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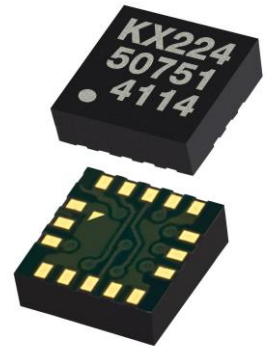
± 8g / 16g / 32g Tri-axis Digital Accelerometer Specifications

PART NUMBER:

KX224-1053
Rev. 2.0
22-Dec-2017

Product Description

The KX224-1053 is a tri-axis $\pm 8g$, $\pm 16g$ or $\pm 32g$ silicon micromachined accelerometer with integrated 2048-byte buffer, orientation, Directional-Tap™/Double-Tap™, activity detecting, and Free fall 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 1.71V – 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. I²C or SPI digital protocol is used to communicate with the chip to configure and check for updates to the orientation, Directional-Tap™/Double-Tap™ detection, Free fall detection, and activity monitoring algorithms.



Features

- 3 x 3 x 0.9 mm LGA
- User-selectable g Range up to $\pm 32g$
- User-selectable Output Data Rate up to 25600Hz
- User-selectable Low Power or High Resolution modes
- Digital High-Pass Filter Outputs
- Extra-large embedded 2048 byte FIFO/FILO buffer
- Low Power Consumption with FlexSet™ Performance Optimization
- Internal voltage regulator
- Enhanced integrated Free fall, Directional-Tap™/Double-Tap™, and Device-orientation Algorithms
- User-configurable wake-up function
- Digital I²C up to 3.4MHz and Digital SPI up to 10MHz
- Lead-free Solderability
- Excellent Temperature Performance
- High Shock Survivability
- Factory Programmed Offset and Sensitivity
- Self-test Function


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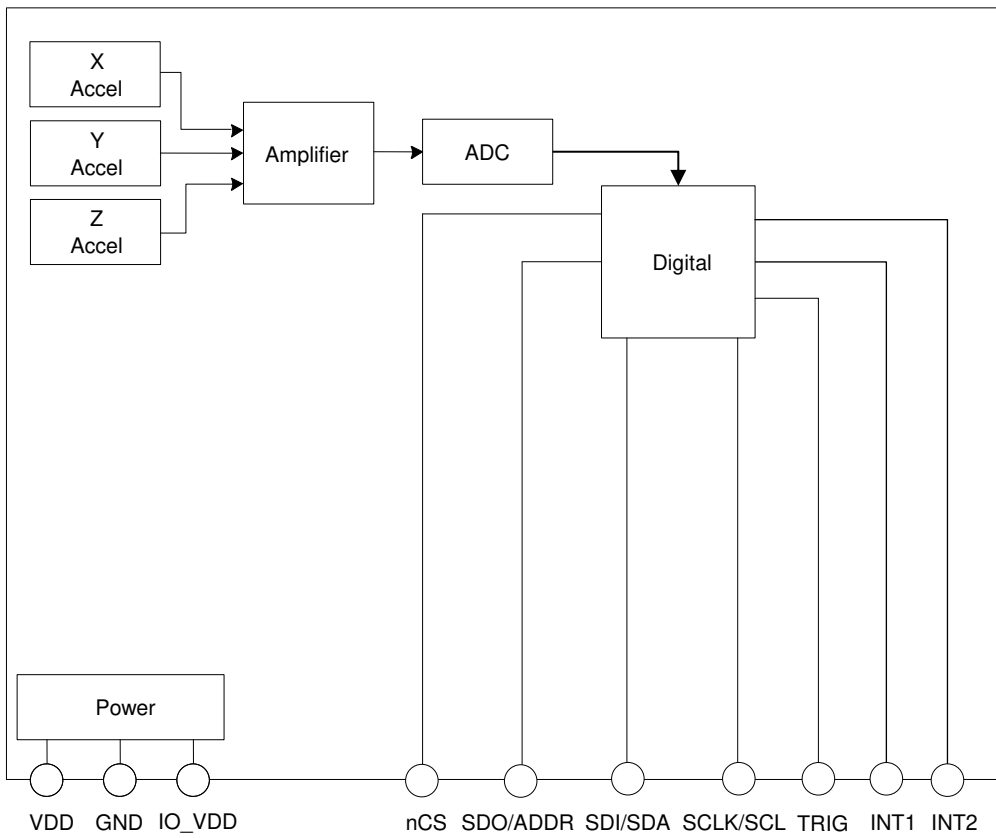



