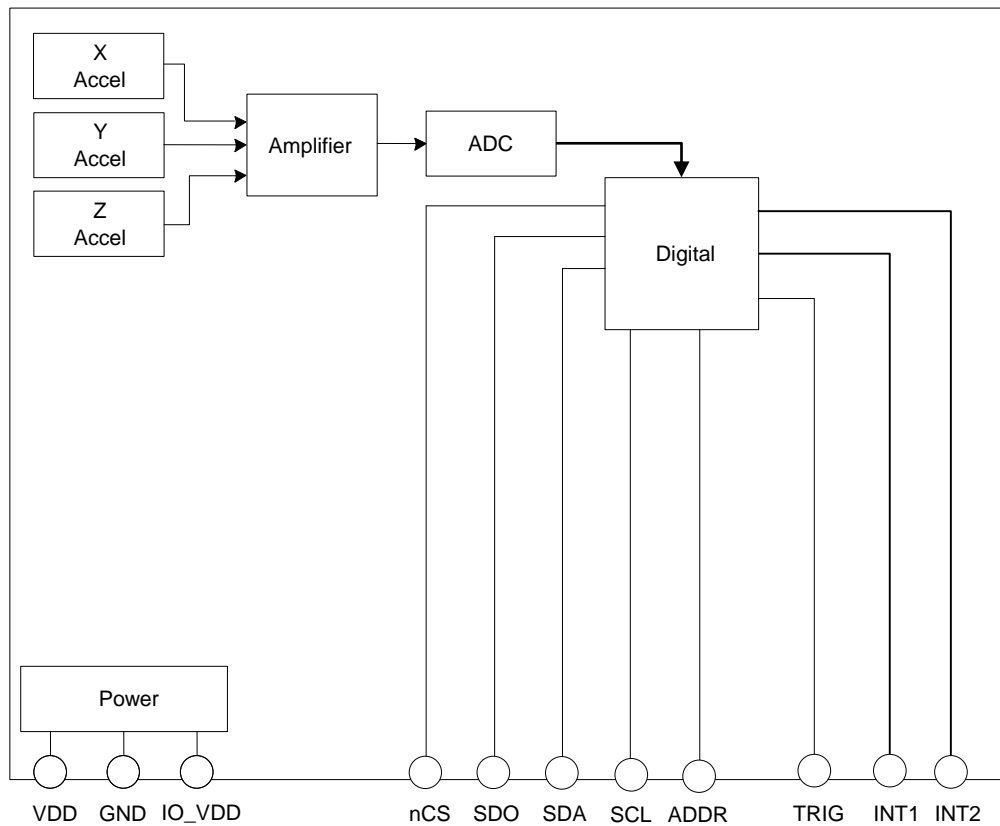
GENERAL PRECAUTION 77



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Functional Diagram





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Product Specifications

Mechanical

(Specifications are for operation at VDD = 2.5V and T = RT = 25°C unless stated otherwise)

| Parameters | | Units | Min | Typical | Max |
|---|-------------------------|----------|-------|-----------------------|-------|
| Operating Temperature Range | | °C | -40 | - | 85 |
| Zero-g Offset | | mg | | ±25 | ±90 |
| Zero-g Offset Variation from RT over Temp. | | mg/°C | | 0.2 | |
| Sensitivity ¹ | GSEL1=0, GSEL0=0 (± 2g) | counts/g | 15565 | 16384 | 17203 |
| | GSEL1=0, GSEL0=1 (± 4g) | | 7782 | 8192 | 8602 |
| | GSEL1=1, GSEL0=0 (± 8g) | | 3891 | 4096 | 4301 |
| Sensitivity (Buffer 8-bit mode) ^{1,2} | GSEL1=0, GSEL0=0 (± 2g) | counts/g | 61 | 64 | 67 |
| | GSEL1=0, GSEL0=1 (± 4g) | | 30 | 32 | 34 |
| | GSEL1=1, GSEL0=0 (± 8g) | | 15 | 16 | 17 |
| Sensitivity Variation from RT over Temp. | | %/°C | | 0.01 | |
| Positive Self-Test Output change on Activation ⁵ | | g | 0.35 | 0.5 | 0.65 |
| Mechanical Resonance (-3dB) ³ | | Hz | | 3500 (xy) 1800 (z) | |
| Non-Linearity | | % of FS | | 0.6 | |
| Cross Axis Sensitivity | | % | | 2 | |
| Noise (RMS at 50Hz with low-pass filter = ODR/9) ⁴ | | mg | | 0.75 | |

Table 1: Mechanical Specifications

Notes:

1. Resolution and acceleration ranges are user selectable via I²C or SPI.
2. Sensitivity is proportional to BRES in BUF_CNTL2.
3. Resonance as defined by the dampened mechanical sensor.
4. Noise varies with Output Data Rate (ODR) and Current Consumption settings. Contact Kionix Engineering for additional details on FlexSet™ Performance Optimization.
5. Requires changing of STPOL bit in INC1 register to 1 prior to performing self-test.



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Electrical

(Specifications are for operation at VDD = 2.5V and T = 25°C unless stated otherwise)

| Parameters | | Units | Min | Typical | Max |
|---|---------------------------------------|-------|--------------|---------|--------------|
| Supply Voltage (VDD) | Operating | V | 1.71 | 2.5 | 3.6 |
| I/O Pads Supply Voltage (IO_VDD) | | V | 1.7 | | VDD |
| Current Consumption | High Resolution Mode (RES = 1) | μA | | 145 | |
| | Low Power Mode ¹ (RES = 0) | | | 10 | |
| | Standby | | | 0.9 | |
| Output Low Voltage (IO_VDD < 2V) ² | | V | - | - | 0.2 * IO_VDD |
| Output Low Voltage (IO_VDD ≥ 2V) ² | | V | - | - | 0.4 |
| Output High Voltage | | V | 0.8 * IO_VDD | - | - |
| Input Low Voltage | | V | - | - | 0.2 * IO_VDD |
| Input High Voltage | | V | 0.8 * IO_VDD | - | - |
| Input Pull-down Current | | μA | | 0 | |
| Start Up Time ³ | | ms | 2.0 | | 650 |
| Power Up Time ⁴ | | ms | | 10 | |
| I ² C Communication Rate | | MHz | | | 3.4 |
| SPI Communication Rate | | MHz | | | 10 |
| Output Data Rate (ODR) ⁵ | | Hz | 0.781 | 50 | 1600 |
| Bandwidth (-3dB) ⁶ | RES = 0 | Hz | | 800 | |
| | RES = 1 | Hz | | ODR/2 | |

Table 2: Electrical Specifications

Notes:

1. Current varies with Output Data Rate (ODR) as shown the chart below, and with Noise level settings. Contact Kionix Engineering for additional details on FlexSet™ Performance Optimization.
2. For I²C communication, this assumes a minimum 1.5KΩ pull-up resistor on SCL and SDA pins.
3. Startup time is from PC1 set to valid outputs. Time varies with Output Data Rate (ODR); see chart below
4. Power up time is from VDD valid to device boot completion.
5. User selectable through I²C or SPI.
6. User selectable and dependent on ODR and RES.

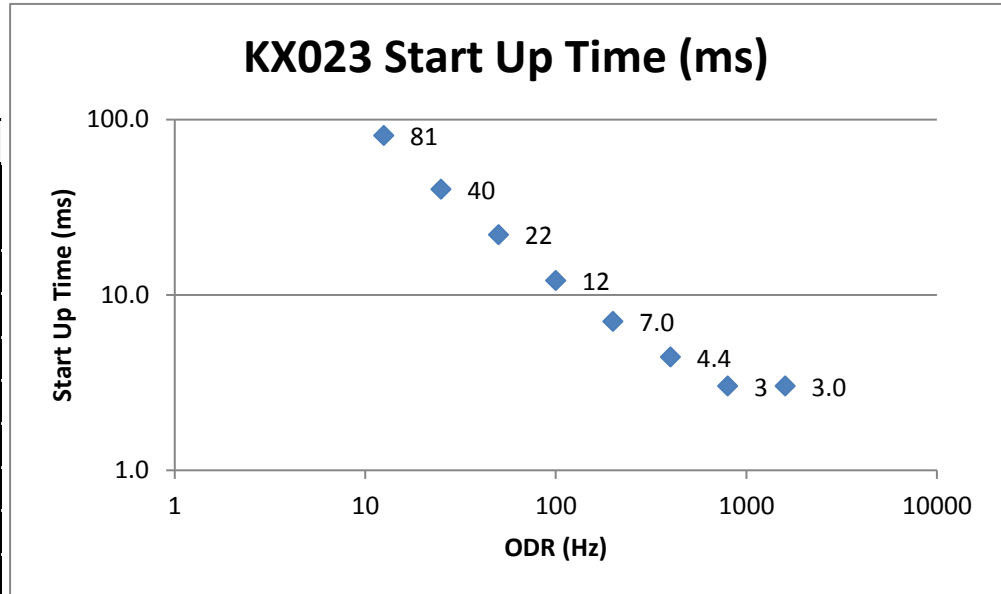


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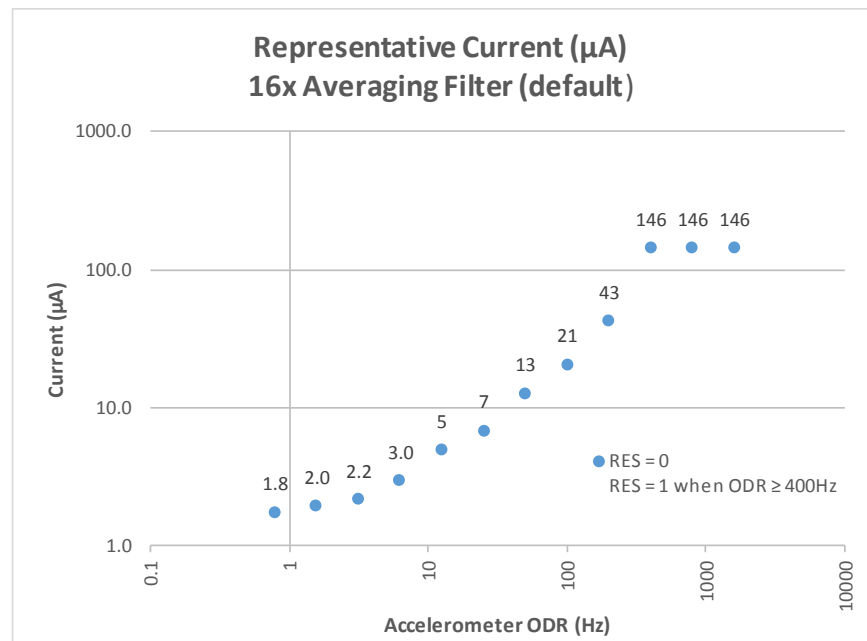
Start Up Time Profile

| KX023 Start Up Time | |
|---------------------|-----------|
| ODR (Hz) | Time (ms) |
| 1600 | 3.0 |
| 800 | 3.0 |
| 400 | 4.4 |
| 200 | 7.0 |
| 100 | 12 |
| 50 | 22 |
| 25 | 40 |
| 12.5 | 81 |



Current Profile

| Representative Current Profile | | |
|--------------------------------|---------|--------------|
| ODR (Hz) | RES | Current (µA) |
| 0 | Standby | 0.9 |
| 0.781 | 0 | 1.8 |
| 1.563 | 0 | 2.0 |
| 3.125 | 0 | 2.2 |
| 6.25 | 0 | 3.0 |
| 12.5 | 0 | 5 |
| 25 | 0 | 7 |
| 50 | 0 | 13 |
| 100 | 0 | 21 |
| 200 | 0 | 43 |
| 400 | 1 | 146 |
| 800 | 1 | 146 |
| 1600 | 1 | 146 |





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Power-On Procedure

Proper functioning of power-on reset (POR) is dependent on the specific **VDD**, **VDD_{Low}**, **T_{VDD}** (rise time), and **T_{VDD_off}** profile of individual applications. It is recommended to minimize **VDD_{Low}**, and **T_{VDD}**, and maximize **T_{VDD_off}**. It is also advised that the **VDD** ramp up time **T_{VDD}** be monotonic. Note that the outputs will not be stable until **VDD** has reached its final value.

- ! *To assure proper POR, the application should be evaluated over the customer specified range of VDD, VDD_{Low}, T_{VDD}, T_{VDD_off} and temperature as POR performance can vary depending on these parameters.*

Please refer to Technical Note **TN014 KX022, KX023 Accelerometer Power-On Procedure** for more information.



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Environmental

| Parameters | | Units | Min | Typical | Max |
|-------------------------------------|-----------------|-------|------|---------|-----------------------------------|
| Supply Voltage (VDD) | Absolute Limits | V | -0.5 | - | 3.63 |
| Operating Temperature Range | | °C | -40 | - | 85 |
| Storage Temperature Range | | °C | -55 | - | 150 |
| Mech. Shock (powered and unpowered) | | g | - | - | 5000 for 0.5ms 10000 for 0.2ms |
| ESD | HBM | V | - | - | 2000 |

Table 3: Environmental Specifications



Caution: ESD Sensitive and Mechanical Shock Sensitive Component, improper handling can cause permanent damage to the device.



These products conform to RoHS Directive 2011/65/EU of the European Parliament and of the Council of the European Union that was issued June 8, 2011. Specifically, these products do not contain any non-exempted amounts of lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE) above the maximum concentration values (MCV) by weight in any of its homogenous materials. Homogenous materials are “of uniform composition throughout”. The MCV for lead, mercury, hexavalent chromium, PBB, and PBDE is 0.10%. The MCV for cadmium is 0.010%.

Applicable Exemption: 7C-1 - *Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors (piezoelectronic devices) or in a glass or ceramic matrix compound.*



These products are also in conformance with REACH Regulation No 1907/2006 of the European Parliament and of the Council that was issued Dec. 30, 2011. They do not contain any Substances of Very High Concern (SVHC-161) as identified by the European Chemicals Agency as of 17 December 2014.



This product is halogen-free per IEC 61249-2-21. Specifically, the materials used in this product contain a maximum total halogen content of 1500 ppm with less than 900-ppm bromine and less than 900-ppm chlorine.

Soldering

Soldering recommendations are available upon request or from www.kionix.com.



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Terminology

g

A unit of acceleration equal to the acceleration of gravity at the earth's surface.

$$1g = 9.8 \frac{m}{s^2}$$

One thousandth of a g (0.0098 m/ s²) is referred to as 1 milli-g (1 mg).

Sensitivity

The sensitivity of an accelerometer is the change in output per unit of input acceleration at nominal VDD and temperature. The term is essentially the gain of the sensor expressed in counts per g (counts/g) or LSB's per g (LSB/g). Occasionally, sensitivity is expressed as a resolution, i.e. milli-g per LSB (mg/LSB) or milli-g per count (mg/count). Sensitivity for a given axis is determined by measurements of the formula:

$$Sensitivity = \frac{(Output @ +1g - Output @ -1g)}{2g}$$

The sensitivity tolerance describes the range of sensitivities that can be expected from a large population of sensors at room temperature and over life. When the temperature deviates from room temperature (25°C), the sensitivity will vary by the amount shown in Table 1.

Zero-g offset

Zero-g offset or 0-g offset describes the actual output of the accelerometer when no acceleration is applied. Ideally, the output would always be in the middle of the dynamic range of the sensor (content of the OUTX, OUTY, OUTZ registers = 00h, expressed as a 2's complement number). However, because of mismatches in the sensor, calibration errors, and mechanical stress, the output can deviate from 00h. This deviation from the ideal value is called 0-g offset. The zero-g offset tolerance describes the range of 0-g offsets of a population of sensors over the operating temperature range.

Self-test

Self-test allows a functional test of the sensor without applying a physical acceleration to it. When activated, an electrostatic force is applied to the sensor, simulating an input acceleration. The sensor outputs respond accordingly. If the output signals change within the amplitude specified in Table 1, then the sensor is working properly and the parameters of the interface chip are within the defined specifications.



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Functionality

Sense element

The sense element is fabricated using Kionix's proprietary plasma micromachining process technology. This process technology allows Kionix to create mechanical silicon structures which are essentially mass-spring systems that move in the direction of the applied acceleration. Acceleration sensing is based on the principle of a differential capacitance arising from the acceleration-induced motion. Capacitive plates on the moving mass move relative to fixed capacitive plates anchored to the substrate. The sense element is hermetically sealed at the wafer level by bonding a second silicon lid wafer to the device using a glass frit.

ASIC interface

A separate ASIC device packaged with the sense element provides all of the signal conditioning and communication with the sensor. The complete measurement chain is composed by a low-noise capacitance to voltage amplifier which converts the differential capacitance of the MEMS sensor into an analog voltage that is sent through an analog-to-digital converter. The acceleration data may be accessed through the I²C digital communications provided by the ASIC. In addition, the ASIC contains all of the logic to allow the user to choose data rates, g-ranges, filter settings, and interrupt logic. Plus, there are two programmable state machines which allow the user to create unique embedded functions based on changes in acceleration.

Factory calibration

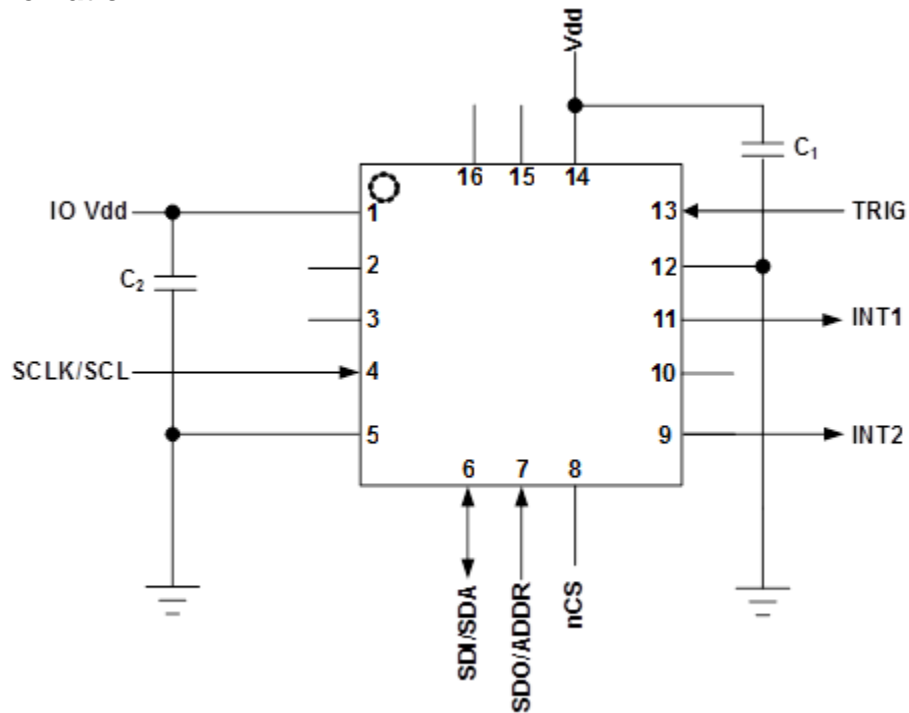
Kionix trims the offset and sensitivity of each accelerometer by adjusting gain (sensitivity) and 0-g offset trim codes stored in nonvolatile memory (OTP). Additionally, all functional register default values are also programmed into the nonvolatile memory. Every time the device is turned on or a software reset command is issued, the trimming parameters and default register values are downloaded into the volatile registers to be used during active operation. This allows the device to function without further calibration.



