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July 2016

FIS1100
6D Inertial Measurement Unit with Motion Co-Processor and Sensor Fusion Library

Features

- World's First Complete Consumer Inertial Measurement Unit (IMU) with Sensor Fusion Library to Specify Orientation Accuracy: ±3° Pitch and Roll, ±5° Yaw/Heading
- 3-Axis Gyroscope and 3-Axis Accelerometer in a Small 3.3 x 3.3 x 1 mm LGA Package
- Integrated AttitudeEngine™ Motion Co-processor with Vector DSP Performs Sensor Fusion at 1 kHz Sampling Rate, while Outputting Data to Host Processor at a Lower Rate – Improving Accuracy while Reducing Processor MIPS, Power, and Interrupt Requirements
- High-Performance XKF3 6/9-Axis Sensor Fusion with in-Run Calibration for Correction of Gyro Bias Drift Over Temperature and Lifetime
- Low Latency, Wide Bandwidth, Low Noise OIS Mode for Camera and Drone Gimbal Stabilization
- Low Noise 50 μg/√Hz Accelerometer and 10 mdps/√Hz Gyroscope
- New Motion on Demand Technology for Polling Based Synchronization
- Large 1536 Byte FIFO can be used to Buffer 9DOF Sensor Data to Lower System Power Dissipation
- Large Dynamic Range from ±32°/s to ±2,560°/s and ±2 g to ±8 g
- Low Power and Warm-Start Modes for Effective Power Management
- Digitally Programmable Sampling Rate and Filters
- Host Serial Interface Supporting I^2C or SPI
- I^2C Master for Interfacing External Magnetometer
- Embedded Temperature Sensor
- Wide Extended Operating Temperature Range (-40°C to 85°C)

Description

FIS1100 is the world's first complete consumer 6D MEMS Inertial Measurement Unit (IMU) with sensor fusion to specify system level orientation accuracy. When using the FIS1100 in combination with the supplied XKF3 9D sensor fusion, the system features an accurate ±3° pitch and roll orientation, and a ±5° yaw/heading typical specification.

The FIS1100 incorporates a 3-axis Gyroscope and a 3-axis Accelerometer and can connect an external 3-axis magnetometer through an I^2C master thus forming a complete 9DOF system.

The FIS1100 also incorporates an advanced vector Digital Signal Processor (DSP) motion co-processor called the AttitudeEngine™. The AttitudeEngine efficiently encodes high frequency motion at high internal sampling rates, preserving full accuracy across any output data rate.

This enables the application to utilize low Output Data Rates (ODR) or on-demand (host polling) and still acquire accurate 3D motion data. The AttitudeEngine allows reducing the data processing and interrupt load on a host processor with no compromises in 3D motion tracking accuracy. The result is very low total system power in combination with high accuracy, which are essential to many portable and battery powered applications.

Applications

- Drone Flight Control and Gimbal Stabilization
- Optical Image Stabilization (OIS) and Electrical Image Stabilization (EIS)
- Virtual Reality and Augmented Reality
- Robotic Orientation and Position Tracking
- Sport & Fitness Wearables
- Pedestrian Navigation and GNSS Augmentation