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Functional Diagram



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Product Specifications

Mechanical


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

Parameters		Units	Min	Typical	Max
Operating Temperature Range		°C	-40	-	+85
Zero-g Offset		mg		±75	±175
Zero-g Offset Variation from RT over Temp.		mg/°C		0.5	
Sensitivity ¹	GSEL1=0, GSEL0=0 (±8g)	counts/g	3768	4096	4424
	GSEL1=0, GSEL0=1 (±16g)		1884	2048	2212
	GSEL1=1, GSEL0=0 (±32g)		942	1024	1106
Sensitivity (Buffer 8-bit mode) ^{1,2}	GSEL1=0, GSEL0=0 (±8g)	counts/g	15	16	17
	GSEL1=0, GSEL0=1 (±16g)		7	8	9
	GSEL1=1, GSEL0=0 (±32g)		3	4	5
Sensitivity Variation from RT over Temp.		%/°C		0.01	
Positive Self Test Output change on Activation ⁴		g		0.5	
Signal Bandwidth (-3dB)		Hz		8000 (xy) 5100 (z)	
Non-Linearity		% of FS		0.6	
Cross Axis Sensitivity		%		2	
Noise ^{3,5}	RMS	mg		3.3	
	Density	µg/√Hz		630	

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. Noise varies with Output Data Rate (ODR), and the Average Filter Control settings and can be tested using Kionix FlexSet™ Performance Optimization Tool found at <http://www.kionix.com/flexset>
4. Requires changing of STPOL bit in INC1 register to 1 prior to performing self-test
5. Measured with ODR=50Hz, IIR_BYPASS=0, LPRO=1 (filter corner frequency set to ODR/2)

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Electrical

(specifications are for operation at 2.5V and T = 25C 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		3.6
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	-	-
Start Up Time ³		ms	2		1300
Power Up Time ⁴		ms		20	50
I ² C Communication Rate		MHz			3.4
I ² C Slave Address (7-bit)				0x1E / 0x1F	
SPI Communication Rate		MHz			10
Output Data Rate (ODR) ⁵		Hz	0.781	50	25600
Bandwidth (-3dB) ⁶		Hz		ODR/9 or ODR/2	

Table 2: Electrical Specifications

Notes:

1. Current varies with Output Data Rate (ODR) as shown in Figure 2, types and number of enabled digital engines, and the Average Filter Control settings that can be tested using Kionix FlexSet™ Performance Optimization Tool found at <http://www.kionix.com/flexset>.
2. For I²C communication, this assumes a minimum 1.5kΩ pull-up resistor on SCL and SDA pins.
3. Start up time is from PC1 set to valid outputs. Time varies with Output Data Rate (ODR) and power mode setting. See Figure 1 for details.
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. See ODCNTL register description for details.