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Application Schematic



Pin Descriptions

| Pin | Name | Description |
|-----|----------|--|
| 1 | IO_VDD | The power supply input for the digital communication bus. Optionally decouple this pin to ground with a 0.1uF ceramic capacitor. |
| 2 | NC | Not Internally Connected – Can be connected to VDD, IO_VDD, GND or Float |
| 3 | NC | Not Internally Connected – Can be connected to VDD, IO_VDD, GND or Float |
| 4 | SCLK/SCL | SPI and I ² C Serial Clock |
| 5 | GND | Ground |
| 6 | SDI/SDA | SPI Data input / I2C Serial Data |
| 7 | SDO/ADDR | Serial Data Out pin during 4 wire SPI communication and part of the device address during I2C communication. |
| 8 | nCS | SPI enable / I2C mode select (GND = SPI enabled, I2C communication disabled / IO_VDD = SPI disabled, I2C communication enabled) |
| 9 | INT2 | Physical Interrupt 2 |
| 10 | NC | Not Internally Connected – Can be connected to VDD, IO_VDD, GND or Float |
| 11 | INT1 | Physical Interrupt 1 |
| 12 | GND | Ground |
| 13 | TRIG | Trigger pin for FIFO buffer control – Connect to GND when not using external trigger option |
| 14 | VDD | The power supply input. Decouple this pin to ground with a 0.1uF ceramic capacitor. |
| 15 | NC | Not Internally Connected – Can be connected to VDD, IO_VDD, GND or Float |
| 16 | NC | Not Internally Connected – Can be connected to VDD, IO_VDD, GND or Float |

Table 4: Pin Descriptions

| | | |
|---|---|---|
|  | ± 2g / 4g / 8g Tri-axis Digital Accelerometer Specifications | PART NUMBER: KX023-1025 Rev. 12.0 5-Apr-16 |
|---|---|---|

Test Specifications

Special Characteristics:

These characteristics have been identified as being critical to the customer. Every part is tested to verify its conformance to specification prior to shipment.

| Parameter | Specification | Test Conditions |
|--|----------------------|-------------------|
| Zero-g Offset @ RT ¹ (2g range) | 0 ± 1475 counts | 25°C, VDD = 2.5 V |
| Sensitivity @ RT ¹ (2g range) | 16384 ± 819 counts/g | 25°C, VDD = 2.5 V |

Table 5: Test Specifications

¹Room Temperature = 25°C



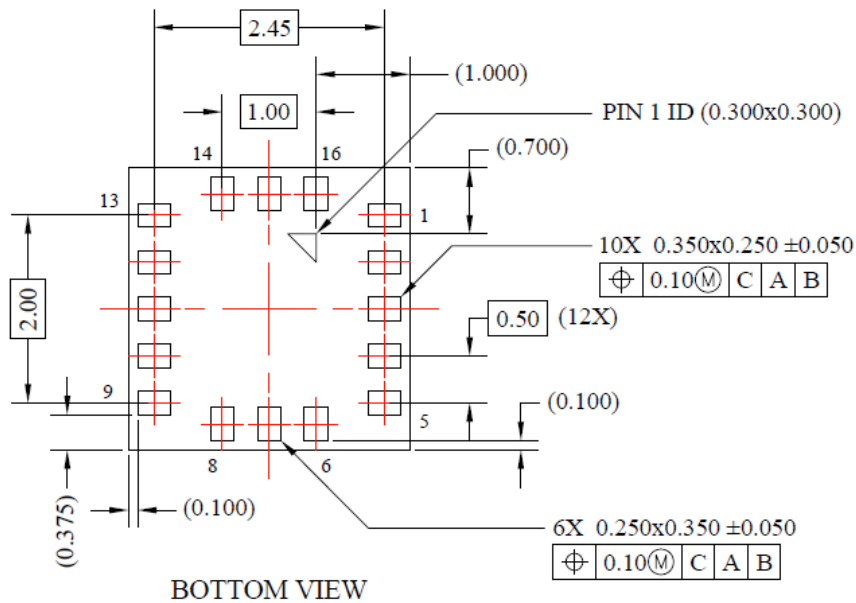
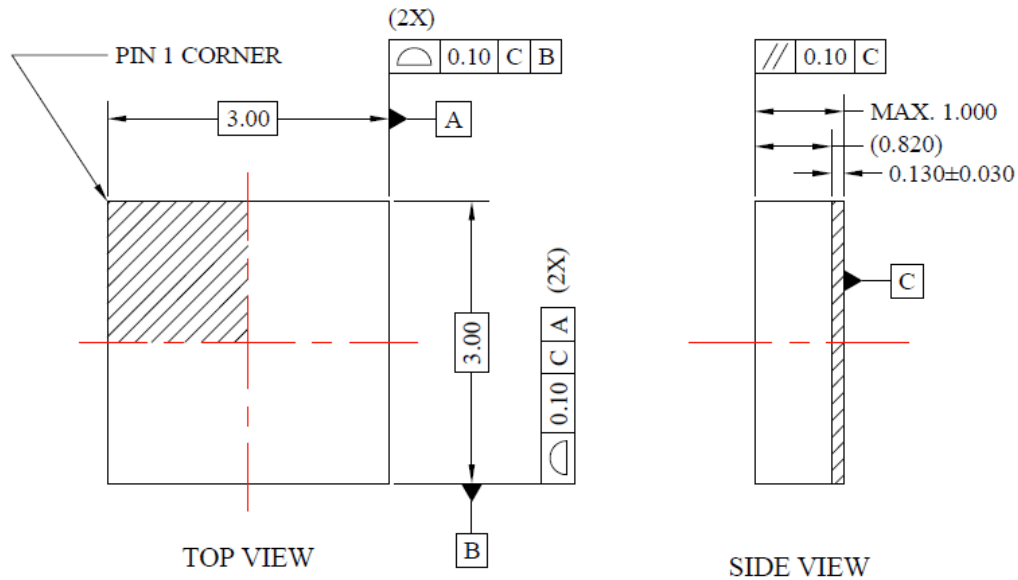
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Package Dimensions and Orientation

Dimensions

3 x 3 x 0.9 mm LGA



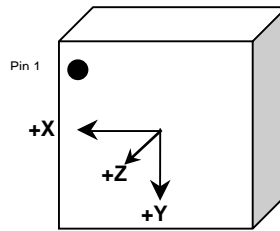
All dimensions and tolerances conform to ASME Y14.5M-1994



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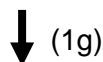
Orientation



When device is accelerated in +X, +Y or +Z direction, the corresponding output will increase.

Static X/Y/Z Output Response versus Orientation to Earth's surface (1g): GSEL1=0, GSEL0=0 (± 2g)

| Position | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | |
|-------------------|--------|-----|--------|-----|-------|----|-------|----|-------------------|-------------------|--------|-----|
| Diagram | | | | | | | | | Top Bottom | Bottom Top | | |
| Resolution (bits) | 16 | 8 | 16 | 8 | 16 | 8 | 16 | 8 | 16 | 8 | 16 | 8 |
| X (counts) | 0 | 0 | -16384 | -64 | 0 | 0 | 16384 | 64 | 0 | 0 | 0 | 0 |
| Y (counts) | -16384 | -64 | 0 | 0 | 16384 | 64 | 0 | 0 | 0 | 0 | 0 | 0 |
| Z (counts) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16384 | 64 | -16384 | -64 |
| X-Polarity | 0 | | - | | 0 | | + | | 0 | | 0 | |
| Y-Polarity | - | | 0 | | + | | 0 | | 0 | | 0 | |
| Z-Polarity | 0 | | 0 | | 0 | | 0 | | + | | - | |



Earth's Surface

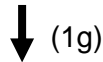


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Static X/Y/Z Output Response versus Orientation to Earth's surface (1g): GSEL1=0, GSEL0=1 (± 4g)

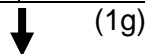
| Position | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | |
|-------------------|-------|-----|-------|-----|------|----|------|----|-------------------|----|-------------------|-----|
| Diagram | | | | | | | | | Top Bottom | | Bottom Top | |
| Resolution (bits) | 16 | 8 | 16 | 8 | 16 | 8 | 16 | 8 | 16 | 8 | 16 | 8 |
| X (counts) | 0 | 0 | -8192 | -32 | 0 | 0 | 8192 | 32 | 0 | 0 | 0 | 0 |
| Y (counts) | -8192 | -32 | 0 | 0 | 8192 | 32 | 0 | 0 | 0 | 0 | 0 | 0 |
| Z (counts) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8192 | 32 | -8192 | -32 |
| X-Polarity | 0 | | - | | 0 | | + | | 0 | | 0 | |
| Y-Polarity | - | | 0 | | + | | 0 | | 0 | | 0 | |
| Z-Polarity | 0 | | 0 | | 0 | | 0 | | + | | - | |



Earth's Surface

Static X/Y/Z Output Response versus Orientation to Earth's surface (1g): GSEL1=1, GSEL0=0 (± 8g)

| Position | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | |
|-------------------|-------|-----|-------|-----|------|----|------|----|-------------------|----|-------------------|-----|
| Diagram | | | | | | | | | Top Bottom | | Bottom Top | |
| Resolution (bits) | 16 | 8 | 16 | 8 | 16 | 8 | 16 | 8 | 16 | 8 | 16 | 8 |
| X (counts) | 0 | 0 | -4096 | -16 | 0 | 0 | 4096 | 16 | 0 | 0 | 0 | 0 |
| Y (counts) | -4096 | -16 | 0 | 0 | 4096 | 16 | 0 | 0 | 0 | 0 | 0 | 0 |
| Z (counts) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4096 | 16 | -4096 | -16 |
| X-Polarity | 0 | | - | | 0 | | + | | 0 | | 0 | |
| Y-Polarity | - | | 0 | | + | | 0 | | 0 | | 0 | |
| Z-Polarity | 0 | | 0 | | 0 | | 0 | | + | | - | |



Earth's Surface

| | | |
|---|---|---|
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|---|---|---|

Digital Interface

The Kionix KX023 digital accelerometer has the ability to communicate via the I²C and SPI digital serial interface protocols. This allows for easy system integration by eliminating analog-to-digital converter requirements and by providing direct communication with system micro-controllers.

The serial interface terms and descriptions as indicated in Table 6 below will be observed throughout this document.

| Term | Description |
|-------------|---|
| Transmitter | The device that transmits data to the bus. |
| Receiver | The device that receives data from the bus. |
| Master | The device that initiates a transfer, generates clock signals, and terminates a transfer. |
| Slave | The device addressed by the Master. |

Table 6. Serial Interface Terminologies

I²C Serial Interface

As previously mentioned, the KX023 has the ability to communicate on an I²C bus. I²C is primarily used for synchronous serial communication between a Master device and one or more Slave devices. The Master, typically a micro controller, provides the serial clock signal and addresses Slave devices on the bus. The KX023 always operates as a Slave device during standard Master-Slave I²C operation.

I²C is a two-wire serial interface that contains a Serial Clock (SCL) line and a Serial Data (SDA) line. SCL is a serial clock that is provided by the Master, but can be held low by any Slave device, putting the Master into a wait condition. SDA is a bi-directional line used to transmit and receive data to and from the interface. Data is transmitted MSB (Most Significant Bit) first in 8-bit per byte format, and the number of bytes transmitted per transfer is unlimited. The I²C bus is considered free when both lines are high.

The I²C interface is compliant with high-speed mode, fast mode and standard mode I²C protocols.



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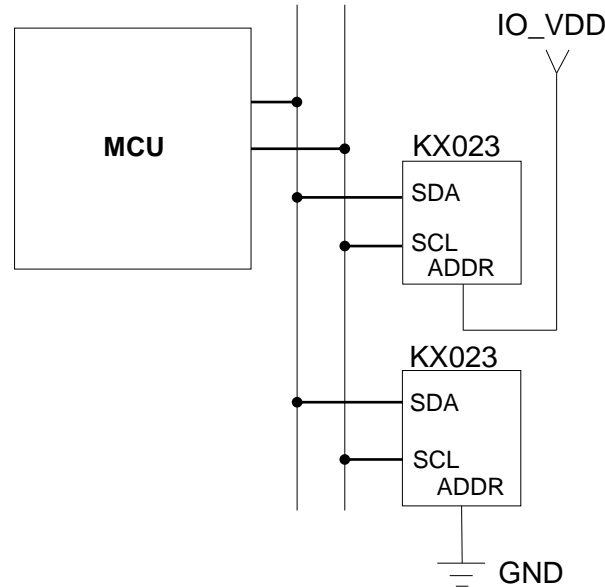


Figure 1: Multiple KX023 I²C Connection

I²C Address

| Description | Address Pad | 7 bit Address | Address | <7> | <6> | <5> | <4> | <3> | <2> | <1> | <0> |
|---------------------|-------------|---------------|---------|-----|-----|-----|-----|-----|-----|-----|-----|
| I ² C Wr | IO_VDD | 1Fh | 3Eh | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| I ² C Rd | IO_VDD | 1Fh | 3Fh | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| I ² C Wr | GND | 1Eh | 3Ch | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| I ² C Rd | GND | 1Eh | 3Dh | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 |

I²C Operation

Transactions on the I²C bus begin after the Master transmits a start condition (S), which is defined as a high-to-low transition on the data line while the SCL line is held high. The bus is considered busy after this condition. The next byte of data transmitted after the start condition contains the Slave Address (SAD) in the seven MSBs (Most Significant Bits), and the LSB (Least Significant Bit) tells whether the Master will be receiving data '1' from the Slave or transmitting data '0' to the Slave. When a Slave Address is sent, each device on the bus compares the seven MSBs with its internally stored address. If they match, the device considers itself addressed by the Master. The KX023's Slave Address is comprised of a programmable part and a fixed part, which allows for connection of multiple KX023's to the same I²C bus. The Slave Address associated with the KX023 is 001111X, where the programmable bit, X, is determined by the assignment of ADDR (pin 7) to GND or IO_VDD. Figure 1 above shows how two KX023's would be implemented on an I²C bus.



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It is mandatory that receiving devices acknowledge (ACK) each transaction. Therefore, the transmitter must release the SDA line during this ACK pulse. The receiver then pulls the data line low so that it remains stable low during the high period of the ACK clock pulse. A receiver that has been addressed, whether it is Master or Slave, is obliged to generate an ACK after each byte of data has been received. To conclude a transaction, the Master must transmit a stop condition (P) by transitioning the SDA line from low to high while SCL is high. The I²C bus is now free. Note that if the KX023 is accessed through I²C protocol before the startup is finished a NACK signal is sent.

Writing to 8-bit Register

Upon power up, the Master must write to the KX023's control registers to set its operational mode. Therefore, when writing to a control register on the I²C bus, as shown Sequence 1 on the following page, the following protocol must be observed: After a start condition, SAD+W transmission, and the KX023 ACK has been returned, an 8-bit Register Address (RA) command is transmitted by the Master. This command is telling the KX023 to which 8-bit register the Master will be writing the data. Since this is I²C mode, the MSB of the RA command should always be zero (0). The KX023 acknowledges the RA and the Master transmits the data to be stored in the 8-bit register. The KX023 acknowledges that it has received the data and the Master transmits a stop condition (P) to end the data transfer. The data sent to the KX023 is now stored in the appropriate register. The KX023 automatically increments the received RA commands and, therefore, multiple bytes of data can be written to sequential registers after each Slave ACK as shown in Sequence 2 on the following page.

Note** If a STOP condition is sent on the least significant bit of write data or the following master acknowledge cycle, the last write operation is not guaranteed and it may alter the content of the affected registers.

Reading from 8-bit Register

When reading data from a KX023 8-bit register on the I²C bus, as shown in Sequence 3 on the next page, the following protocol must be observed: The Master first transmits a start condition (S) and the appropriate Slave Address (SAD) with the LSB set at '0' to write. The KX023 acknowledges and the Master transmits the 8-bit RA of the register it wants to read. The KX023 again acknowledges, and the Master transmits a repeated start condition (Sr). After the repeated start condition, the Master addresses the KX023 with a '1' in the LSB (SAD+R) to read from the previously selected register. The Slave then acknowledges and transmits the data from the requested register. The Master does not acknowledge (NACK) it received the transmitted data, but transmits a stop condition to end the data transfer. The accelerometer automatically increments through its sequential registers, allowing data to be read from multiple registers following a single SAD+R command as shown below in Sequence 4 on the following page. Reading data from a buffer read register is a special case because if register address (RA) is set to buffer read register (BUF_READ) in Sequence 4, the register auto-increment feature is automatically disabled. Instead, the Read Pointer will increment to the next data in the buffer, thus allowing reading multiple bytes of data from the buffer using a single SAD+R command.

Note** Accelerometer's output data should be read in a single transaction using the auto-increment feature to prevent output data from being updated prior to intended completion of the read transaction.