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1 General Information

1.1 Ordering Information

Table 1. Ordering Information

Part Number	Package	Packing Method
FIS1100	LGA16	Tape & Reel

1.2 Marking Information

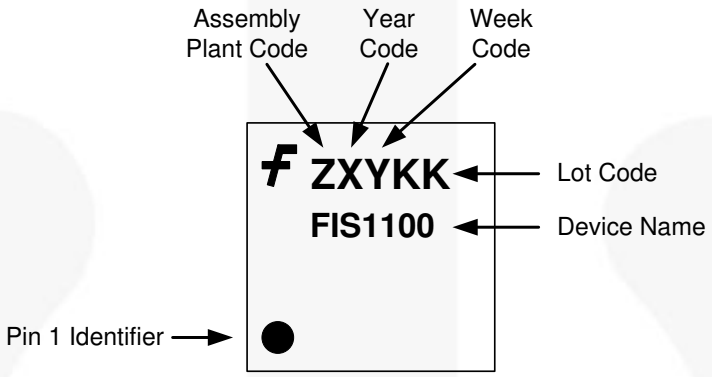


Figure 1. Top Mark

1.3 Internal Block Diagram

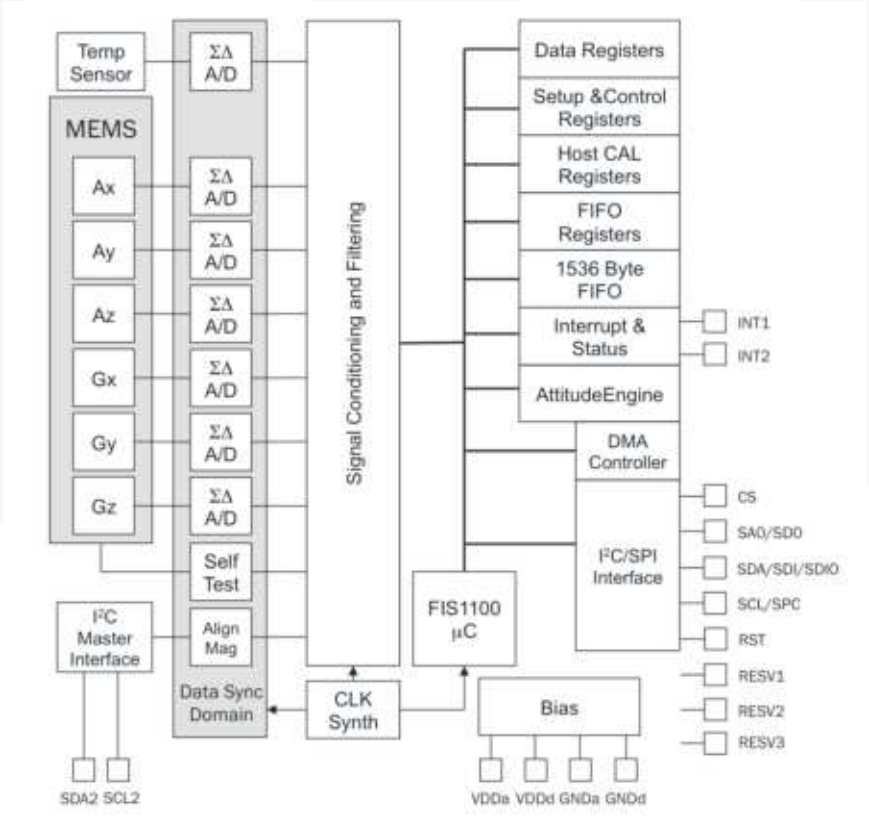


Figure 2. Internal Block Diagram

1.4 Application Diagram

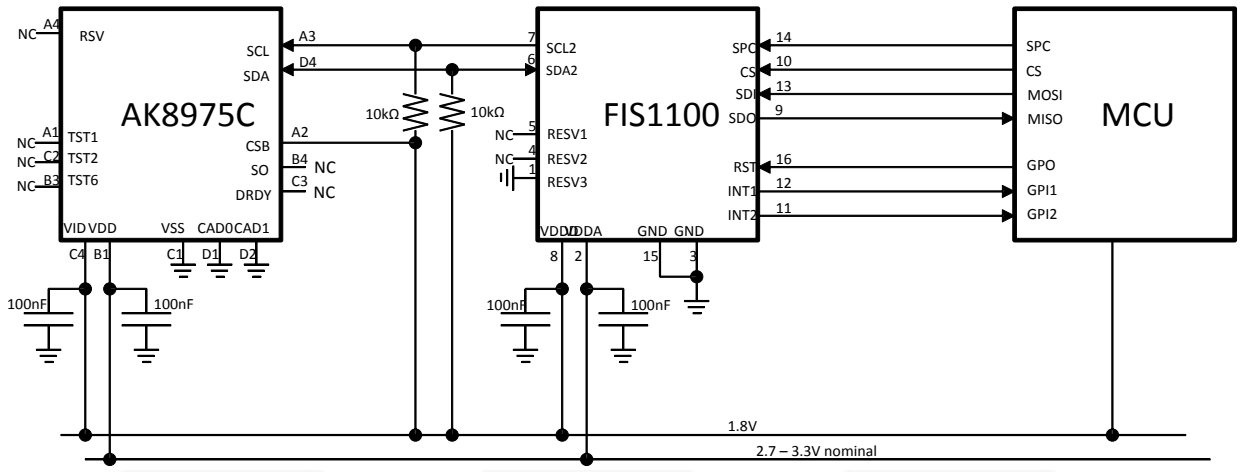


Figure 3. Typical Application Diagram (Showing Magnetometer Connected through FIS1100 Master I²C and a SPI 4 Wire Interface Connected to the Host Processor)

1.5 Package & Pin Information

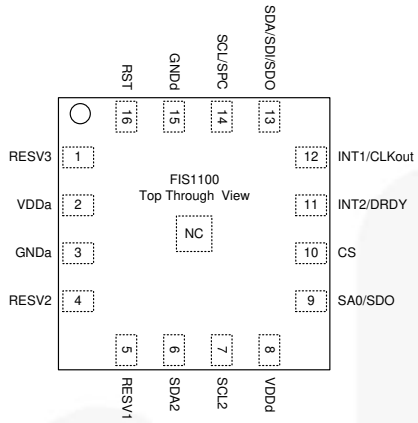


Figure 4. Pins Face Down (Top View) Do Not Solder Center Pin (NC)

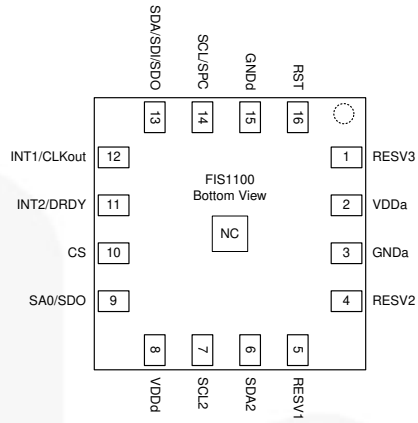


Figure 5. Pins Face Up (Bottom View) Do Not Solder Center Pin (NC)

Table 2. Pin Definitions

Pin #	Name	Alternate Name	Alternate Name	Description
1	RESV3			Reserved. Connect to Board Ground (GND)
2	VDDa			Power Supply for Analog
3	GNDa			Ground for Analog
4	RESV2			Reserved. No Connection (NC)