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Start Up Time Profile

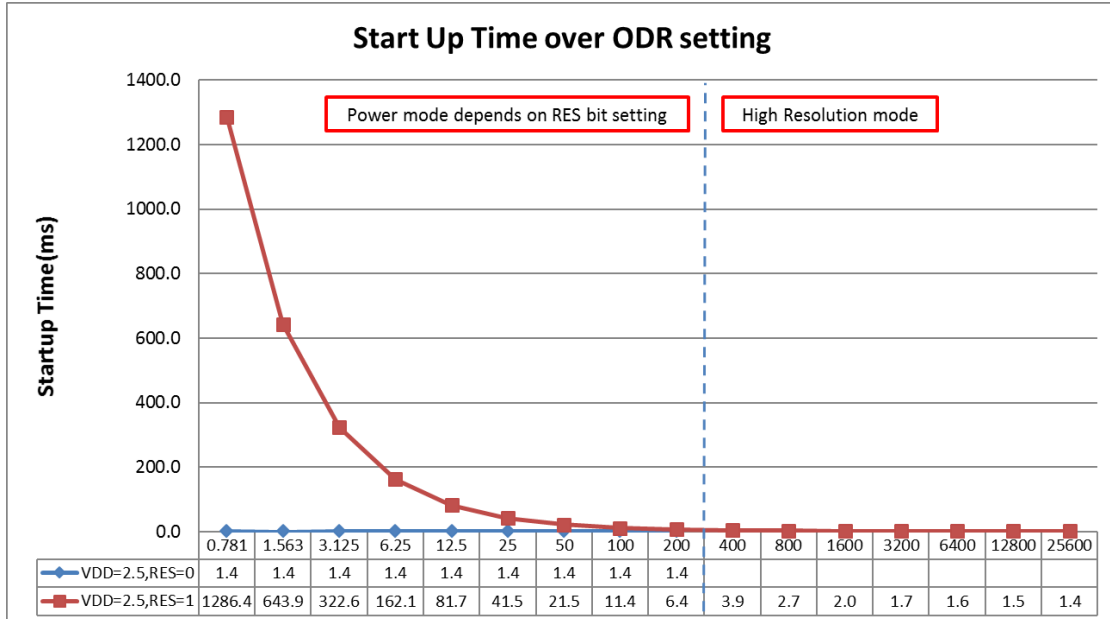


Figure 1: Start up Time as a function of the Output Data Rate (ODR) and Power Mode Settings

Current Profile

Representative Current Profile (µA)		
ODR (Hz)	High Res	Low Power
Standby	0.9	0.9
0.781	145	1.8
1.563	145	2.0
3.125	145	2.2
6.25	145	3.0
12.5	145	5
25	145	7
50	145	13
100	145	21
200	145	43
400	145	145
800	145	145
1600	145	145
3200	145	145
6400	145	145
12800	145	145
25600	145	145

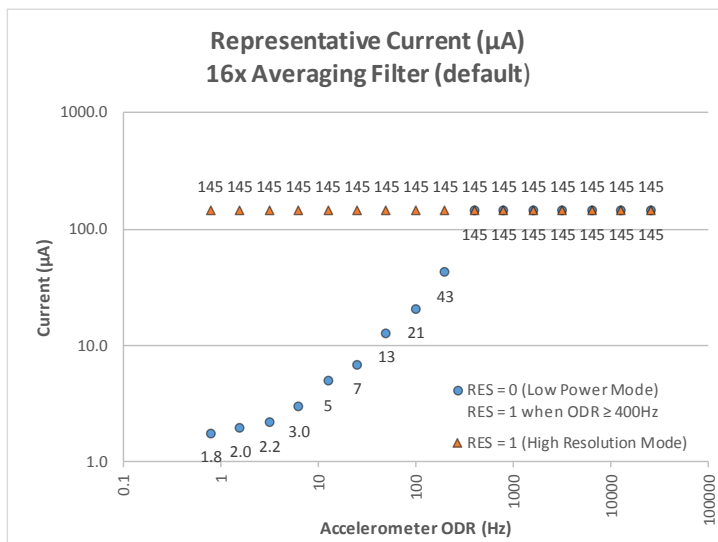



Figure 2: Current as a function of the Output Data Rate (ODR) and Power Mode Settings


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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 [TN004 Power-On Procedure](#) for more information.

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Environmental

Parameters		Units	Min	Typical	Max
Supply Voltage (VDD)	Absolute Limits	V	-0.5	-	3.60
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-I - 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-174) as identified by the European Chemicals Agency as of 12 July 2017.



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

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

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 XOUT, YOUT, ZOUT registers = 0x00, expressed as a 2's complement number). However, because of mismatches in the sensor, calibration errors, and mechanical stress, the output can deviate from 0x00. 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 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 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 non-volatile 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.



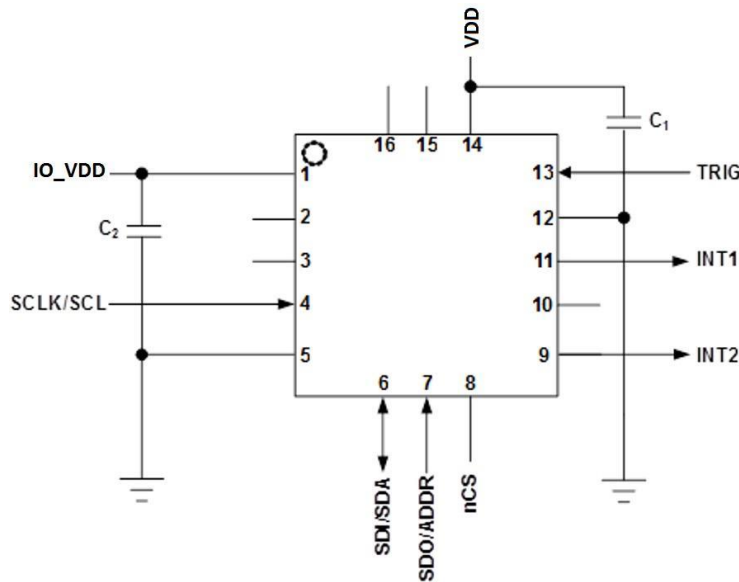
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Application Schematic and Pin Description