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Data Transfer Sequences

The following information clearly illustrates the variety of data transfers that can occur on the I²C bus and how the Master and Slave interact during these transfers. **Table 7** defines the I²C terms used during the data transfers.

| Term | Definition |
|------|---------------------------|
| S | Start Condition |
| Sr | Repeated Start Condition |
| SAD | Slave Address |
| W | Write Bit |
| R | Read Bit |
| ACK | Acknowledge |
| NACK | Not Acknowledge |
| RA | Register Address |
| Data | Transmitted/Received Data |
| P | Stop Condition |

Table 7: I²C Terms

Sequence 1: The Master is writing one byte to the Slave.

| | | | | | | | | |
|--------|---|---------|-----|----|-----|------|-----|---|
| Master | S | SAD + W | | RA | | DATA | | P |
| Slave | | | ACK | | ACK | | ACK | |

Sequence 2: The Master is writing multiple bytes to the Slave.

| | | | | | | | | | | |
|--------|---|---------|-----|----|-----|------|-----|------|-----|---|
| Master | S | SAD + W | | RA | | DATA | | DATA | | P |
| Slave | | | ACK | | ACK | | ACK | | ACK | |

Sequence 3: The Master is receiving one byte of data from the Slave.

| | | | | | | | | | | | |
|--------|---|---------|-----|----|-----|----|---------|-----|------|------|---|
| Master | S | SAD + W | | RA | | Sr | SAD + R | | | NACK | P |
| Slave | | | ACK | | ACK | | | ACK | DATA | | |

Sequence 4: The Master is receiving multiple bytes of data from the Slave.

| | | | | | | | | | | | | | |
|--------|---|---------|-----|----|-----|----|---------|-----|------|-----|------|------|---|
| Master | S | SAD + W | | RA | | Sr | SAD + R | | | ACK | | NACK | P |
| Slave | | | ACK | | ACK | | | ACK | DATA | | DATA | | |



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HS-mode

To enter the 3.4MHz high speed mode of communication, the device must receive the following sequence of conditions from the master: a Start condition followed by a Master code (00001XXX) and a Master Non-acknowledge. Once recognized, the device switches to HS-mode communication. Read/write data transfers then proceed as described in the sequences above. Devices return to the FS-mode after a STOP occurrence on the bus.

Sequence 5: HS-mode data transfer of the Master writing multiple bytes to the Slave.

| Speed | FS-mode | | | HS-mode | | | | | | | | FS-mode |
|--------|---------|--------|------|---------|---------|-----|----|-----|------|-----|---|---------|
| Master | S | M-code | NACK | Sr | SAD + W | | RA | | DATA | | P | |
| Slave | | | | | | ACK | | ACK | | ACK | | |

n bytes + ack.

Sequence 6: HS-mode data transfer of the Master receiving multiple bytes of data from the Slave.

| Speed | FS-mode | | | HS-mode | | | | |
|--------|---------|--------|------|---------|---------|-----|----|-----|
| Master | S | M-code | NACK | Sr | SAD + W | | RA | |
| Slave | | | | | | ACK | | ACK |

| Speed | HS-mode | | | | | | | | FS-mode |
|--------|---------|---------|-----|------|-----|------|------|---|---------|
| Master | Sr | SAD + R | | | | | NACK | P | |
| Slave | | | ACK | DATA | ACK | DATA | | | |

(n-1) bytes + ack.



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I²C Timing Diagram

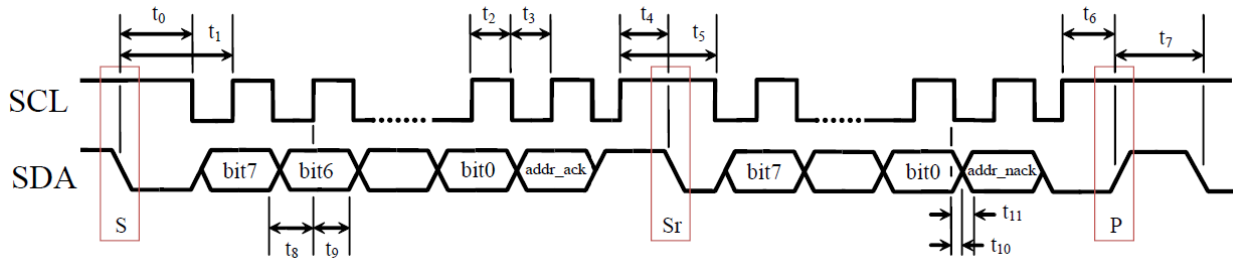


Table 8: I2C Timing (Fast Mode)

| Number | Description | MIN | MAX | Units |
|----------|--|-----|-----|-------|
| t_0 | SDA low to SCL low transition (Start event) | 50 | - | ns |
| t_1 | SDA low to first SCL rising edge | 100 | - | ns |
| t_2 | SCL pulse width: high | 100 | - | ns |
| t_3 | SCL pulse width: low | 100 | - | ns |
| t_4 | SCL high before SDA falling edge (Start Repeated) | 50 | - | ns |
| t_5 | SCL pulse width: high during a S/Sr/P event | 100 | - | ns |
| t_6 | SCL high before SDA rising edge (Stop) | 50 | - | ns |
| t_7 | SDA pulse width: high | 25 | - | ns |
| t_8 | SDA valid to SCL rising edge | 50 | - | ns |
| t_9 | SCL rising edge to SDA invalid | 50 | - | ns |
| t_{10} | SCL falling edge to SDA valid (when slave is transmitting) | - | 100 | ns |
| t_{11} | SCL falling edge to SDA invalid (when slave is transmitting) | 0 | - | ns |
| Note | Recommended I ² C CLK | 2.5 | - | us |



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SPI Communications

4-Wire SPI Interface

The KX023 also utilizes an integrated 4-Wire Serial Peripheral Interface (SPI) for digital communication. The SPI interface is primarily used for synchronous serial communication between one Master device and one or more Slave devices. The Master, typically a micro controller, provides the SPI clock signal (SCLK) and determines the state of Chip Select (nCS). The KX023 always operates as a Slave device during standard Master-Slave SPI operation.

4-wire SPI is a synchronous serial interface that uses two control and two data lines. With respect to the Master, the Serial Clock output (SCLK), the Data Output (SDI or MOSI) and the Data Input (SDO or MISO) are shared among the Slave devices. The Master generates an independent Chip Select (nCS) for each Slave device that goes low at the start of transmission and goes back high at the end. The Slave Data Output (SDO) line, remains in a high-impedance (hi-z) state when the device is not selected, so it does not interfere with any active devices. This allows multiple Slave devices to share a master SPI port as shown in Figure 2 below.

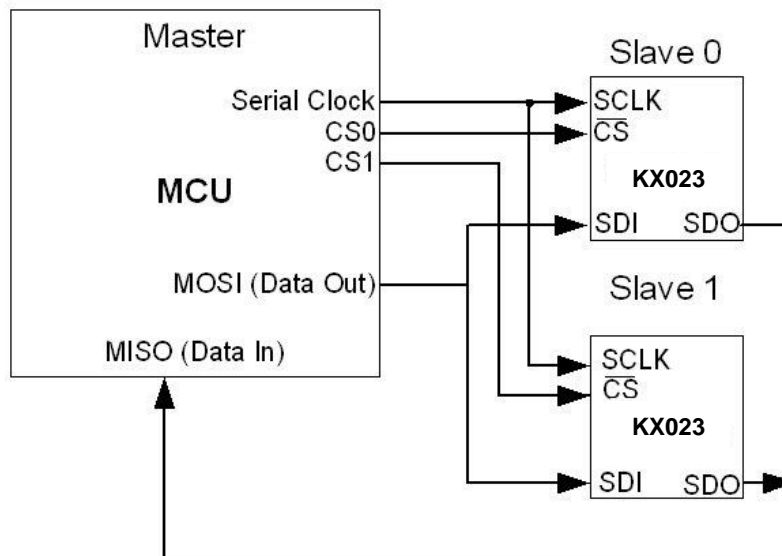


Figure 2: 4-wire SPI Connections



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4-Wire SPI Timing Diagram

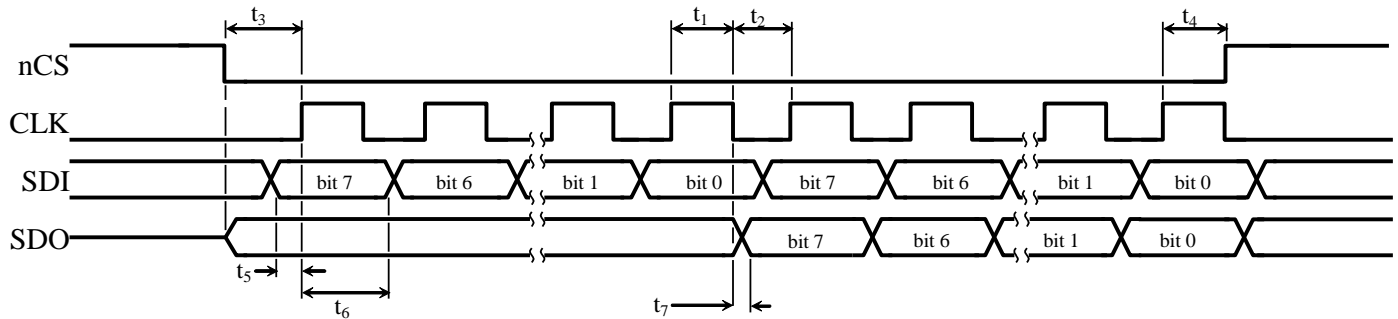


Table 9: 4-Wire SPI Timing

| Number | Description | MIN | MAX | Units |
|----------------|---|-----|-----|-------|
| t ₁ | CLK pulse width: high | 40 | | ns |
| t ₂ | CLK pulse width: low | 40 | | ns |
| t ₃ | nCS low to first CLK rising edge | 20 | | ns |
| t ₄ | nCS low after the final CLK rising edge | 30 | | ns |
| t ₅ | SDI valid to CLK rising edge | 10 | | ns |
| t ₆ | CLK rising edge to SDI invalid | 10 | | ns |
| t ₇ | CLK falling edge to SDO valid | | 35 | ns |

Notes

1. t₇ is only present during reads.
2. Timings are for VDD of 1.8V to 3.6V with 1KΩ pull-up resistor and maximum 20pF load capacitor on SDO.



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4-Wire Read and Write Registers

The registers embedded in the KX023 have 8-bit addresses. Upon power up, the Master must write to the accelerometer's control registers to set its operational mode. On the falling edge of nCS, a 2-byte command is written to the appropriate control register. The first byte initiates the write to the appropriate register, and is followed by the user-defined, data byte. The MSB (Most Significant Bit) of the register address byte will indicate "0" when writing to the register and "1" when reading from the register. This operation occurs over 16 clock cycles. All commands are sent MSB first. The host must return nCS high for at least one clock cycle before the next data request. However, when data is being read from a buffer read register (BUF_READ), the nCS signal can remain low until the buffer is read. Figure 3 below shows the timing diagram for carrying out an 8-bit register write operation.

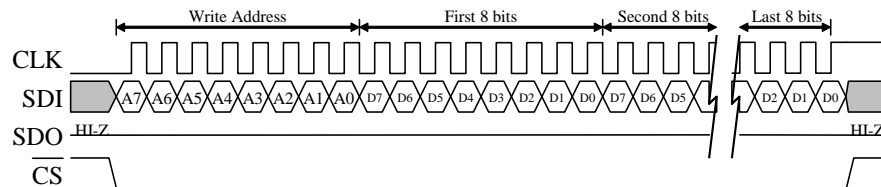


Figure 3: Timing Diagram for 8-Bit Register Write Operation

In order to read an 8-bit register, an 8-bit register address must be written to the accelerometer to initiate the read. The MSB of this register address byte will indicate "0" when writing to the register and "1" when reading from the register. Upon receiving the address, the accelerometer returns the 8-bit data stored in the addressed register. This operation also occurs over 16 clock cycles. All returned data is sent MSB first, and the host must return nCS high for at least one clock cycle before the next data request. Figure 4 shows the timing diagram for an 8-bit register read operation.

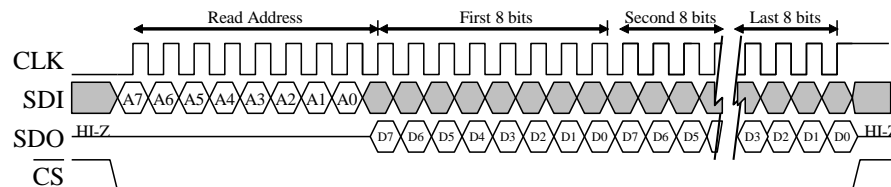


Figure 4: Timing Diagram for 8-Bit Register Read Operation



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3-Wire SPI Interface

The KX023 also utilizes an integrated 3-Wire Serial Peripheral Interface (SPI) for digital communication. 3-wire SPI is a synchronous serial interface that uses two control lines and one data line. With respect to the Master, the Serial Clock output (SCLK), the Data Output/Input (SDI) are shared among the Slave devices. The Master generates an independent Chip Select ($\bar{n}CS$) for each Slave device that goes low at the start of transmission and goes back high at the end. This allows multiple Slave devices to share a master SPI port as shown in Figure 5 below.

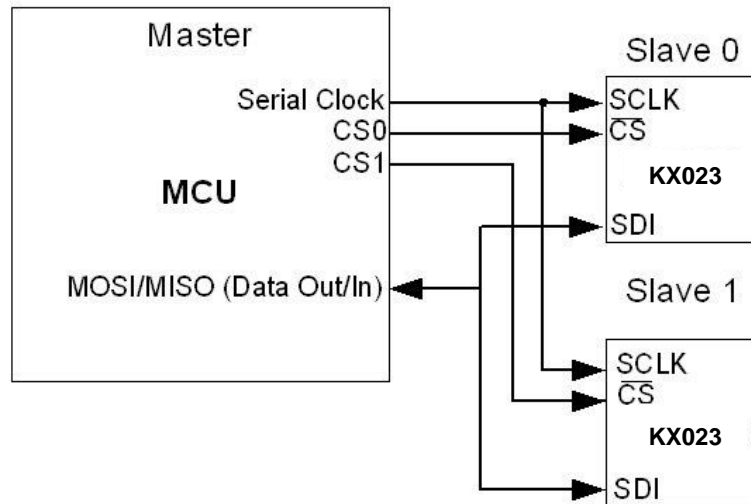


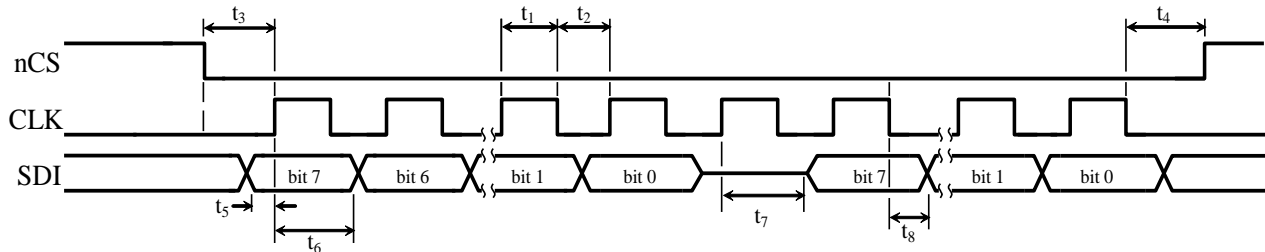
Figure 5: 3-wire SPI Connections



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3-Wire SPI Timing Diagram



| Number | Description | MIN | MAX | Units |
|----------------|---|-----|-----|-------|
| t ₁ | CLK pulse width: high | 40 | - | ns |
| t ₂ | CLK pulse width: low | 40 | - | ns |
| t ₃ | nCS low to first CLK rising edge | 20 | - | ns |
| t ₄ | nCS low after the final CLK falling edge | 20 | - | ns |
| t ₅ | SDI valid to CLK rising edge | 10 | - | ns |
| t ₆ | CLK rising edge to SDI input invalid | 10 | - | ns |
| t ₇ | CLK extra clock cycle rising edge to SDI output | - | - | ns |
| t ₈ | CLK falling edge to SDI output becomes valid | - | 35 | ns |

Table 10: 3-Wire SPI Timing

Notes

1. t₇ and t₈ are only present during reads.
2. Timings are for VDD of 1.8V to 3.6V with 1KΩ pull-up resistor and maximum 20pF load capacitor on SDI.



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3-Wire Read and Write Registers

The registers embedded in the KX023 have 8-bit addresses. Upon power up, the Master must write to the accelerometer's control registers to set its operational mode. On the falling edge of nCS, a 2-byte command is written to the appropriate control register. The first byte initiates the write to the appropriate register, and is followed by the user-defined, data byte. The MSB (Most Significant Bit) of the register address byte will indicate "0" when writing to the register and "1" when reading from the register. A read operation occurs over 17 clock cycles and a write operation occurs over 16 clock cycles. All commands are sent MSB first. The host must return nCS high for at least one clock cycle before the next data request. However, when data is being read from a buffer read register (BUF_READ), the nCS signal can remain low until the buffer is read. Figure 6 below shows the timing diagram for carrying out an 8-bit register write operation.

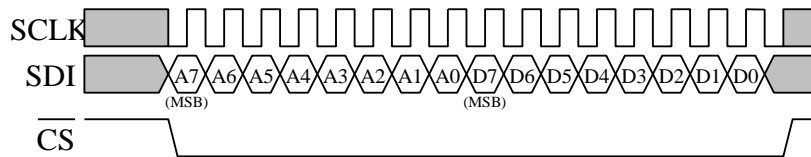


Figure 6: Timing Diagram for 8-Bit Register Write Operation

In order to read an 8-bit register, an 8-bit register address must be written to the accelerometer to initiate the read. The MSB of this register address byte will indicate "0" when writing to the register and "1" when reading from the register. Upon receiving the address, the accelerometer returns the 8-bit data stored in the addressed register. For 3-wire read operations, one extra clock cycle between the address byte and the data output byte is required. Therefore, this operation occurs over 17 clock cycles. All returned data is sent MSB first, and the host must return nCS high for at least one clock cycle before the next data request. Figure 7 shows the timing diagram for an 8-bit register read operation.