5	RESV1			Reserved. No Connection (NC)
6	SDA2			Master I^2C Serial Data
7	SCL2			Master I^2CSerial Clock
8	VDDd			Power Supply for Digital and IO Pins
9	SA0(1)(3)	SDO		Host I^2C Slave Address LSB (SA0); Host 4-Wire SPI Serial Data Output (SDO)
10(1)	CS			Host SPI Chip Select (1 = I^2C Mode). *See SPI Mode Configuration section*
11	INT2	DRDY		Interrupt2. Data Ready/FIFO Interrupt
12	INT1	CLKout		Interrupt1. General Purpose Interrupt. Clock out in OIS Mode
13	SDA	SDI(2)(3)	SDIO(2)(3)	Host I^2C Serial Data (SDA); Host 4-Wire SPI Serial Data Input (SDI); Host 3-Wire SPI Serial Data Output (SDIO)
14	SCL	SPC(2)(3)		Host I^2C Serial Clock (SCL); Host SPI Serial Clock (SPC)
15	GNDd			Ground
16	RST ***			Reset Input. Assert for at least 5 μs. Part ready for communication 50 μs after assertion. After RST, the device will go through its boot process, please refer to Table 7 and Table 8 for wakeup times.

Notes:

1. This pin has an internal 200 KΩ pull up resistor.
2. In SPI mode (not in I^2C Mode), there is an internal pull down 200 KΩ resistor.
3. Refer to Section 1 for detailed configuration information.