Application Schematic



Pin Description

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 leave floating.
3	NC	Not Internally Connected - Can be connected to VDD, IO_VDD, GND or leave floating.
4	SCLK/SCL	SPI and I2C 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. Do not leave floating.
8	nCS	Chip Select (active LOW) for SPI communication. Connect to IO_VDD for I2C communication. Do not leave floating.
9	INT2	Physical Interrupt 2 (Push-Pull). The pin is in High-Z state during POR and driven LOW following POR. Leave floating if not used.
10	NC	Not Internally Connected - Can be connected to VDD, IO_VDD, GND or leave floating.
11	INT1	Physical Interrupt 1 (Push-Pull). The pin is in High-Z state during POR and driven LOW following POR. Leave floating if not used.
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 leave floating.
16	NC	Not Internally Connected - Can be connected to VDD, IO_VDD, GND or leave floating.

Table 4: Pin Description



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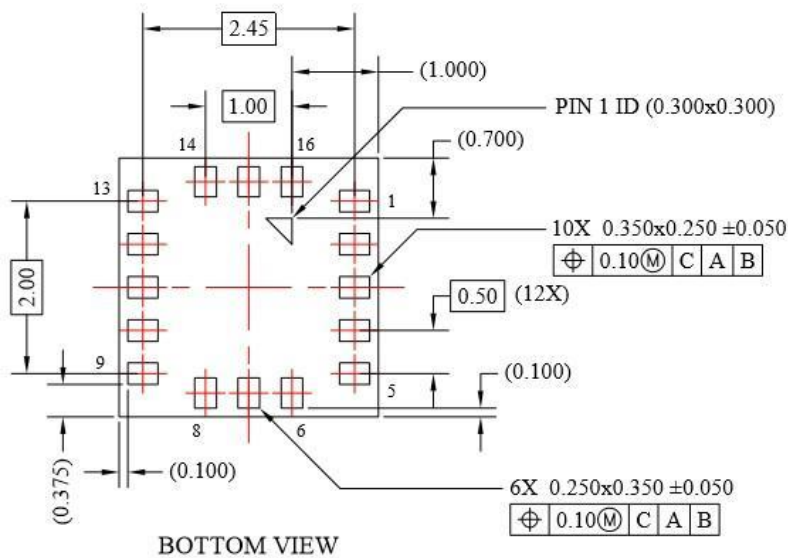
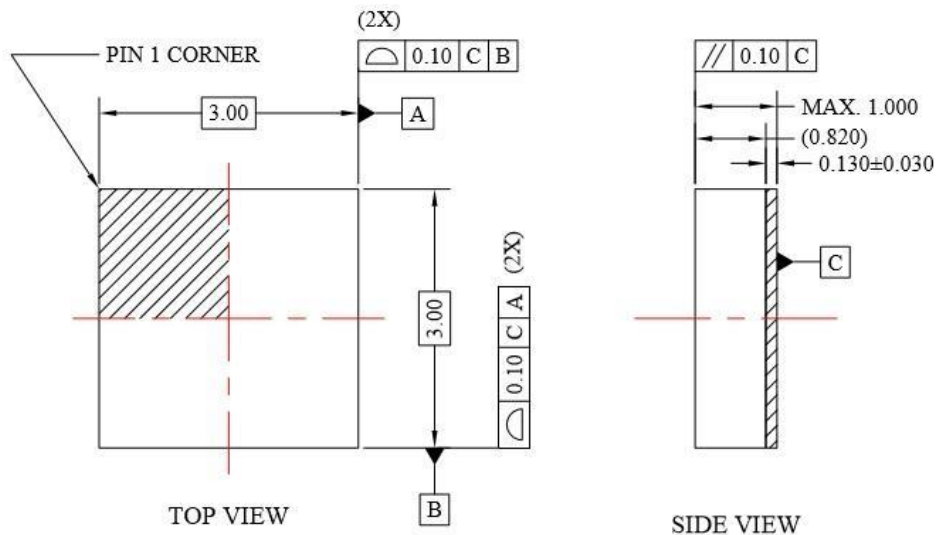
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Package Dimensions and Orientation