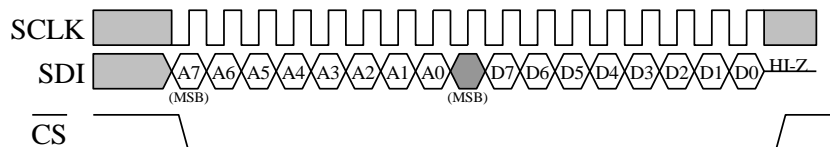


Figure 7: Timing Diagram for 8-Bit Register Read Operation



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Embedded Registers

The KX023 has 57 embedded 8-bit registers that are accessible by the user. This section contains the addresses for all embedded registers and also describes bit functions of each register. Table 11 below provides a listing of the accessible 8-bit registers and their addresses.

| Address | Register Name | R/W | Address | Register Name | R/W |
|---------|-----------------|-----|---------|-----------------|-----|
| 00h | XHPL | R | 21h | INC6* | R/W |
| 01h | XHPH | R | 22h | TILT_TIMER* | R/W |
| 02h | YHPL | R | 23h | WUFC* | R/W |
| 03h | YHPH | R | 24h | TDTRC* | R/W |
| 04h | ZHPL | R | 25h | TDTC* | R/W |
| 05h | ZHPH | R | 26h | TTH* | R/W |
| 06h | XOUTL | R | 27h | TTL* | R/W |
| 07h | XOUTH | R | 28h | FTD* | R/W |
| 08h | YOUTL | R | 29h | STD* | R/W |
| 09h | YOUTH | R | 2Ah | TLT* | R/W |
| 0Ah | ZOUTL | R | 2Bh | TWS* | R/W |
| 0Bh | ZOUTH | R | 2Ch | Kionix Reserved | |
| 0Ch | COTR | R | 2Dh | Kionix Reserved | |
| 0Dh | Kionix Reserved | | 2Eh | Kionix Reserved | |
| 0Eh | Kionix Reserved | | 2Fh | Kionix Reserved | |
| 0Fh | Who_AM_I | R/W | 30h | ATH* | R/W |
| 10h | TSCP | R | 31h | Kionix Reserved | |
| 11h | TSPP | R | 32h | TILT_ANGLE_LL* | R/W |
| 12h | INS1 | R | 33h | TILT_ANGLE_HL* | R/W |
| 13h | INS2 | R | 34h | HYST_SET* | R/W |
| 14h | INS3 | R | 35h | LP_CNTL* | R/W |
| 15h | STAT | R | 36h | Kionix Reserved | |
| 16h | Kionix Reserved | | 37h | Kionix Reserved | |
| 17h | INT_REL | R | 38h | Kionix Reserved | |
| 18h | CNTL1* | R/W | 39h | Kionix Reserved | |
| 19h | CNTL2* | R/W | 3Ah | BUF_CNTL1* | R/W |
| 1Ah | CNTL3* | R/W | 3Bh | BUF_CNTL2* | R/W |
| 1Bh | ODCNTL* | R/W | 3Ch | BUF_STATUS_1 | R |
| 1Ch | INC1* | R/W | 3Dh | BUF_STATUS_2 | R |
| 1Dh | INC2* | R/W | 3Eh | BUF_CLEAR | W |
| 1Eh | INC3* | R/W | 3Fh | BUF_READ | R |
| 1Fh | INC4* | R/W | 60h | SELF_TEST | W |
| 20h | INC5* | R/W | | | |

* Note: - When changing the contents of these registers, the PC1 bit in CNTL1 must first be set to "0".
 - Reserved registers should not be written.

Table 11: Register Map



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Register Descriptions

Accelerometer Outputs

These registers contain up to 16-bits of valid acceleration data for each axis. Depending on the setting of the RES bit in CNTL1, the user may choose to read only the 8 MSB thus reading an effective 8-bit resolution. When BRES = '0' in BUF_CNTL2 the 8 MSB is the only data recorded in the buffer. The data is updated every user-defined ODR period, is protected from overwrite during each read, and can be converted from digital counts to acceleration (g) per Table 12 below. The register acceleration output binary data is represented in 2's complement format. For example, if N = 16 bits, then the Counts range is from -32768 to 32767, and if N = 8 bits, then the Counts range is from -128 to 127.

| 16-bit Register Data (2's complement) | Equivalent Counts in decimal | Range = ±2g | Range = ±4g | Range = ±8g |
|---------------------------------------|------------------------------|-------------|-------------|-------------|
| 0111 1111 1111 1111 | 32767 | +1.99994g | +3.99988g | +7.99976g |
| 0111 1111 1111 1110 | 32766 | +1.99988g | +3.99976g | +7.99951g |
| ... | ... | ... | ... | ... |
| 0000 0000 0001 | 1 | +0.00006g | +0.00012g | +0.00024g |
| 0000 0000 0000 | 0 | 0.000g | 0.0000g | 0.0000g |
| 1111 1111 1111 1111 | -1 | -0.00006g | -0.00012g | -0.00024g |
| ... | ... | ... | ... | ... |
| 1000 0000 0000 0001 | -32767 | -1.99994g | -3.99988g | -7.99976g |
| 1000 0000 0000 0000 | -32768 | -2.00000g | -4.00000g | -8.00000g |

| 8-bit Register Data (2's complement) | Equivalent Counts in decimal | Range = ±2g | Range = ±4g | Range = ±8g |
|--------------------------------------|------------------------------|-------------|-------------|-------------|
| 0111 1111 | 127 | +1.9844g | +3.9688g | +7.9375g |
| 0111 1110 | 126 | +1.9688g | +3.9375g | +7.8750g |
| ... | ... | ... | ... | ... |
| 0000 0001 | 1 | +0.0156g | +0.0313g | +0.0625g |
| 0000 0000 | 0 | 0.0000g | 0.0000g | 0.0000g |
| 1111 1111 | -1 | -0.0156g | -0.0313g | -0.0625g |
| ... | ... | ... | ... | ... |
| 1000 0001 | -127 | -1.9844g | -3.9688g | -7.9375g |
| 1000 0000 | -128 | -2.000g | -4.000g | -8.000g |

Table 12: Acceleration (g) Calculation



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XHP_L

X-axis high pass filter accelerometer output least significant byte. Data is updated at the ODR frequency determined by OWUF in CNTL3.

| | | | | | | | |
|---------------------------------|-------|-------|-------|-------|-------|-------|-------|
| R | R | R | R | R | R | R | R |
| XHPD7 | XHPD6 | XHPD5 | XHPD4 | XHPD3 | XHPD2 | XHPD1 | XHPD0 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x00h | | | | | | | |

XHP_H

X-axis high pass filter accelerometer output most significant byte. Data is updated at the ODR frequency determined by OWUF in CNTL3.

| | | | | | | | |
|---------------------------------|--------|--------|--------|--------|--------|-------|-------|
| R | R | R | R | R | R | R | R |
| XHPD15 | XHPD14 | XHPD13 | XHPD12 | XHPD11 | XHPD10 | XHPD9 | XHPD8 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x01h | | | | | | | |

YHP_L

Y-axis high pass filter accelerometer output least significant byte. Data is updated at the ODR frequency determined by OWUF in CNTL3.

| | | | | | | | |
|---------------------------------|-------|-------|-------|-------|-------|-------|-------|
| R | R | R | R | R | R | R | R |
| YHPD7 | YHPD6 | YHPD5 | YHPD4 | YHPD3 | YHPD2 | YHPD1 | YHPD0 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x02h | | | | | | | |

YHP_H

Y-axis high pass filter accelerometer output most significant byte. Data is updated at the ODR frequency determined by OWUF in CNTL3.

| | | | | | | | |
|---------------------------------|--------|--------|--------|--------|--------|-------|-------|
| R | R | R | R | R | R | R | R |
| YHPD15 | YHPD14 | YHPD13 | YHPD12 | YHPD11 | YHPD10 | YHPD9 | YHPD8 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x03h | | | | | | | |



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ZHP_L

Z-axis high pass filter accelerometer output least significant byte. Data is updated at the ODR frequency determined by OWUF in CNTL3.

| | | | | | | | |
|---------------------------------|-------|-------|-------|-------|-------|-------|-------|
| R | R | R | R | R | R | R | R |
| ZHPD7 | ZHPD6 | ZHPD5 | ZHPD4 | ZHPD3 | ZHPD2 | ZHPD1 | ZHPD0 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x04h | | | | | | | |

ZHP_H

Z-axis high pass filter accelerometer output most significant byte. Data is updated at the ODR frequency determined by OWUF in CNTL3.

| | | | | | | | |
|---------------------------------|--------|--------|--------|--------|--------|-------|-------|
| R | R | R | R | R | R | R | R |
| ZHPD15 | ZHPD14 | ZHPD13 | ZHPD12 | ZHPD11 | ZHPD10 | ZHPD9 | ZHPD8 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x05h | | | | | | | |

XOUT_L

X-axis accelerometer output least significant byte. Data is updated at the ODR frequency determined by OSA in ODCNTL.

| | | | | | | | |
|---------------------------------|--------|--------|--------|--------|--------|--------|--------|
| R | R | R | R | R | R | R | R |
| XOUTD7 | XOUTD6 | XOUTD5 | XOUTD4 | XOUTD3 | XOUTD2 | XOUTD1 | XOUTD0 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x06h | | | | | | | |

XOUT_H

X-axis accelerometer output most significant byte. Data is updated at the ODR frequency determined by OSA in ODCNTL.

| | | | | | | | |
|---------------------------------|---------|---------|---------|---------|---------|--------|--------|
| R | R | R | R | R | R | R | R |
| XOUTD15 | XOUTD14 | XOUTD13 | XOUTD12 | XOUTD11 | XOUTD10 | XOUTD9 | XOUTD8 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x07h | | | | | | | |



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YOUT_L

Y-axis accelerometer output least significant byte. Data is updated at the ODR frequency determined by OSA in ODCNTL.

| | | | | | | | |
|---------------------------------|--------|--------|--------|--------|--------|--------|--------|
| R | R | R | R | R | R | R | R |
| YOUTD7 | YOUTD6 | YOUTD5 | YOUTD4 | YOUTD3 | YOUTD2 | YOUTD1 | YOUTD0 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x08h | | | | | | | |

YOUT_H

Y-axis accelerometer output most significant byte. Data is updated at the ODR frequency determined by OSA in ODCNTL.

| | | | | | | | |
|---------------------------------|---------|---------|---------|---------|---------|--------|--------|
| R | R | R | R | R | R | R | R |
| YOUTD15 | YOUTD14 | YOUTD13 | YOUTD12 | YOUTD11 | YOUTD10 | YOUTD9 | YOUTD8 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x09h | | | | | | | |

ZOUT_L

Z-axis accelerometer output least significant byte. Data is updated at the ODR frequency determined by OSA in ODCNTL.

| | | | | | | | |
|---------------------------------|--------|--------|--------|--------|--------|--------|--------|
| R | R | R | R | R | R | R | R |
| ZOUTD7 | ZOUTD6 | ZOUTD5 | ZOUTD4 | ZOUTD3 | ZOUTD2 | ZOUTD1 | ZOUTD0 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x0Ah | | | | | | | |

ZOUT_H

Z-axis accelerometer output most significant byte. Data is updated at the ODR frequency determined by OSA in ODCNTL.

| | | | | | | | |
|---------------------------------|---------|---------|---------|---------|---------|--------|--------|
| R | R | R | R | R | R | R | R |
| YOUTD15 | YOUTD14 | YOUTD13 | YOUTD12 | YOUTD11 | YOUTD10 | YOUTD9 | YOUTD8 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x0Bh | | | | | | | |



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COTR

This register can be used to verify proper integrated circuit functionality. It always has a byte value of 0x55h unless the COTC bit in CNTL2 is set. At that point this value is set to 0xAAh. The byte value is returned to 0x55h after reading this register and the COTC bit in CNTL2 is cleared.

| | | | | | | | | |
|---------------------------------|--------|--------|--------|--------|--------|--------|--------|-------------|
| R | R | R | R | R | R | R | R | |
| DCSTR7 | DCSTR6 | DCSTR5 | DCSTR4 | DCSTR3 | DCSTR2 | DCSTR1 | DCSTR0 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 01010101 |
| I ² C Address: 0x0Ch | | | | | | | | |

WHO_AM_I

This register can be used for supplier recognition, as it can be factory written to a known byte value. The default value is 0x15h.

| | | | | | | | | |
|---------------------------------|------|------|------|------|------|------|------|-------------|
| R | R | R | R | R | R | R | R | |
| WIA7 | WIA6 | WIA5 | WIA4 | WIA3 | WIA2 | WIA1 | WIA0 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00010101 |
| I ² C Address: 0x0Fh | | | | | | | | |

Tilt Position Registers

These two registers report previous and current position data that is updated at the user-defined ODR frequency and is protected during register read. Table 13 describes the reported position for each bit value.

TSCP

Current Tilt Position Register.

| | | | | | | | | |
|---------------------------------|------|------|------|------|------|------|------|-------------|
| R | R | R | R | R | R | R | R | |
| 0 | 0 | LE | RI | DO | UP | FD | FU | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00100000 |
| I ² C Address: 0x10h | | | | | | | | |



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TSPP

Previous Tilt Position Register.

| | | | | | | | | |
|------|------|------|------|------|------|------|------|---------------------------------|
| R | R | R | R | R | R | R | R | |
| 0 | 0 | LE | RI | DO | UP | FD | FU | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00100000 |
| | | | | | | | | I ² C Address: 0x11h |

| Bit | Description |
|-----|----------------------|
| LE | Left State (X-) |
| RI | Right State (X+) |
| DO | Down State (Y-) |
| UP | Up State (Y+) |
| FD | Face-Down State (Z-) |
| FU | Face-Up State (Z+) |

Table 13: Tilt Position

Interrupt Source Registers

These three registers report interrupt state changes. This data is updated when a new interrupt event occurs and each application's result is latched until the interrupt release register is read.

INS1

This register indicates the triggering axis when a tap/double tap interrupt occurs. Data is updated at the ODR settings determined by OTDT<2:0> in CNTL3.

| | | | | | | | | |
|------|------|------|------|------|------|------|------|---------------------------------|
| R | R | R | R | R | R | R | R | |
| 0 | 0 | TLE | TRI | TDO | TUP | TFD | TFU | |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | |
| | | | | | | | | I ² C Address: 0x12h |

| Bit | Description |
|-----|--------------------------|
| TLE | X Negative (X-) Reported |
| TRI | X Positive (X+) Reported |
| TDO | Y Negative (Y-) Reported |
| TUP | Y Positive (Y+) Reported |
| TFD | Z Negative (Z-) Reported |
| TFU | Z Positive (Z+) Reported |

Table 14: Directional Tap™ Reporting



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INS2

This register tells which function caused an interrupt.

| | | | | | | | |
|---------------------------------|------|------|------|-------|-------|------|------|
| R | R | R | R | R | R | R | R |
| 0 | BFI | WMI | DRDY | TDTS1 | TDTS0 | WUFS | TPS |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x13h | | | | | | | |

BFI – indicates buffer full interrupt. Automatically cleared when buffer is read.

BFI = 0 – Buffer is not full

BFI = 1 – Buffer is full

WMI – Watermark interrupt, bit is set to one when FIFO has filled up to the value stored in the sample bits. This bit is automatically cleared when FIFO/FILO is read and the content returns to a value below the value stored in the sample bits.

WMI = 0 – Buffer watermark has not been exceeded

WMI = 1 – Buffer watermark has been exceeded

DRDY – indicates that new acceleration data (0x06h to 0x0Bh) is available. This bit is cleared when acceleration data is read or the interrupt release register INT_REL is read.

DRDY = 0 - new acceleration data not available

DRDY = 1 - new acceleration data available

TDTS(1,0) – status of tap/double tap, bit is released when interrupt release register INT_REL is read.

| TDTS1 | TDTS0 | Event |
|-------|-------|--------------|
| 0 | 0 | No Tap |
| 0 | 1 | Single Tap |
| 1 | 0 | Double Tap |
| 1 | 1 | Do not exist |

WUFS – Status of Wake up. This bit is cleared when the interrupt release register INT_REL is read.

WUFS = 1 – Motion has activated the interrupt

WUFS = 0 – No motion

TPS – Tilt Position status. This bit is cleared when the interrupt release register INT_REL is read.

TPS = 0 – Position not changed

TPS = 1 – Position changed



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INS3

This register reports the axis and direction of detected motion.

| | | | | | | | |
|---------------------------------|------|------|------|------|------|------|------|
| R | R | R | R | R | R | R | R |
| 0 | 0 | XNWU | XPWU | YNWU | YPWU | ZNWU | ZPWU |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x14h | | | | | | | |

| Bit | Description |
|------|--------------------------|
| XNWU | X Negative (X-) Reported |
| XPWU | X Positive (X+) Reported |
| YNWU | Y Negative (Y-) Reported |
| YPWU | Y Positive (Y+) Reported |
| ZNWU | Z Negative (Z-) Reported |
| ZPWU | Z Positive (Z+) Reported |

Table 15: Motion Detection™ Reporting

STATUS_REG

This register reports the status of the interrupt.

| | | | | | | | |
|---------------------------------|------|------|------|------|------|------|------|
| R | R | R | R | R | R | R | R |
| 0 | 0 | 0 | INT | 0 | 0 | 0 | 0 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x15h | | | | | | | |

INT reports the combined (OR) interrupt information of all features. When BFI and WMI in INS2 are 0, the INT bit is released to 0 when INL is read. If WMI or BFI is 1, INT bit remains at 1 until they are cleared by FIFO/FILO buffer read.

0 = no interrupt event

1 = interrupt event has occurred

INT_REL

Latched interrupt source information (INS1, INS2, INS3 except WMI/BFI and INT when WMI/BFI is zero) is cleared and physical interrupt latched pin is changed to its inactive state when this register is read. Read value is dummy.

| | | | | | | | |
|---------------------------------|------|------|------|------|------|------|------|
| R | R | R | R | R | R | R | R |
| X | X | X | X | X | X | X | X |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x17h | | | | | | | |



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CNTL1

Read/write control register that controls the main feature set.

| | | | | | | | | |
|---------------------------------|------|-------|-------|-------|------|------|------|-------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
| PC1 | RES | DRDYE | GSEL1 | GSEL0 | TDTE | WUFE | TPE | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00000000 |
| I ² C Address: 0x18h | | | | | | | | |

PC1 controls the operating mode of the KX023. When in RES = 0, please allow 1.2/ODR delay time when transitioning from stand-by PC1 = 0 to operating mode PC1 = 1 to allow new settings to load.

0 = stand-by mode
 1 = operating mode

RES determines the performance mode of the KX023. The noise varies with ODR, RES and different LP_CNTL settings possibly reducing the effective resolution. Note that to change the value of this bit, the PC1 bit must first be set to "0".

0 = low current.
 1 = high resolution. Bandwidth (Hz) = ODR/2

DRDYE enables the reporting of the availability of new acceleration data as an interrupt. Note that to change the value of this bit, the PC1 bit must first be set to "0".

0 = availability of new acceleration data is not reflected as an interrupt
 1 = availability of new acceleration data is reflected as an interrupt

GSEL1, GSEL0 selects the acceleration range of the accelerometer outputs per Table 16. Note that to change the value of this bit, the PC1 bit must first be set to "0".

| GSEL1 | GSEL0 | Range |
|-------|-------|-------|
| 0 | 0 | ±2g |
| 0 | 1 | ±4g |
| 1 | 0 | ±8g |

Table 16: Selected Acceleration Range

TDTE enables the Directional Tap™ function that will detect single and double tap events. Note that to change the value of this bit, the PC1 bit must first be set to "0".

TDTE = 0 – disable
 TDTE = 1 - enable



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WUFE enables the Wake Up (motion detect) function. 0= disabled, 1= enabled. Note that to change the value of this bit, the PC1 bit must first be set to "0".

0 = Wake Up function disabled
 1 = Wake Up function enabled

TPE enables the Tilt Position function that will detect changes in device orientation. Note that to change the value of this bit, the PC1 bit must first be set to "0".