Dimensions

3 x 3 x 0.9 mm LGA



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

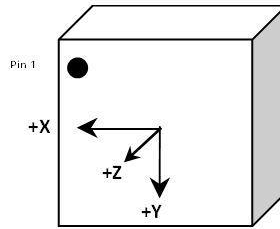


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Orientation



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 (±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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Static X/Y/Z Output Response versus Orientation to Earth's surface (1g): GSEL1=0, GSEL0=1 (±16g)

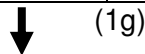
Position	1		2		3		4		5		6	
Diagram												
Resolution (bits)	16	8	16	8	16	8	16	8	16	8	16	8
X (counts)	0	0	-2048	-8	0	0	+2048	+8	0	0	0	0
Y (counts)	-2048	-8	0	0	+2048	+8	0	0	0	0	0	0
Z (counts)	0	0	0	0	0	0	0	0	+2048	+8	-2048	-8
X-Polarity	0		-		0		+		0		0	
Y-Polarity	-		0		+		0		0		0	
Z-Polarity	0		0		0		0		+		-	




Earth's Surface

Static X/Y/Z Output Response versus Orientation to Earth's surface (1g): GSEL1=1, GSEL0=0 (±32g)

Position	1		2		3		4		5		6	
Diagram												
Resolution (bits)	16	8	16	8	16	8	16	8	16	8	16	8
X (counts)	0	0	-1024	-4	0	0	+1024	+4	0	0	0	0
Y (counts)	-1024	-4	0	0	+1024	+4	0	0	0	0	0	0
Z (counts)	0	0	0	0	0	0	0	0	+1024	+4	-1024	-4
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 KX224 digital accelerometer can 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 5 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 5: Serial Interface Terminologies

I²C Serial Interface

As previously mentioned, the KX224 accelerometer can 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 KX224 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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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 KX224 Slave Address is comprised of a user programmable part, a factory programmable part, and a fixed part, which allows for connection of multiple accelerometers to the same I²C bus. The Slave Address associated with the KX224 is 00111YX, where the user programmable bit X, is determined by the assignment of ADDR pin to GND or IO_VDD. Also, the factory programmable bit Y is set at the factory. **For KX224-1053, the factory programmable bit Y is fixed to 1** (contact your Kionix sales representative for list of available devices). Table 6 lists possible I²C addresses for KX224-1053. It is possible to have up to four accelerometers on a shared I²C bus as shown in Figure 3 (i.e. two KX224-1053 accelerometers and two additional accelerometers with the factory programmable bit Y set to 0).

Description	Address Pad	7-bit Address	Address	<7>	<6>	<5>	<4>	<3>	Y		X	
									<2>	<1>	<0>	<0>
I2C Wr	GND	0x1E	0x3C	0	0	1	1	1	1	0	0	0
I2C Rd	GND	0x1E	0x3D	0	0	1	1	1	1	0	1	1
I2C Wr	IO_VDD	0x1F	0x3E	0	0	1	1	1	1	1	1	0
I2C Rd	IO_VDD	0x1F	0x3F	0	0	1	1	1	1	1	1	1

Table 6: I²C Slave Addresses for KX224-1053

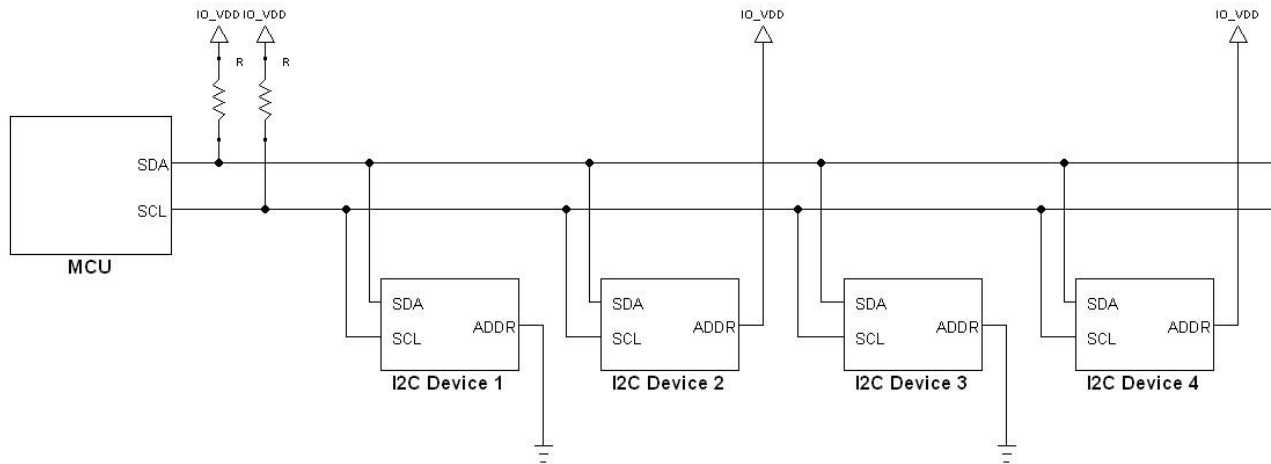
It is mandatory that receiving devices acknowledge (ACK) each transaction. Therefore, the transmitter must release the SDA line during this ACK pulse. The receiver then pulls the data line LOW so that it remains stable LOW during the HIGH period of the ACK clock pulse. A receiver that has been addressed, 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 accelerometer is accessed through I²C protocol before the startup is finished a NACK signal is sent.



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I ² C Device	Part Number	ADDR Pin	Slave Address	Bit Y (Bit 1 in 7-bit address)
1	KX224-1053	GND	0x1E	Factory Set to 1
2	KX224-1053	IO_VDD	0x1F	Factory Set to 1
3	*KXMMM	GND	0x1C	Factory Set to 0
4	*KXMMM	IO_VDD	0x1D	Factory Set to 0


* KXMMM – contact Kionix sales representative for list of compatible devices

Figure 3: Multiple KX224 Accelerometers on a Shared I²C Bus

Writing to an 8-bit Register

Upon power up, the Master must write to the KX224's control registers to set its operational mode. Therefore, when writing to a control register on the I²C bus, as shown Sequence 1, the following protocol must be observed: After a start condition, SAD+W transmission, and the KX224 ACK has been returned, an 8-bit Register Address (RA) command is transmitted by the Master. This command is telling the KX224 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 KX224 acknowledges the RA and the Master transmits the data to be stored in the 8-bit register. The KX224 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 KX224 is now stored in the appropriate register. The KX224 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.


****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.

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Reading from an 8-bit Register

When reading data from a KX224 8-bit register on the I²C bus, as shown in Sequence 3, 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 KX224 acknowledges and the Master transmits the 8-bit RA of the register it wants to read. The KX224 again acknowledges, and the Master transmits a repeated start condition (Sr). After the repeated start condition, the Master addresses the KX224 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. Note that the KX224 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. 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 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.

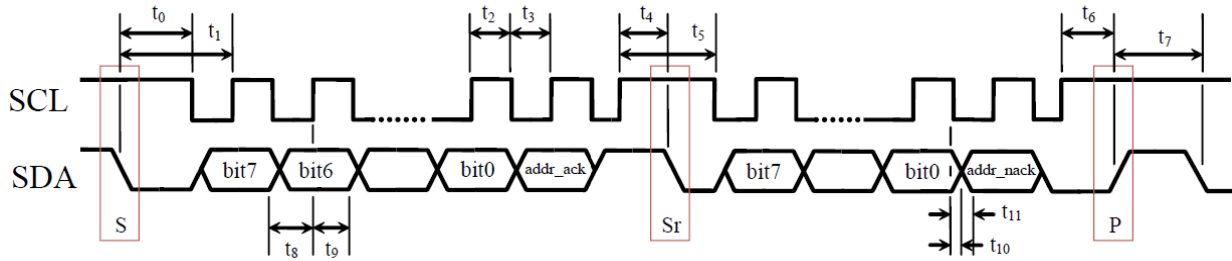


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I²C Timing Diagram



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	-	μs

Table 8: I²C Timing (Fast Mode)

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SPI Communications

4-Wire SPI Interface

The KX224 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 KX224 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 4 below.