TPE = 0 – disable
 TPE = 1 - enable

CNTL2

Read/write control register that provides more feature set control. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to "0".

| | | | | | | | | |
|------|------|------|------|------|------|------|------|---------------------------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
| SRST | COTC | LEM | RIM | DOM | UPM | FDM | FUM | 00111111 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | |
| | | | | | | | | I ² C Address: 0x19h |

SRST initiates software reset, which performs the RAM reboot routine. This bit will remain 1 until the RAM reboot routine is finished.

SRST = 0 – no action
 SRST = 1 – start RAM reboot routine

COTC Command test control.

DCST = 0 – no action
 DCST = 1 – sets COTR register to 0xAAh and when COTR is read, sets this bit to 0 and sets COTR to 0x55h

TLEM, TRIM, TDOM, TUPM, TFDM these bits control the tilt axis mask. Per Table 17, if a direction's bit is set to one (1), tilt in that direction will generate an interrupt. If it is set to zero (0), tilt in that direction will not generate an interrupt. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to "0".

| Bit | Description |
|------|-----------------|
| TLEM | X Negative (X-) |
| TRIM | X Positive (X+) |
| TDOM | Y Negative (Y-) |
| TUPM | Y Positive (Y+) |
| TFDM | Z Negative (Z-) |
| TFUM | Z Positive (Z+) |

Table 17: Tilt Direction™ Axis Mask



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CNTL3

Read/write control register that provides more feature set control. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| | | | | | | | | |
|------|------|-------|-------|-------|-------|-------|-------|---------------------------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
| OTP1 | OTP0 | OTDT2 | OTDT1 | OTDT0 | OWUF2 | OWUF1 | OWUF0 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 10011000 |
| | | | | | | | | I ² C Address: 0x1Ah |

OTPA, OTPB sets the output data rate for the Tilt Position function per Table 18. The default Tilt Position ODR is 12.5Hz.

| OTP1 | OTP0 | Output Data Rate |
|------|------|------------------|
| 0 | 0 | 1.563Hz |
| 0 | 1 | 6.25Hz |
| 1 | 0 | 12.5Hz |
| 1 | 1 | 50Hz |

Table 18: Tilt Position Function Output Data Rate

OTDTA, OTDTB sets the output data rate for the Directional Tap™ function per Table 19. The default Directional Tap™ ODR is 400Hz.

| OTDT2 | OTDT1 | OTDT0 | Output Data Rate |
|-------|-------|-------|------------------|
| 0 | 0 | 0 | 50Hz |
| 0 | 0 | 1 | 100Hz |
| 0 | 1 | 0 | 200Hz |
| 0 | 1 | 1 | 400Hz |
| 1 | 0 | 0 | 12.5Hz |
| 1 | 0 | 1 | 25Hz |
| 1 | 1 | 0 | 800Hz |
| 1 | 1 | 1 | 1600Hz |

Table 19: Directional Tap™ Function Output Data Rate



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OWUF2, OWUF1, OWUF0 sets the output data rate for the general motion detection function and the high-pass filtered outputs per Table 20. The default Motion Wake Up ODR is 0.781Hz.

| OWUF2 | OWUF1 | OWUF0 | Output Data Rate |
|-------|-------|-------|------------------|
| 0 | 0 | 0 | 0.781Hz |
| 0 | 0 | 1 | 1.563Hz |
| 0 | 1 | 0 | 3.125Hz |
| 0 | 1 | 1 | 6.250Hz |
| 1 | 0 | 0 | 12.5Hz |
| 1 | 0 | 1 | 25Hz |
| 1 | 1 | 0 | 50Hz |
| 1 | 1 | 1 | 100Hz |

Table 20: Motion Wake Up Function Output Data Rate



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ODCNTL

This register is responsible for configuring ODR (output data rate) and filter settings. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to "0".

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
|---------------------------------|------|----------|----------|------|------|------|------|-------------|
| IIR_BYPASS | LPRO | RESERVED | RESERVED | OSA3 | OSA2 | OSA1 | OSA0 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 0000010 |
| I ² C Address: 0x1Bh | | | | | | | | |

IIR_BYPASS filter bypass mode

IIR_BYPASS = 0 – filtering applied

IIR_BYPASS = 1 – filter bypassed

LPRO low-pass filter roll off control

LPRO = 0 – filter corner frequency set to ODR/9

LPRO = 1 – filter corner frequency set to ODR/2

Reserved – The Reserved bits should remain at their Reset state to avoid unexpected behavior.

OSA3, OSA2, OSA1, OSA0 acceleration output data rate. The default ODR is 50Hz.

| OSA3 | OSA2 | OSA1 | OSA0 | Output Data Rate |
|------|------|------|------|------------------|
| 0 | 0 | 0 | 0 | 12.5Hz* |
| 0 | 0 | 0 | 1 | 25Hz* |
| 0 | 0 | 1 | 0 | 50Hz* |
| 0 | 0 | 1 | 1 | 100Hz* |
| 0 | 1 | 0 | 0 | 200Hz* |
| 0 | 1 | 0 | 1 | 400Hz |
| 0 | 1 | 1 | 0 | 800Hz |
| 0 | 1 | 1 | 1 | 1600Hz |
| 1 | 0 | 0 | 0 | 0.781Hz* |
| 1 | 0 | 0 | 1 | 1.563Hz* |
| 1 | 0 | 1 | 0 | 3.125Hz* |
| 1 | 0 | 1 | 1 | 6.25Hz* |

Table 21: Accelerometer Output Data Rates (ODR)

* Low power mode available, all other data rates will default to high resolution mode



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INC1

This register controls the settings for the physical interrupt pin INT1. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| | | | | | | | | |
|----------|----------|------|------|------|----------|-------|-------|---------------------------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
| Reserved | Reserved | IEN1 | IEA1 | IEL1 | Reserved | STPOL | SPI3E | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00010000 |
| | | | | | | | | I ² C Address: 0x1Ch |

IEN enables/disables the physical interrupt pin
IEN = 0 – physical interrupt pin is disabled
IEN = 1 – physical interrupt pin is enabled

IEA sets the polarity of the physical interrupt pin
IEA = 0 – polarity of the physical interrupt pin is active low
IEA = 1 – polarity of the physical interrupt pin is active high

IEL sets the response of the physical interrupt pin
IEL = 0 – the physical interrupt pin latches until it is cleared by reading INT_REL
IEL = 1 – the physical interrupt pin will transmit one pulse with a period of 50 us

STPOL sets the polarity of Self-Test
STPOL = 0 – Negative
STPOL = 1 – Positive

SPI3E sets the 3-wire SPI interface
SPI3E = 0 – disabled
SPI3E = 1 – enabled

Reserved – The Reserved bits should remain at their Reset state to avoid unexpected behavior.

INC2

This register controls which axis and direction of detected motion can cause an interrupt. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| | | | | | | | | |
|------|------|-------|-------|-------|-------|-------|-------|---------------------------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
| 0 | 0 | XNWUE | XPWUE | YNWUE | YPWUE | ZNWUE | ZPWUE | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00111111 |
| | | | | | | | | I ² C Address: 0x1Dh |



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***XNWU** – x negative (x-): 0 = disabled, 1 = enabled*
***XPWU** – x positive (x+): 0 = disabled, 1 = enabled*
***YNWU** – y negative (y-): 0 = disabled, 1 = enabled*
***YPWU** – y positive (y+): 0 = disabled, 1 = enabled*
***ZNWU** – z negative (z-): 0 = disabled, 1 = enabled*
***ZPWU** – z positive (z+): 0 = disabled, 1 = enabled*

INC3

This register controls which axis and direction of tap/double tap can cause an interrupt. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| | | | | | | | | |
|------|------|------|------|------|------|------|------|---------------------------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
| 0 | 0 | TLEM | TRIM | TDOM | TUPM | TFDM | TFUM | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00111111 |
| | | | | | | | | I ² C Address: 0x1Eh |

***TLEM** – x negative (x-): 0 = disabled, 1 = enabled*
***TRIM** – x positive (x+): 0 = disabled, 1 = enabled*
***TDOM** – y negative (y-): 0 = disabled, 1 = enabled*
***TUPM** – y positive (y+): 0 = disabled, 1 = enabled*
***TFDM** – z negative (z-): 0 = disabled, 1 = enabled*
***TFUM** – z positive (z+): 0 = disabled, 1 = enabled*

INC4

This register controls routing of an interrupt reporting to physical interrupt pin INT1. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| | | | | | | | | |
|------|------|------|--------|----------|-------|-------|------|---------------------------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
| 0 | BF11 | WMI1 | DRDY11 | Reserved | TDT11 | WUF11 | TPI1 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00000000 |
| | | | | | | | | I ² C Address: 0x1Fh |

***BF11** – Buffer full interrupt reported on physical interrupt pin INT1*
***WMI1** - Watermark interrupt reported on physical interrupt pin INT1*
***DRDY11** – Data ready interrupt reported on physical interrupt pin INT1*
***TDT11** - Tap/Double Tap interrupt reported on physical interrupt pin INT1*
***WUF11** – Wake-Up (motion detect) interrupt reported on physical interrupt pin INT1*
***TPI1** – Tilt position interrupt reported on physical interrupt pin INT1*

Reserved – The Reserved bits should remain at their Reset state to avoid unexpected behavior.



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INC5

This register controls the settings for the physical interrupt pin INT2. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
|---------------------------------|----------|------|------|------|----------|----------|----------|-------------|
| Reserved | Reserved | IEN2 | IEA2 | IEL2 | Reserved | Reserved | Reserved | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00010000 |
| I ² C Address: 0x20h | | | | | | | | |

IEN2 enables/disables the physical interrupt pin
 IEN2 = 0 – physical interrupt pin is disabled
 IEN2 = 1 – physical interrupt pin is enabled

IEA2 sets the polarity of the physical interrupt pin
 IEA2 = 0 – polarity of the physical interrupt pin is active low
 IEA2 = 1 – polarity of the physical interrupt pin is active high

IEL2 sets the response of the physical interrupt pin
 IEL2 = 0 – the physical interrupt pin latches until it is cleared by reading INT_REL
 IEL2 = 1 – the physical interrupt pin will transmit one pulse with a period of 50 us

Reserved – The Reserved bits should remain at their Reset state to avoid unexpected behavior.

INC6

This register controls routing of interrupt reporting to physical interrupt pin INT2. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
|---------------------------------|------|------|--------|----------|-------|-------|------|-------------|
| 0 | BFI2 | WMI2 | DRDYI2 | Reserved | TDTI2 | WUFI2 | TPI2 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00000000 |
| I ² C Address: 0x21h | | | | | | | | |

BFI2 – Buffer full interrupt reported on physical interrupt pin INT2
WMI2 - Watermark interrupt reported on physical interrupt pin INT2
DRDYI2 – Data ready interrupt reported on physical interrupt pin INT2
TDTI2 - Tap/Double Tap interrupt reported on physical interrupt pin INT2
WUFI2 – Wake-Up (motion detect) interrupt reported on physical interrupt pin INT2
TPI2 – Tilt position interrupt reported on physical interrupt pin INT2
Reserved – The Reserved bits should remain at their Reset state to avoid unexpected behavior.



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TILT_TIMER

This register is the initial count register for the tilt position state timer (0 to 255 counts). Every count is calculated as 1/ODR delay period, where the ODR is user-defined per Table 18. A new state must be valid as many measurement periods before the change is accepted. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| | | | | | | | | |
|------|------|------|------|------|------|------|------|---------------------------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
| TSC7 | TSC6 | TSC5 | TSC4 | TSC3 | TSC2 | TSC1 | TSC0 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00000000 |
| | | | | | | | | I ² C Address: 0x22h |

WUFC

This register is the initial count register for the motion detection timer (0 to 255 counts). Every count is calculated as 1/ODR delay period, where the ODR is user-defined per Table 20. A new state must be valid as many measurement periods before the change is accepted. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| | | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|---------------------------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
| WUFC7 | WUFC6 | WUFC5 | WUFC4 | WUFC3 | WUFC2 | WUFC1 | WUFC0 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00000000 |
| | | | | | | | | I ² C Address: 0x23h |

TDTRC

This register is responsible for enabling/disabling reporting of Tap/Double Tap. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| | | | | | | | | |
|------|------|------|------|------|------|------|------|---------------------------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
| 0 | 0 | 0 | 0 | 0 | 0 | DTRE | STRE | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00000011 |
| | | | | | | | | I ² C Address: 0x24h |

DTRE enables/disables the double tap interrupt

DTRE = 0 – do not update/trigger interrupts on double tap events

DTRE = 1 –update interrupts on double tap events

STRE enables/disables single tap interrupt

STRE = 0 – do not update/trigger interrupts on single tap events

STRE = 1 –update interrupts on single tap events



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TDTC

This register contains counter information for the detection of a double tap event. When the Directional Tap™ ODR is 400Hz or less, every count is calculated as 1/ODR delay period. When the Directional Tap™ ODR is 800Hz, every count is calculated as 2/ODR delay period. When the Directional Tap™ ODR is 1600Hz, every count is calculated as 4/ODR delay period. The Directional Tap™ ODR is user-defined per Table 19. The TDTC counts starts at the beginning of the first tap and it represents the minimum time separation between the first tap and the second tap in a double tap event. More specifically, the second tap event must end outside of the TDTC. The Kionix recommended default value is 0.3 seconds (0x78h). Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| | | | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|-------------|---------------------------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
| TDTC7 | TDTC6 | TDTC5 | TDTC4 | TDTC3 | TDTC2 | TDTC1 | TDTC0 | Reset Value | |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 01111000 | |
| | | | | | | | | | I ² C Address: 0x25h |

TTH

This register represents the 8-bit jerk high threshold to determine if a tap is detected. Though this is an 8-bit register, the register value is internally multiplied by two in order to set the high threshold. This multiplication results in a range of 0d to 510d with a resolution of two counts. The Performance Index (PI) is the jerk signal that is expected to be less than this threshold, but greater than the TTL threshold during single and double tap events. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”. The Kionix recommended default value is 203 (0xCBh) and the Performance Index is calculated as:

$$\begin{aligned} X' &= X \text{ (current)} - X \text{ (previous)} \\ Y' &= Y \text{ (current)} - Y \text{ (previous)} \\ Z' &= Z \text{ (current)} - Z \text{ (previous)} \end{aligned}$$

$$PI = |X'| + |Y'| + |Z'|$$

Equation 1: Performance Index

| | | | | | | | | | |
|------|------|------|------|------|------|------|------|-------------|---------------------------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | | |
| TTH7 | TTH6 | TTH5 | TTH4 | TTH3 | TTH2 | TTH1 | TTH0 | Reset Value | |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 11001011 | |
| | | | | | | | | | I ² C Address: 0x26h |



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TTL

This register represents the 8-bit (0d– 255d) jerk low threshold to determine if a tap is detected. The Performance Index (PI) is the jerk signal that is expected to be greater than this threshold and less than the TTH threshold during single and double tap events. The Kionix recommended default value is 26 (0x1Ah). Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| | | | | | | | | |
|---------------------------------|------|------|------|------|------|------|------|-------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
| TTL7 | TTL6 | TTL5 | TTL4 | TTL3 | TTL2 | TTL1 | TTL0 | 00011010 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | |
| I ² C Address: 0x27h | | | | | | | | |

FTD

This register contains counter information for the detection of any tap event. When the Directional Tap™ ODR is 400Hz or less, every count is calculated as 1/ODR delay period. When the Directional Tap™ ODR is 800Hz, every count is calculated as 2/ODR delay period. When the Directional Tap™ ODR is 1600Hz, every count is calculated as 4/ODR delay period. The Directional Tap™ ODR is user-defined per Table 19. In order to ensure that only tap events are detected, these time limits are used. A tap event must be above the performance index threshold for at least the low limit (FTDL0 – FTDL2) and no more than the high limit (FTDH0 – FTDH4). The Kionix recommended default value for the high limit is 0.05 seconds and for the low limit is 0.005 seconds (0xA2h). Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| | | | | | | | | |
|---------------------------------|-------|-------|-------|-------|-------|-------|-------|-------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
| FTDH4 | FTDH3 | FTDH2 | FTDH1 | FTDH0 | FTDL2 | FTDL1 | FTDL0 | 10100010 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | |
| I ² C Address: 0x28h | | | | | | | | |

STD

This register contains counter information for the detection of a double tap event. When the Directional Tap™ ODR is 400Hz or less, every count is calculated as 1/ODR delay period. When the Directional Tap™ ODR is 800Hz, every count is calculated as 2/ODR delay period. When the Directional Tap™ ODR is 1600Hz, every count is calculated as 4/ODR delay period. The Directional Tap™ ODR is user-defined per Table 19. In order to ensure that only tap events are detected, this time limit is used. This register sets the total amount of time that the two taps in a double tap event can be above the PI threshold (TTL). The Kionix recommended default value for STD is 0.09 seconds (0x24h). Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.