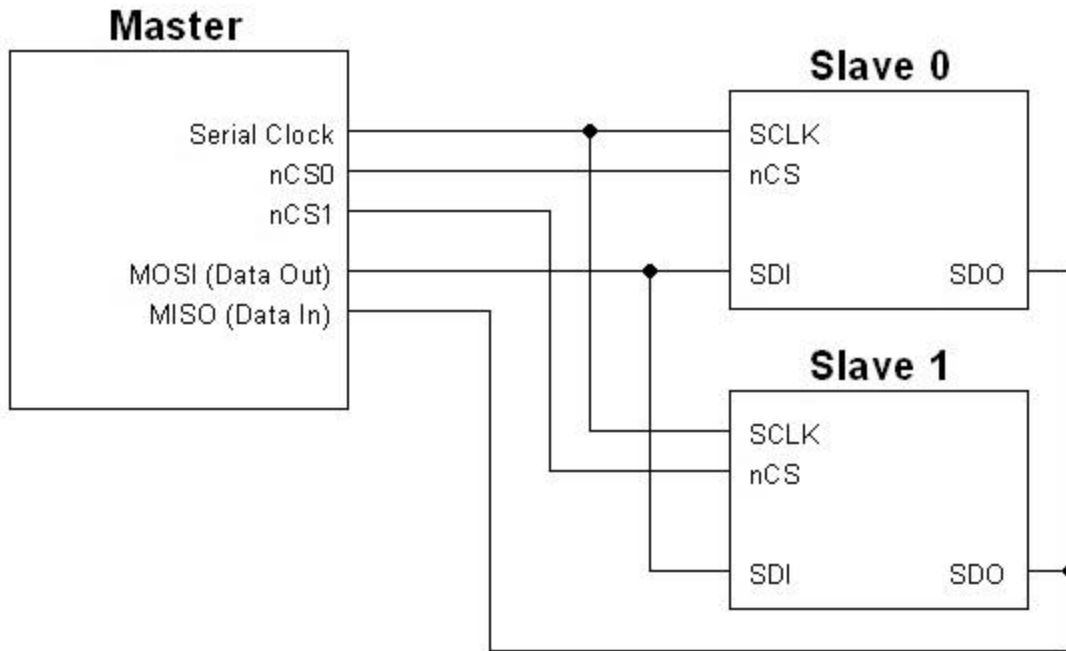


Figure 4: 4-wire SPI Connections

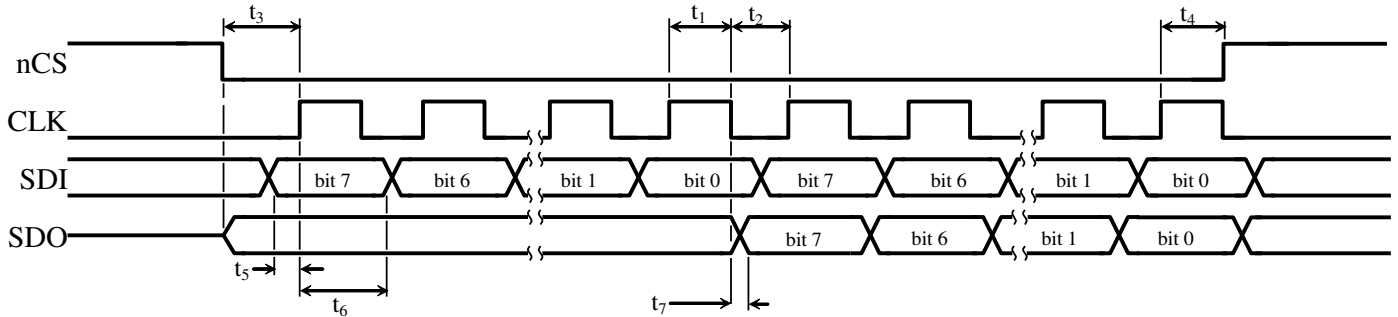


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4-Wire SPI Timing Diagram



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 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

Table 9: 4-Wire SPI Timing

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.