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| | | | | | | | | |
|------|------|------|------|------|------|------|------|---------------------------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
| STD7 | STD6 | STD5 | STD4 | STD3 | STD2 | STD1 | STD0 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00100100 |
| | | | | | | | | I ² C Address: 0x29h |

TLT

This register contains counter information for the detection of a tap event. When the Directional Tap™ ODR is 400Hz or less, every count is calculated as 1/ODR delay period. When the Directional Tap™ ODR is 800Hz, every count is calculated as 2/ODR delay period. When the Directional Tap™ ODR is 1600Hz, every count is calculated as 4/ODR delay period. The Directional Tap™ ODR is user-defined per Table 19. In order to ensure that only tap events are detected, this time limit is used. This register sets the total amount of time that the tap algorithm will count samples that are above the PI threshold (TTL) during a potential tap event. It is used during both single and double tap events. However, reporting of single taps on the physical interrupt pin INT1 or INT2 will occur at the end of the TWS. The Kionix recommended default value for TLT is 0.1 seconds (0x28h). Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| | | | | | | | | |
|------|------|------|------|------|------|------|------|---------------------------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
| TLT7 | TLT6 | TLT5 | TLT4 | TLT3 | TLT2 | TLT1 | TLT0 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00101000 |
| | | | | | | | | I ² C Address: 0x2Ah |

TWS

This register contains counter information for the detection of single and double taps. When the Directional Tap™ ODR is 400Hz or less, every count is calculated as 1/ODR delay period. When the Directional Tap™ ODR is 800Hz, every count is calculated as 2/ODR delay period. When the Directional Tap™ ODR is 1600Hz, every count is calculated as 4/ODR delay period. The Directional Tap™ ODR is user-defined per Table 19. It defines the time window for the entire tap event, single or double, to occur. Reporting of single taps on the physical interrupt pin INT1 or INT2 will occur at the end of this tap window. The Kionix recommended default value for TWS is 0.4 seconds (0xA0h). Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| | | | | | | | | |
|------|------|------|------|------|------|------|------|---------------------------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
| TWS7 | TWS6 | TWS5 | TWS4 | TWS3 | TWS2 | TWS1 | TWS0 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 10100000 |
| | | | | | | | | I ² C Address: 0x2Bh |



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ATH

This register sets the threshold for wake-up (motion detect) interrupt is set. The KX023 will ship from the factory with this value set to correspond to a change in acceleration of 0.5g. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
|---------------------------------|------|------|------|------|------|------|------|-------------|
| ATH7 | ATH6 | ATH5 | ATH4 | ATH3 | ATH2 | ATH1 | ATH0 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00001000 |
| I ² C Address: 0x30h | | | | | | | | |

TILT_ANGLE_LL

This register sets the low level threshold for tilt angle detection. The KX023 ships from the factory with tilt angle set to a low threshold of 22° from horizontal. A different default tilt angle can be requested from the factory. Note that the minimum suggested tilt angle is 10°. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
|---------------------------------|------|------|------|------|------|------|------|-------------|
| TA7 | TA6 | TA5 | TA4 | TA3 | TA2 | TA1 | TA0 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00001100 |
| I ² C Address: 0x32h | | | | | | | | |

TILT_ANGLE_HL

This register sets the high level threshold for tilt angle detection. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
|---------------------------------|------|------|------|------|------|------|------|-------------|
| HL7 | HL6 | HL5 | HL4 | HL3 | HL2 | HL1 | HL0 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00101010 |
| I ² C Address: 0x33h | | | | | | | | |



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HYST_SET

This register sets the Hysteresis that is placed in between the Screen Rotation states. The KX023 ships from the factory with HYST_SET set to ±15° of hysteresis. A different default hysteresis can be requested from the factory. Note that when writing a new value to this register the current values of RES0 and RES1 must be preserved. These values are set at the factory and must not change. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
|---------------------------------|------|-------|-------|-------|-------|-------|-------|-------------|
| RES1 | RES0 | HYST5 | HYST4 | HYST3 | HYST2 | HYST1 | HYST0 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00010100 |
| I ² C Address: 0x34h | | | | | | | | |

LP_CNTL

Low Power Control sets the number of samples of accelerometer output to be averaged. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
|---------------------------------|------|------|------|----------|----------|----------|----------|-------------|
| Reserved | AVC2 | AVC1 | AVC0 | Reserved | Reserved | Reserved | Reserved | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 01001011 |
| I ² C Address: 0x35h | | | | | | | | |

AVC<2:0> – Averaging Filter Control, the default setting is 16 samples averaged
 000 = No Averaging
 001 = 2 Samples Averaged
 010 = 4 Samples Averaged
 011 = 8 Samples Averaged
 100 = 16 Samples Averaged (default)
 101 = 32 Samples Averaged
 110 = 64 Samples Averaged
 111 = 128 Samples Averaged

Reserved – The Reserved bits should remain at their Reset state to avoid unexpected behavior.



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BUF_CNTL1

Read/write control register that controls the buffer sample threshold. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| | | | | | | | | |
|------|---------|---------|---------|---------|---------|---------|---------|---------------------------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | |
| - | SMP_TH6 | SMP_TH5 | SMP_TH4 | SMP_TH3 | SMP_TH2 | SMP_TH1 | SMP_TH0 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00000000 |
| | | | | | | | | I ² C Address: 0x3Ah |

SMP_TH[6:0] Sample Threshold; determines the number of samples that will trigger a watermark interrupt or will be saved prior to a trigger event. When BUF_RES=1, the maximum number of samples is 41; when BUF_RES=0, the maximum number of samples is 84.

| Buffer Model | Sample Function |
|--------------|--|
| Bypass | None |
| FIFO | Specifies how many buffer sample are needed to trigger a watermark interrupt. |
| Stream | Specifies how many buffer samples are needed to trigger a watermark interrupt. |
| Trigger | Specifies how many buffer samples before the trigger event are retained in the buffer. |
| FILO | Specifies how many buffer samples are needed to trigger a watermark interrupt. |

Table 22: Sample Threshold Operation by Buffer Mode



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BUF_CNTL2

Read/write control register that controls sample buffer operation. Note that to properly change the value of this register, the PC1 bit in CNTL1 must first be set to “0”.

| | | | | | | | | |
|---------------------------------|------|------|------|------|------|--------|--------|-------------|
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W |
| BUFE | BRES | BFIE | 0 | 0 | 0 | BUF_M1 | BUF_M0 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00000000 |
| I ² C Address: 0x3Bh | | | | | | | | |

BUFE controls activation of the sample buffer.

BUFE = 0 – sample buffer inactive

BUFE = 1 – sample buffer active

BRES determines the resolution of the acceleration data samples collected by the sample buffer.

BUF_RES = 0 – 8-bit samples are accumulated in the buffer

BUF_RES = 1 – 16-bit samples are accumulated in the buffer

BFIE buffer full interrupt enable bit

BFIE = 0 – buffer full interrupt disabled

BFIE = 1 – buffer full interrupt updated in INS2

BUF_M1, BUF_M0 selects the operating mode of the sample buffer per Table 23.

| BUF_M1 | BUF_M0 | Mode | Description |
|--------|--------|---------|--|
| 0 | 0 | FIFO | The buffer collects 84 sets of 8-bit low resolution values or 41 sets of 16bit high resolution values and then stops collecting data, collecting new data only when the buffer is not full. |
| 0 | 1 | Stream | The buffer holds the last 84 sets of 8-bit low resolution values or 41 sets of 16bit high resolution values. Once the buffer is full, the oldest data is discarded to make room for newer data. |
| 1 | 0 | Trigger | When a trigger event occurs, the buffer holds the last data set of SMP_TH[6:0] samples before the trigger event and then continues to collect data until full. New data is collected only when the buffer is not full. |
| 1 | 1 | FILO | The buffer holds the last 84 sets of 8-bit low resolution values or 41 sets of 16bit high resolution values. Once the buffer is full, the oldest data is discarded to make room for newer data. Reading from the buffer in this mode will return the most recent data first. |

Table 23: Selected Buffer Mode



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BUF_STATUS_1

This register reports the status of the sample buffer.

| | | | | | | | |
|---------------------------------|----------|----------|----------|----------|----------|----------|----------|
| R | R | R | R | R | R | R | R |
| SMP_LEV7 | SMP_LEV6 | SMP_LEV5 | SMP_LEV4 | SMP_LEV3 | SMP_LEV2 | SMP_LEV1 | SMP_LEV0 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x3Ch | | | | | | | |

SMP_LEV[7:0] Sample Level; reports the number of data bytes that have been stored in the sample buffer. When *BUF_RES=1*, this count will increase by 6 for each 3-axis sample in the buffer; when *BUF_RES=0*, the count will increase by 3 for each 3-axis sample. If this register reads 0, no data has been stored in the buffer.

BUF_STATUS_2

This register reports the status of the sample buffer trigger function.

| | | | | | | | |
|---------------------------------|------|------|------|------|------|------|------|
| R | R | R | R | R | R | R | R |
| BUF_TRIG | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x3Dh | | | | | | | |

BUF_TRIG reports the status of the buffer's trigger function if this mode has been selected. When using trigger mode, a buffer read should only be performed after a trigger event.

BUF_CLEAR

Latched buffer status information and the entire sample buffer are cleared when any data is written to this register.

| | | | | | | | |
|---------------------------------|------|------|------|------|------|------|------|
| W | W | W | W | W | W | W | W |
| X | X | X | X | X | X | X | X |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x3Eh | | | | | | | |



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BUF_READ

Buffer output register

| | | | | | | | |
|---------------------------------|------|------|------|------|------|------|------|
| R | R | R | R | R | R | R | R |
| X | X | X | X | X | X | X | X |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
| I ² C Address: 0x3Fh | | | | | | | |

Note: new data is not being written to the buffer during the buffer read operation. Thus, care must be taken when reading from the buffer. If data loss is not desired, the buffer read operation should be completed within ODR clock cycle.

SELF_TEST

When 0xCA is written to this register, the MEMS self-test function is enabled. Electrostatic-actuation of the accelerometer, results in a DC shift of the X, Y and Z axis outputs. Writing 0x00 to this register will return the accelerometer to normal operation.

****Note, this is a write-only register. Read back value from this register will always be 0x00.**

| | | | | | | | | |
|---------------------------------|------|------|------|------|------|------|------|-------------|
| W | W | W | W | W | W | W | W | |
| 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | Reset Value |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | 00000000 |
| I ² C Address: 0x60h | | | | | | | | |



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Embedded Applications

Orientation Detection Feature

The Orientation detection feature of the KX023 will report changes in face up, face down, ± vertical and ± horizontal orientation. This intelligent embedded algorithm considers very important factors that provide accurate orientation detection from low cost tri-axis accelerometers. Factors such as: hysteresis, device orientation angle and delay time are described below as these techniques are utilized inside the KX023

Hysteresis

A 45° tilt angle threshold seems like a good choice because it is halfway between 0° and 90°. However, a problem arises when the user holds the device near 45°. Slight vibrations, noise and inherent sensor error will cause the acceleration to go above and below the threshold rapidly and randomly, so the screen will quickly flip back and forth between the 0° and the 90° orientations. This problem is avoided in the KX023 by choosing a 30° threshold angle. With a 30° threshold, the screen will not rotate from 0° to 90° until the device is tilted to 60° (30° from 90°). To rotate back to 0°, the user must tilt back to 30°, thus avoiding the screen flipping problem. This example essentially applies ± 15° of hysteresis in between the four screen rotation states. Table 24 shows the acceleration limits implemented for $\phi_T = 30^\circ$.

| Orientation | X Acceleration (g) | Y Acceleration (g) |
|-------------|--------------------|--------------------|
| 0°/360° | $-0.5 < a_x < 0.5$ | $a_y > 0.866$ |
| 90° | $a_x > 0.866$ | $-0.5 < a_y < 0.5$ |
| 180° | $-0.5 < a_x < 0.5$ | $a_y < -0.866$ |
| 270° | $a_x < -0.866$ | $-0.5 < a_y < 0.5$ |

Table 24: Acceleration at the four orientations with ± 15° of hysteresis

The KX023 allows the user to change the amount of hysteresis in between the four screen rotation states. By simply writing to the HYST_SET register, the user can adjust the amount of hysteresis up to ± 45°. The plot in Figure 8 shows the typical amount of hysteresis applied for a given digital count value of HYST_SET.



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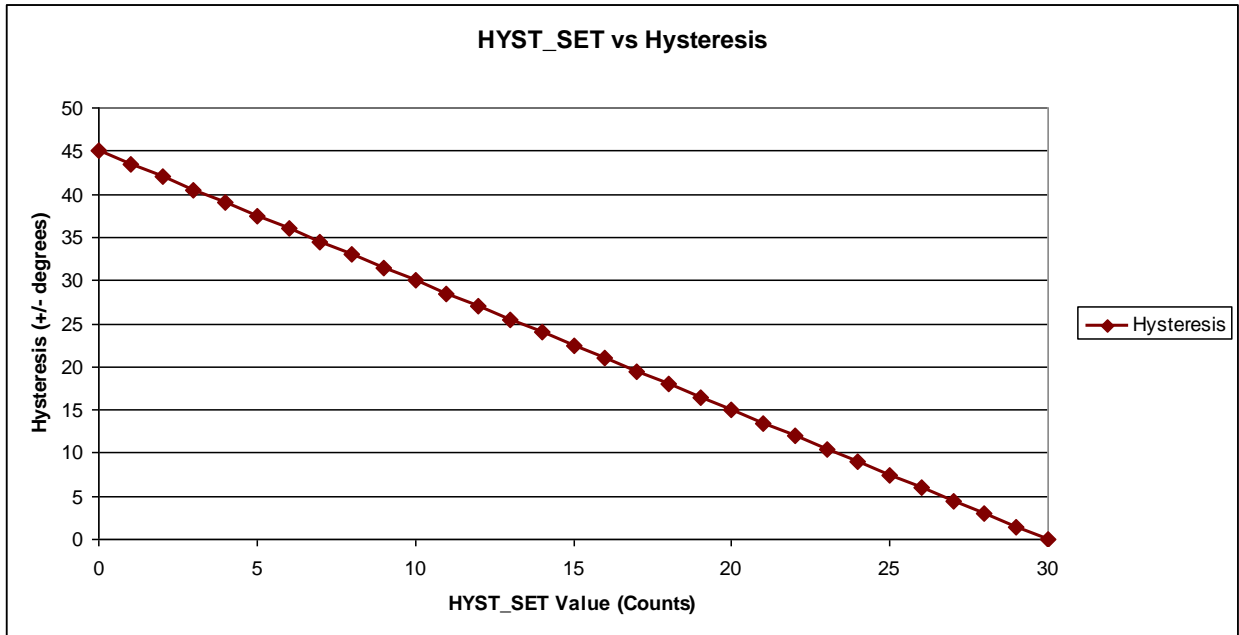


Figure 8: HYST_SET vs Hysteresis

Device Orientation Angle (aka Tilt Angle)

To ensure that horizontal and vertical device orientation changes are detected, even when it isn't in the ideal vertical orientation – where the angle θ in Figure 9 is 90° , the KX023 considers device orientation angle in its algorithm.

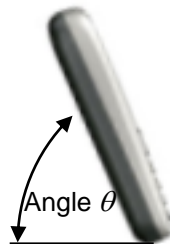


Figure 9: Device Orientation Angle

As the angle in Figure 9 is decreased, the maximum gravitational acceleration on the X-axis or Y-axis will also decrease. Therefore, when the angle becomes small enough, the user will not be able to make the screen orientation change. When the device orientation angle approaches 0° (device is flat on a



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desk or table), $a_x = a_y = 0g$, $a_z = +1g$, and there is no way to determine which way the screen should be oriented, the internal algorithm determines that the device is in either the face-up or face-down orientation, depending on the sign of the z-axis. The KX023 will only change the screen orientation when the orientation angle is above the factory-defaulted/user-defined threshold set in the TILT_ANGLE register. Equation 2 can be used to determine what value to write to the TILT_ANGLE register to set the device orientation angle. The value for TILT_ANGLE_HL is preset at the factory but can be adjusted in special cases (e.g. to reduce the effect of transient g-variation such as when device is being moved rather than just being rotated).

$$\text{TILT_ANGLE (counts)} = \sin \theta * (32 \text{ (counts/g)})$$


Equation 2: Tilt Angle Threshold

Tilt Timer

The 8-bit register, TILT_TIMER can be used to qualify changes in orientation. The KX023 does this by incrementing a counter with a size that is specified by the value in TILT_TIMER for each set of acceleration samples to verify that a change to a new orientation state is maintained. A user defined output data rate (ODR) determines the time period for each sample. Equation 3 shows how to calculate the TILT_TIMER register value for a desired delay time.

$$\text{TILT_TIMER (counts)} = \text{Delay Time (sec)} \times \text{ODR (Hz)}$$

Equation 3: Tilt Position Delay Time

| | | |
|---|---|---|
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|---|---|---|

Motion Interrupt Feature Description

The Motion interrupt feature of the KX023 reports qualified changes in the high-pass filtered acceleration based on the Wake Up (ATH) threshold. If the high-pass filtered acceleration on any axis is greater than the user-defined wake up threshold (ATH), the device has transitioned from an inactive state to an active state. Equation 4 shows how to calculate the ATH register value for a desired wake up threshold. Note that this calculation varies based on the configured g-range of the part.

$$\text{ATH (counts)} = \text{Wake Up Threshold (g)} \times 16 \text{ (counts/g)}$$

Equation 4: Wake Up Threshold

An 8-bit raw unsigned value represents a counter that permits the user to qualify each active/inactive state change. Note that each WUFC Timer count qualifies 1 (one) user-defined ODR period (OWUF). Equation 5 shows how to calculate the WUFC register value for a desired wake up delay time.

$$\text{WUFC (counts)} = \text{Wake Up Delay Time (sec)} \times \text{OWUF (Hz)}$$

Equation 5: Wake Up Delay Time

The latched motion interrupt response algorithm works as following: while the part is in inactive state, the algorithm evaluates differential measurement between each new acceleration data point with the preceding one and evaluates it against the ATH threshold. When the differential measurement is greater than ATH threshold, the wakeup counter starts the count. Differential measurements are now calculated based on the difference between the current acceleration and the acceleration when the counter started. The part will report that motion has occurred at the end of the count assuming each differential measurement has remained above the threshold. If at any moment during the count the differential measurement falls below the threshold, the counter will stop the count and the part will remain in inactive state.

To illustrate how the algorithm works, consider the Figure 10 below that shows the latched response of the motion detection algorithm with WUF Timer (WUFC) set to 10 counts. Note how the difference between the acceleration sample marked in red and the one marked in green resulted in a differential measurements represented with orange bar being above the WUF threshold. At this point, the counter begins to count number of counts stored in WUFC register and the wakeup algorithm will evaluate the difference between each new acceleration measurement and the measurement marked in green that will remain a reference measurement for the duration of the counter count. At the end of the count, assuming all differential measurements were larger than WUF threshold, as is the case in the example showed in Figure 10, a motion event will be reported.



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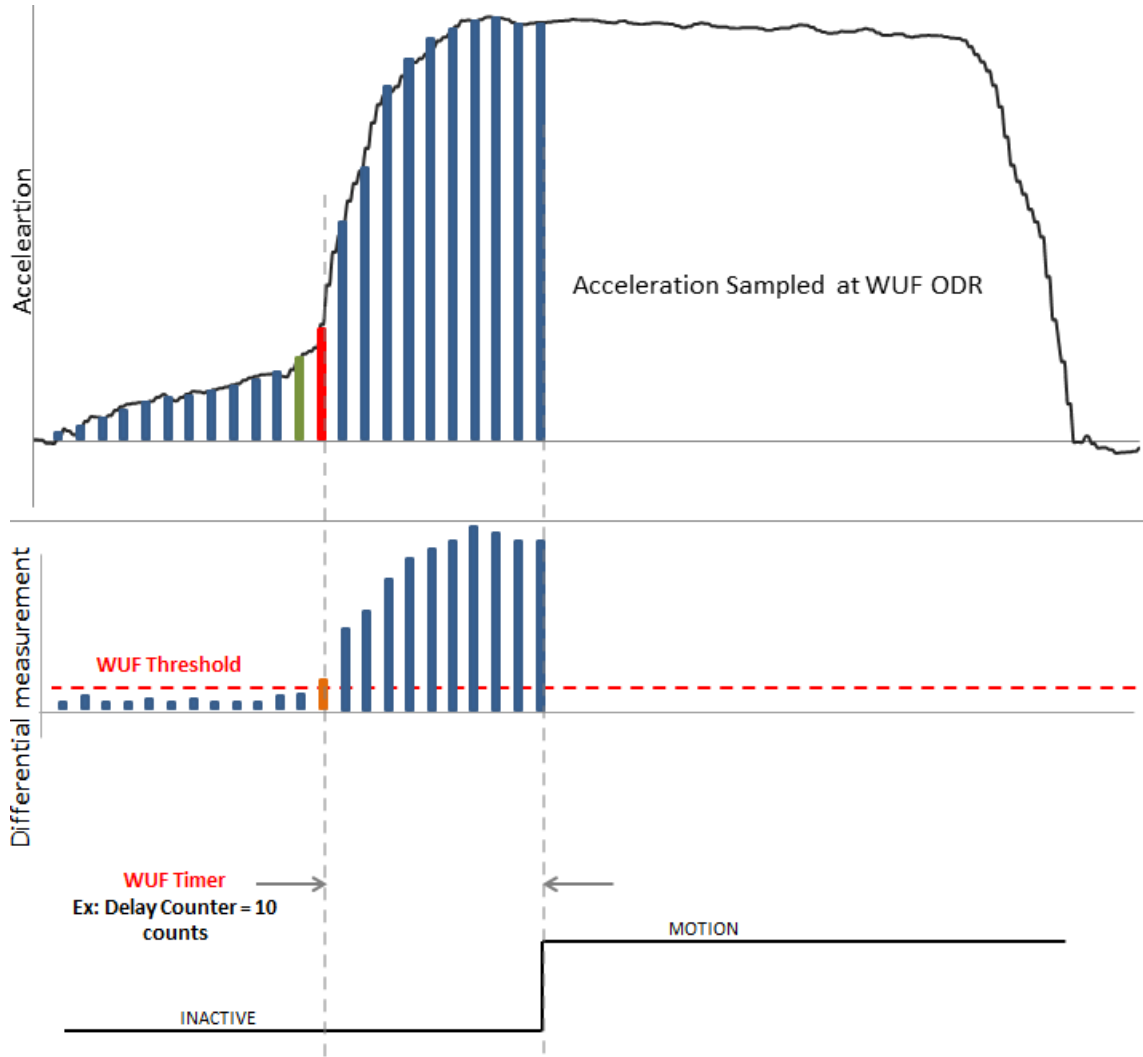


Figure 10: Latched Motion Interrupt Response



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Directional Tap Detection Feature Description

The Directional Tap Detection feature of the KX023 recognizes single and double tap inputs and reports the acceleration axis and direction that each tap occurred. Eight performance parameters, as well as a user-selectable ODR are used to configure the KX023 for a desired tap detection response.

Performance Index

The Directional Tap™ detection algorithm uses low and high thresholds to help determine when a tap event has occurred. A tap event is detected when the previously described jerk summation exceeds the low threshold (TTL) for more than the tap detection low limit, but less than the tap detection high limit as contained in FTD. Samples that exceed the high limit (TTH) will be ignored. Figure 11 shows an example of a single tap event meeting the performance index criteria.

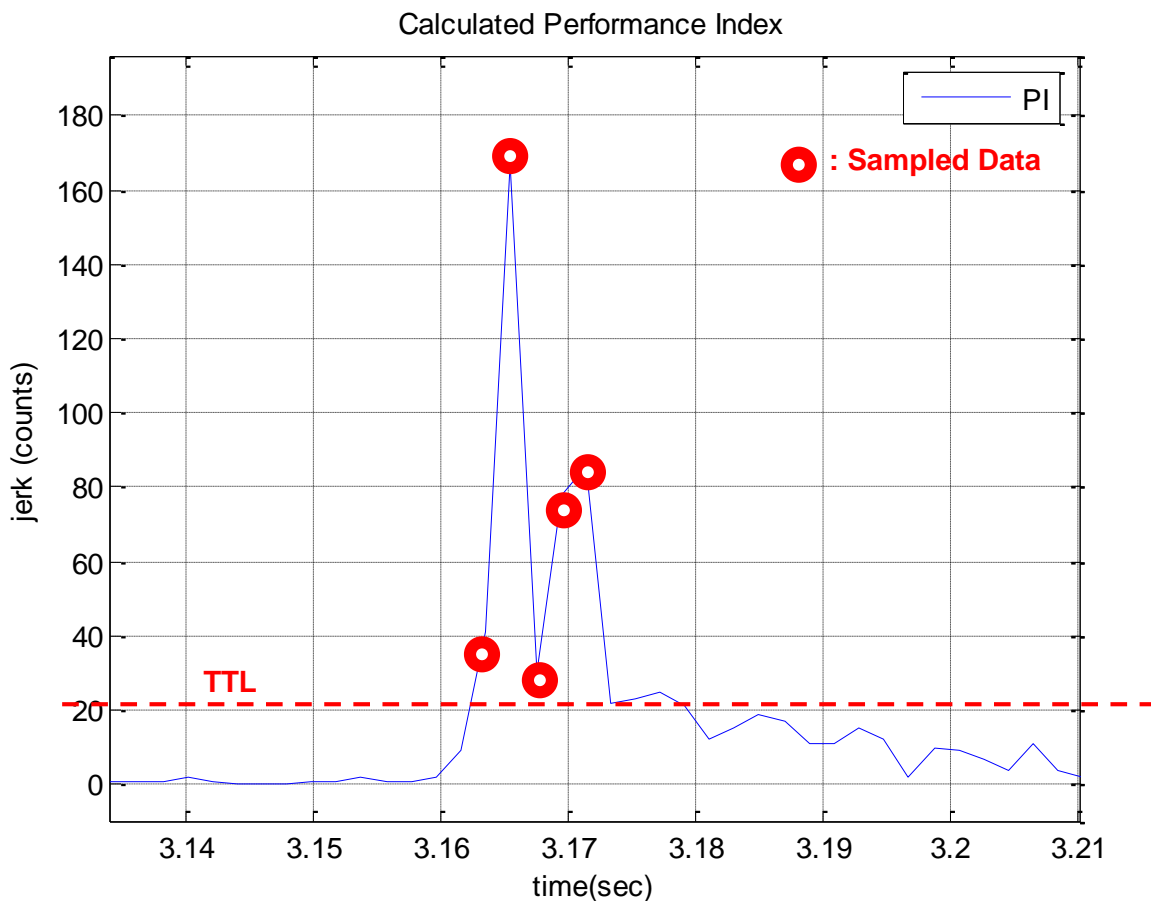


Figure 11: Jerk Summation vs Threshold



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Single Tap Detection

The latency timer (TLT) sets the time period that a tap event will only be characterized as a single tap. A second tap has to occur outside of the latency timer. If a second tap occurs inside the latency time, it will be ignored as it occurred too quickly. The single tap will be reported at the end of the TWS. Figure 12 shows a single tap event meeting the PI, latency and window requirements.

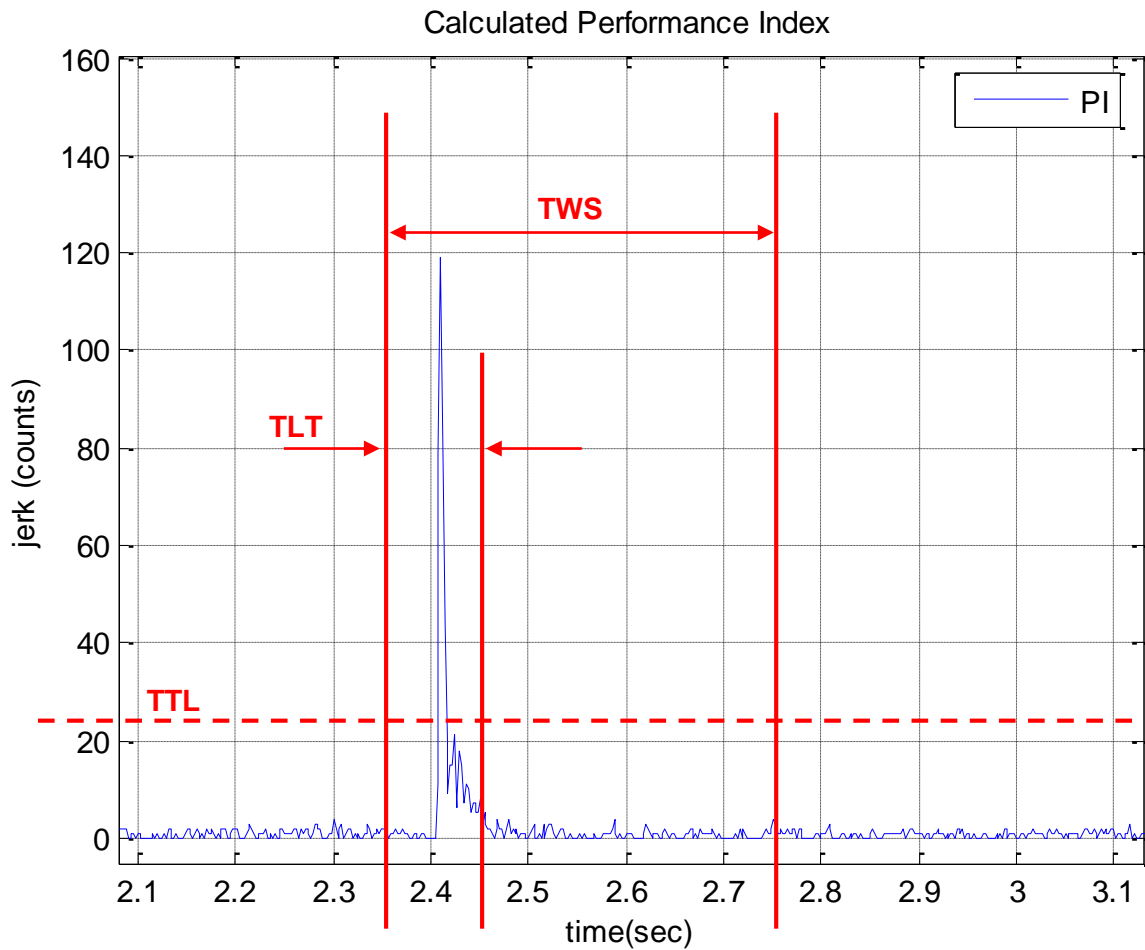


Figure 12: Single Directional Tap™ Timing



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Double Tap Detection

An event can be characterized as a double tap if the second tap crosses up the performance index (TTL) inside the TWS period and ends outside the TDTC. This means that the TDTC determines the minimum time separation that must exist between the two taps of a double tap event. Similar to the single tap, the first tap event must exceed the performance index for the time limit contained in FTD. Also, the duration when the first and second events combined exceed the performance index should not exceed STD. The double tap will be reported at the end of the second TLT. Figure 13 shows a double tap event meeting the PI, latency and window requirements.

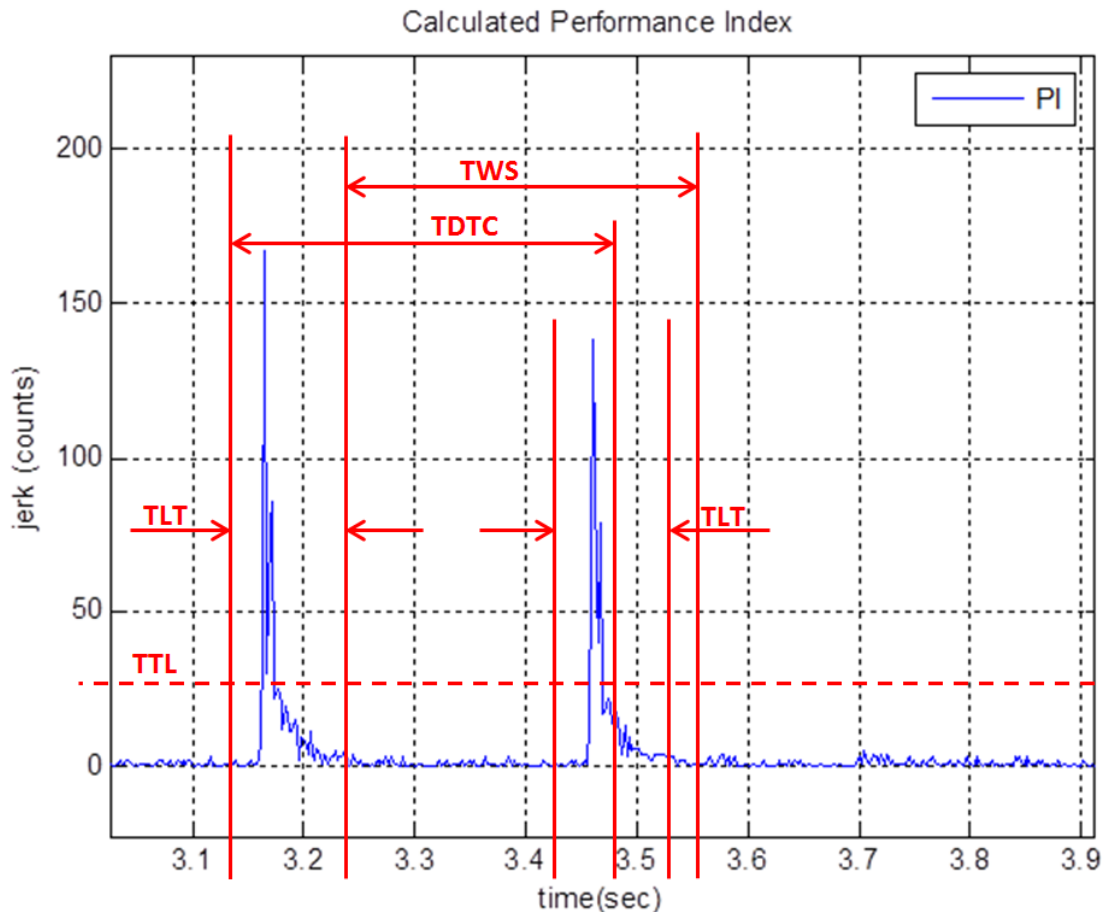


Figure 13: Double Directional Tap™ Timing



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Sample Buffer Feature Description

The sample buffer feature of the KX023 accumulates and outputs acceleration data based on how it is configured. There are 4 buffer modes available, and samples can be accumulated at either low (8-bit) or high (16-bit) resolution. Acceleration data is collected at the ODR specified by OSA[3:0] in the ODCNTL register. Each buffer mode accumulates data, reports data, and interacts with status indicators in a slightly different way.

FIFO Mode

Data Accumulation

Sample collection stops when the buffer is full.

Data Reporting

Data is reported with the oldest byte of the oldest sample first (X_L or X based on resolution).

Status Indicators

A watermark interrupt occurs when the number of samples in the buffer reaches the Sample Threshold. The watermark interrupt stays active until the buffer contains less than this number of samples. This can be accomplished through clearing the buffer or explicitly reading greater than SMPX samples (calculated with Equation 6).

$$\text{BUF_RES}=0: \\ \text{SMPX} = \text{SMP_LEV}[7:0] / 3 - \text{SMP_TH}[6:0]$$

$$\text{BUF_RES}=1: \\ \text{SMPX} = \text{SMP_LEV}[7:0] / 6 - \text{SMP_TH}[6:0]$$

Equation 6. Samples Above Sample Threshold

Stream Mode

Data Accumulation

Sample collection continues when the buffer is full; older data is discarded to make room for newer data.

Data Reporting

Data is reported with the oldest sample first (uses FIFO read pointer).

Status Indicators

A watermark interrupt occurs when the number of samples in the buffer reaches the Sample Threshold. The watermark interrupt stays active until the buffer contains less than this number of samples. This can be accomplished through clearing the buffer or explicitly reading greater than SMPX samples (calculated with Equation 6).



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Trigger Mode

Data Accumulation

When a physical interrupt is caused by one of the digital engines or when a logic high signal occurs on the TRIG pin, the trigger event is asserted and SMP_TH[6:0] samples prior to the event are retained. Sample collection continues until the buffer is full.

Data Reporting

Data is reported with the oldest sample first (uses FIFO read pointer).

Status Indicators

When a physical interrupt occurs and there are at least SMP_TH[6:0] samples in the buffer, BUF_TRIG in BUF_STATUS_2 is asserted.

FILO Mode

Data Accumulation

Sample collection continues when the buffer is full; older data is discarded to make room for newer data.

Data Reporting

Data is reported with the newest byte of the newest sample first (Z_H or Z based on resolution).

Status Indicators

A watermark interrupt occurs when the number of samples in the buffer reaches the Sample Threshold. The watermark interrupt stays active until the buffer contains less than this number of samples. This can be accomplished through clearing the buffer or explicitly reading greater than SMPX samples (calculated with Equation 6).

Buffer Operation

The following diagrams illustrate the operation of the buffer conceptually. Actual physical implementation has been abstracted to offer a simplified explanation of how the different buffer modes operate. Figure 14 represents a high-resolution 3-axis sample within the buffer. Figure 15 – Figure 23 represent a 10-sample version of the buffer (for simplicity), with Sample Threshold set to 8.

Regardless of the selected mode, the buffer fills sequentially, one byte at a time. It is important to keep in mind that new data is not being written to the buffer during the buffer read operation. Thus, care must be taken when reading from the buffer. If data loss is not desired, the buffer read operation should be completed within ODR clock cycle.



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Figure 14 shows one 6-byte data sample. Note the location of the FILO read pointer versus that of the FIFO read pointer.

| Index | Byte | |
|-------|------|-----------------------|
| 0 | X_L | ←-- FIFO read pointer |
| 1 | X_H | |
| 2 | Y_L | |
| 3 | Y_H | |
| 4 | Z_L | |
| 5 | Z_H | ←-- FILO read pointer |
| 6 | | |

buffer write pointer --→

Figure 14: One Buffer Sample

Regardless of the selected mode, the buffer fills sequentially, one sample at a time. Note in Figure 15 the location of the FILO read pointer versus that of the FIFO read pointer. The buffer write pointer shows where the next sample will be written to the buffer.

| Index | Sample | |
|-------|--------|---------------------|
| 0 | Data0 | ← FIFO read pointer |
| 1 | Data1 | |
| 2 | Data2 | ← FILO read pointer |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | ← Sample Threshold |
| 8 | | |
| 9 | | |

buffer write pointer →

Figure 15: Buffer Filling



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The buffer continues to fill sequentially until the Sample Threshold is reached. Note in Figure 16 the location of the FILO read pointer versus that of the FIFO read pointer.

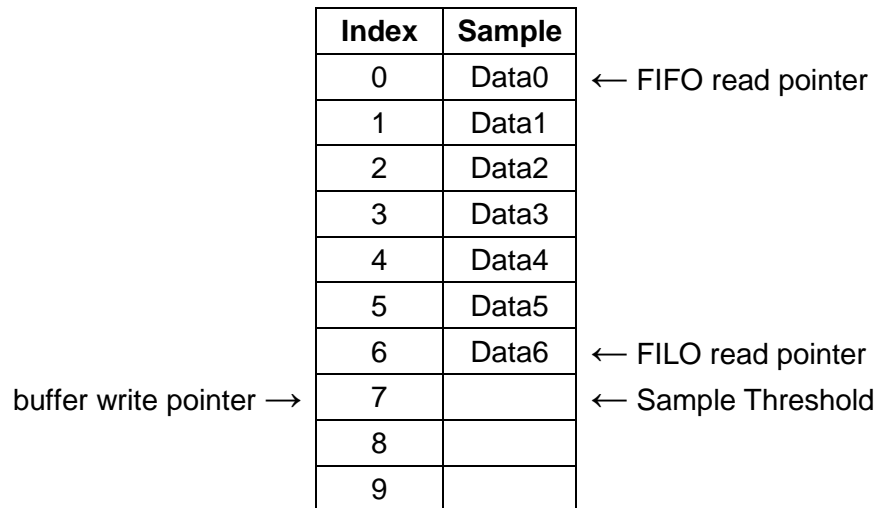


Figure 16: Buffer Approaching Sample Threshold

In FIFO, Stream, and FILO modes, a watermark interrupt is issued when the number of samples in the buffer reaches the Sample Threshold. In trigger mode, this is the point where the oldest data in the buffer is discarded to make room for newer data.

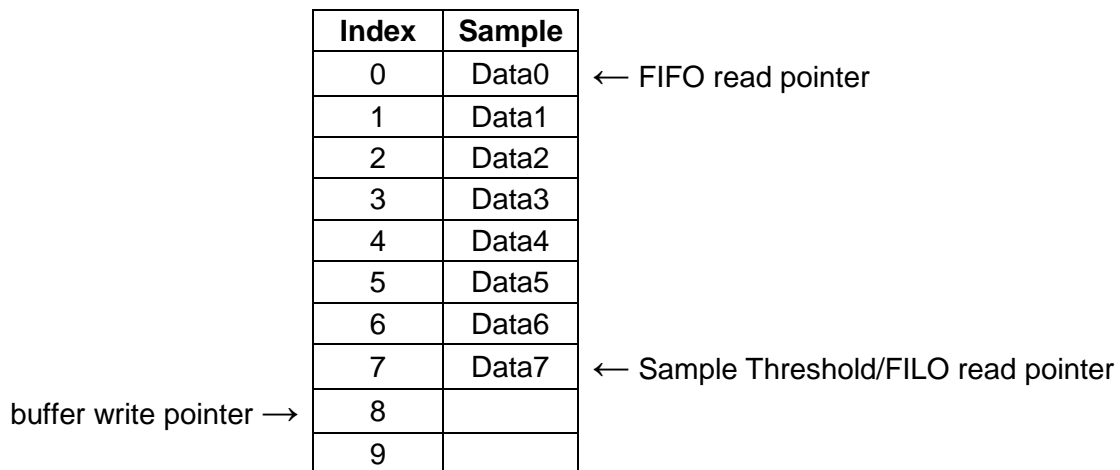


Figure 17: Buffer at Sample Threshold



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In trigger mode, data is accumulated in the buffer sequentially until the Sample Threshold is reached. Once the Sample Threshold is reached, the oldest samples are discarded when new samples are collected. Note in Figure 18 how Data0 was thrown out to make room for Data8.

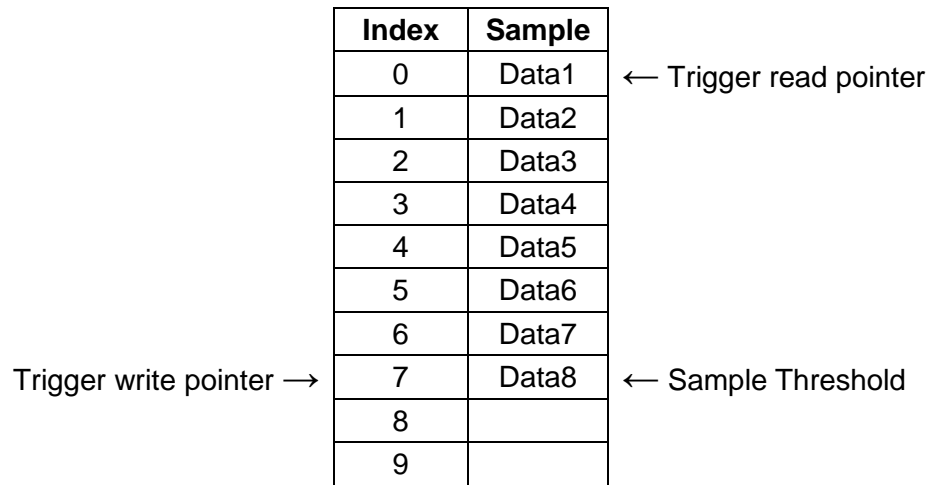


Figure 18: Additional Data Prior to Trigger Event

After a trigger event occurs, the buffer no longer discards the oldest samples, and instead begins accumulating samples sequentially until full. The buffer then stops collecting samples, as seen in Figure 19. This results in the buffer holding SMP_TH[6:0] samples prior to the trigger event, and SMPX samples after the trigger event.

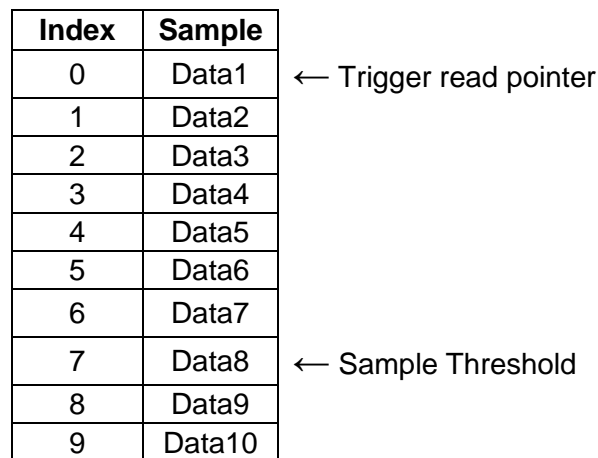


Figure 19: Additional Data After Trigger Event



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In FIFO, Stream, FILO, and Trigger (after a trigger event has occurred) modes, the buffer continues filling sequentially after the Sample Threshold is reached. Sample accumulation after the buffer is full depends on the selected operation mode. FIFO and Trigger modes stop accumulating samples when the buffer is full, and Stream and FILO modes begin discarding the oldest data when new samples are accumulated.

| Index | Sample | |
|-------|--------|---------------------|
| 0 | Data0 | ← FIFO read pointer |
| 1 | Data1 | |
| 2 | Data2 | |
| 3 | Data3 | |
| 4 | Data4 | |
| 5 | Data5 | |
| 6 | Data6 | |
| 7 | Data7 | ← Sample Threshold |
| 8 | Data8 | |
| 9 | Data9 | ← FILO read pointer |

Figure 20: Buffer Full

After the buffer has been filled in FILO or Stream mode, the oldest samples are discarded when new samples are collected. Note in Figure 21 how Data0 was thrown out to make room for Data10.

| Index | Sample | |
|-------|--------|---------------------|
| 0 | Data1 | ← FIFO read pointer |
| 1 | Data2 | |
| 2 | Data3 | |
| 3 | Data4 | |
| 4 | Data5 | |
| 5 | Data6 | |
| 6 | Data7 | |
| 7 | Data8 | ← Sample Threshold |
| 8 | Data9 | |
| 9 | Data10 | ← FILO read pointer |

Figure 21: Buffer Full – Additional Sample Accumulation in Stream or FILO Mode



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In FIFO, Stream, or Trigger mode, reading one sample from the buffer will remove the oldest sample and effectively shift the entire buffer contents up, as seen in Figure 22.

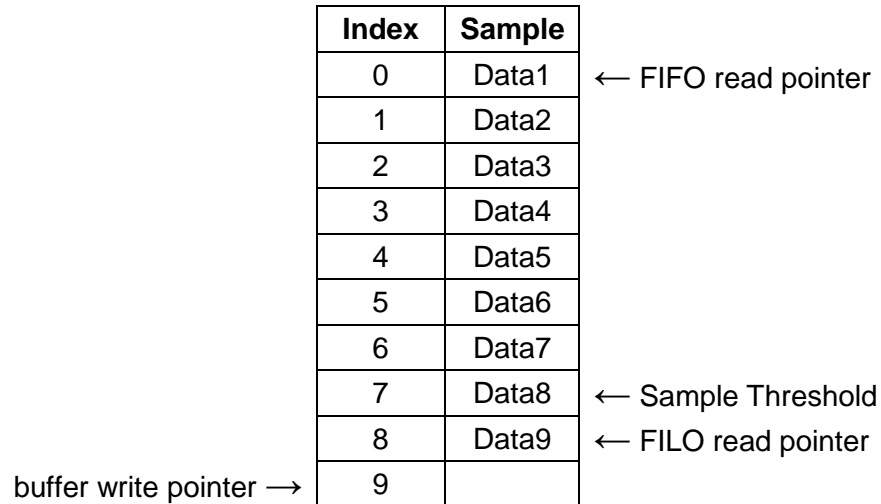


Figure 22: FIFO Read from Full Buffer

In FILO mode, reading one sample from the buffer will remove the newest sample and leave the older samples untouched, as seen in Figure 23.

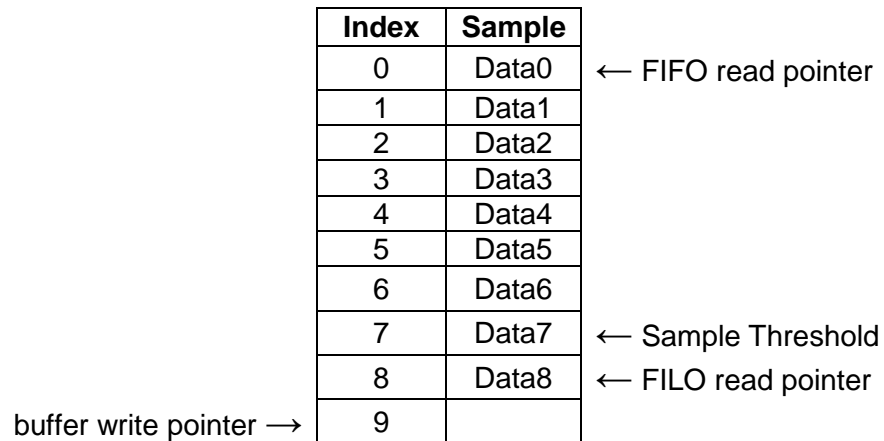


Figure 23: FILO Read from Full Buffer



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Revision History

| REVISION | DESCRIPTION | DATE |
|----------|---|--------------|
| 1.0 | Initial Release | 30-Aug-2013 |
| 1.1 | Added Offset and Sensitivity Tolerances | 12-Sept-2013 |
| 1.2 | Added LP_CNTL Accelerometer Output Averaging Register, Updated Test Spec limits in Table 5 and Table 8. | 02-Oct-2013 |
| 2.0 | Added reference to FlexSet™ Performance Optimization, Updated reference to OSA in ODCNTL for output registers. | 19-Nov-2013 |
| 3.0 | Updated default values for TSPP, TSCP | 03-Dec-2013 |
| 4.0 | Added Min and Max Self-Test limits to Table 1, replaced bottom view of package in diagrams, pictures. | 08-Jan-2014 |
| 5.0 | Improved high resolution and low power mode descriptions, corrected test specification limits Table 5. | 16-Jan-2014 |
| 6.0 | Administrative adjustment | |
| 7.0 | Revised Accelerometer Outputs table | 17-Sep-2014 |
| 8.0 | Updated Package Drawing | 15-Oct-2014 |
| 9.0 | Revised ODR settings and current profile | 08-Dec-2014 |
| 10.0 | Added Power-On procedure details. Updated Figure 1. Updated Motion Interrupt feature plot and description Updated Double-Tap Detection plot and description Fixed factory value set for TILT_ANGLE_LL. | 01-Apr-2015 |
| 11.0 | Updated Table 12: Acceleration (g) Calculation Updated Current Profile plot and table Updated POR section Updated RoHS compliance. Added REACH compliance. Updated "Reading from / Writing To KX023 8-bit Register section Updated I2C Timing diagram Updated I2C address table Added note to Writing to 8-bit Register I2C section Updated 3-Wire and 4-Wire Read and Write Registers Updated Wake Up Threshold equation Added Notice section | 09-Sep-2015 |
| 12.0 | Fixed References to SMPX equation calculations Added note in Reading from 8-bit Register section Changed VSS to GND reference in the I2C Address Table / Figure Updated R / W status for SELF_TEST, BUF_STATUS_1, 2, BUF_READ, BUF_CLEAR registers. Changed minimum operating voltage in Product Description to 1.71V (from 1.8V) Updated Pin Description Table Updated Block Diagram and product photo Updated Sample Buffer Feature description Updated Trigger Buffer description Fixed bit name (SMP>SMP_TH) in BUF_CNTL1 Fixed reference to CNTL1 from CTRL_REG1 Fixed COTC bit description in CNTL2 register Added "Positive" to the Self Test Spec in Mechanical Specifications Table Updated name for RES=1 mode in CNTL1 register Fixed register name from BUF_STATUS_REG2 to BUF_STATUS_2 in Trigger Mode Added note under mechanical spec to change STPOL bit to 1 for Positive Self Test Added note to avoid changing reserved bits from their reset value where applicable. Added note buffer write is blocked during buffer read operation. Updated Intellectual Property Section of the Notice | 05-Apr-2016 |



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| CLASS IV | | CLASS III | |

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 - a) Installation of protection circuits or other protective devices to improve system safety
 - b) Installation of redundant circuits to reduce the impact of single or multiple circuit failure
3. Our Products are designed and manufactured for use under standard conditions and not under any special or extraordinary environments or conditions, as exemplified below. Accordingly, KIONIX shall not be in any way responsible or liable for any damages, expenses or losses arising from the use of any KIONIX’s Products under any special or extraordinary environments or conditions. If you intend to use our Products under any special or extraordinary environments or conditions (as exemplified below), your independent verification and confirmation of product performance, reliability, etc., prior to use, must be necessary:
 - a) Use of our Products in any types of liquid, including water, oils, chemicals, and organic solvents
 - b) Use of our Products outdoors or in places where the Products are exposed to direct sunlight or dust
 - c) Use of our Products in places where the Products are exposed to sea wind or corrosive gases, including Cl₂, H₂S, NH₃, SO₂, and NO₂
 - d) Use of our Products in places where the Products are exposed to static electricity or electromagnetic waves
 - e) Use of our Products in proximity to heat-producing components, plastic cords, or other flammable items
 - f) Sealing or coating our Products with resin or other coating materials
 - g) Use of our Products without cleaning residue of flux (even if you use no-clean type fluxes, cleaning residue of flux is recommended); or Washing our Products by using water or water-soluble cleaning agents for cleaning residue after soldering
 - h) Use of the Products in places subject to dew condensation
4. The Products are not subject to radiation-proof design.
5. Please verify and confirm characteristics of the final or mounted products in using the Products.
6. In particular, if a transient load (a large amount of load applied in a short period of time, such as pulse. Is applied, confirmation of performance characteristics after on-board mounting is strongly recommended. Avoid applying



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power exceeding normal rated power; exceeding the power rating under steady-state loading condition may negatively affect product performance and reliability.

7. De-rate Power Dissipation (Pd) depending on ambient temperature (Ta). When used in sealed area, confirm the actual ambient temperature.
8. Confirm that operation temperature is within the specified range described in the product specification.
9. KIONIX shall not be in any way responsible or liable for failure induced under deviant condition from what is defined in this document.

Precaution for Mounting / Circuit board design

1. When a highly active halogenous (chlorine, bromine, etc.) flux is used, the residue of flux may negatively affect product performance and reliability.
2. In principle, the reflow soldering method must be used; if flow soldering method is preferred, please consult with the KIONIX representative in advance.

For details, please refer to KIONIX Mounting specification.

Precautions Regarding Application Examples and External Circuits


1. If change is made to the constant of an external circuit, please allow a sufficient margin considering variations of the characteristics of the Products and external components, including transient characteristics, as well as static characteristics.
2. You agree that application notes, reference designs, and associated data and information contained in this document are presented only as guidance for Products use. Therefore, in case you use such information, you are solely responsible for it and you must exercise your own independent verification and judgment in the use of such information contained in this document. KIONIX shall not be in any way responsible or liable for any damages, expenses or losses incurred by you or third parties arising from the use of such information.

Precaution for Electrostatic

This Product is electrostatic sensitive product, which may be damaged due to electrostatic discharge. Please take proper caution in your manufacturing process and storage so that voltage exceeding the Products maximum rating will not be applied to Products. Please take special care under dry condition (e.g. Grounding of human body / equipment / solder iron, isolation from charged objects, setting of Ionizer, friction prevention and temperature / humidity control).

Precaution for Storage / Transportation

1. Product performance and soldered connections may deteriorate if the Products are stored in the places where:
 - a) the Products are exposed to sea winds or corrosive gases, including Cl₂, H₂S, NH₃, SO₂, and NO₂
 - b) the temperature or humidity exceeds those recommended by KIONIX
 - c) the Products are exposed to direct sunshine or condensation
 - d) the Products are exposed to high Electrostatic
2. Even under KIONIX recommended storage condition, solderability of products out of recommended storage time period may be degraded. It is strongly recommended to confirm solderability before using Products of which storage time is exceeding the recommended storage time period.
3. Store / transport cartons in the correct direction, which is indicated on a carton with a symbol. Otherwise bent leads may occur due to excessive stress applied when dropping of a carton.
4. Use Products within the specified time after opening a humidity barrier bag. Baking is required before using Products of which storage time is exceeding the recommended storage time period.

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Precaution for Product Label

QR code printed on KIONIX Products label is for KIONIX's internal use only.

Precaution for Disposition

When disposing Products please dispose them properly using an authorized industry waste company.

Precaution for Foreign Exchange and Foreign Trade act

Since our Products might fall under controlled goods prescribed by the applicable foreign exchange and foreign trade act, please consult with KIONIX representative in case of export.

Precaution Regarding Intellectual Property Rights

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General Precaution

1. Before you use our Products, you are requested to carefully read this document and fully understand its contents. KIONIX shall not be in any way responsible or liable for failure, malfunction or accident arising from the use of any KIONIX's Products against warning, caution or note contained in this document.
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