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1.6 Recommended External Components

Table 3. Recommended External Components

Component	Description	Parameter	Typical
C_{p1}	Capacitor	Capacitance	100 nF
C_{p2}	Capacitor	Capacitance	100 nF
R_{pu} (4)	Resistor	Resistance	10 KΩ

Note:

4. R_{pu} is only needed when the Host Serial Interface is configured for I^2C. They are not needed when the Host Serial Interface is configured for SPI. See I^2C Interface section. If Pull-up resistors are used on SCL and SDA, then both SPI and I^2C Modes are possible. If a Pull-up is used on SA0, an alternate slave address is used for I^2C. SPI Mode will be unaltered with the use of Pull-ups for I^2C.

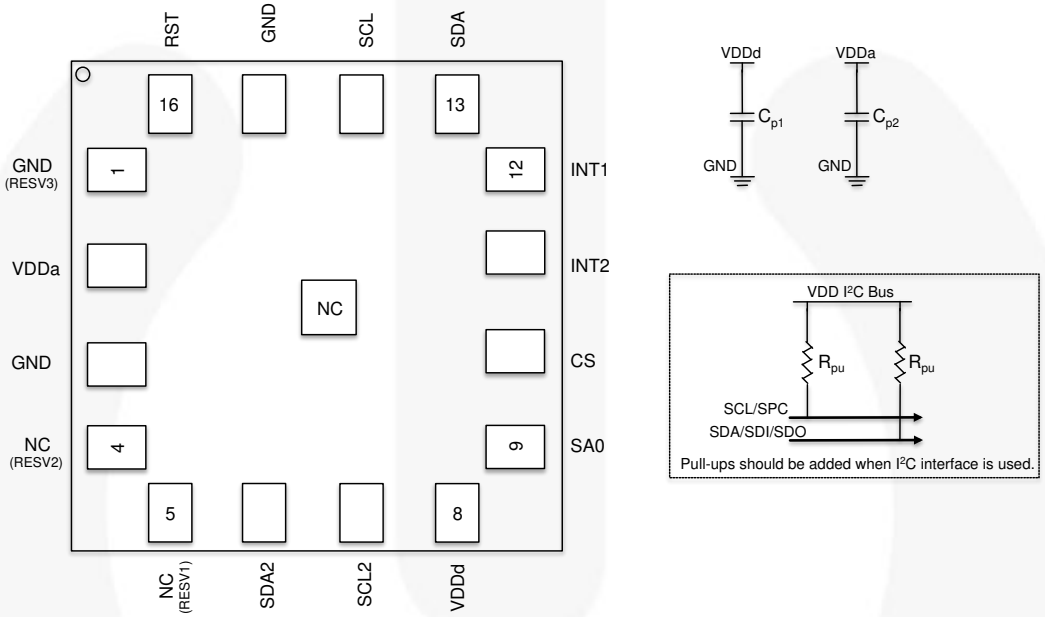


Figure 6. Typical Electrical Connections

2 FIS1100 Architecture

FIS1100 is a smart sensor that combines a high-performance IMU with a powerful Single Instruction Multiple Data (SIMD) based Vector DSP motion co-processor referred to as the AttitudeEngine™ (AE).

Included sensor fusion software (XKF3) allows the device to achieve orientation accuracies of ±3° for pitch and roll and ±5° for yaw/heading.

The FIS1100 includes a microcontroller for data scheduling, combined with Direct Memory Access (DMA) in order to allow efficient data shuttling on the chip. Multi-channel data is easily processed at rates up to 1 kHz with minimal latency in normal operation (non-OIS modes) and at 8 kHz in OIS modes.

An internal block diagram is shown in Figure 2. The MEMS elements are amplified and converted by ΣΔ A/D converters which are synchronized to a common clock so that all the motion measurements of acceleration, angular rate and magnetic heading are sampled at the same time minimizing any skew between channels. The data is then sent to a signal processing chain that accomplishes decimation, filtering and calibration.

Once the data has been processed, it can be sent to the host processor depending on additional configuration settings, such as, enabling the FIFO or using the AttitudeEngine.

2.1 AttitudeEngine Mode Overview

Brief descriptions of the major functions of the AttitudeEngine are discussed below, for more detail see Application note AN-5083. Note that the AttitudeEngine may be enabled or disabled and configured using the CTRL6 register.

- **Calibration**: FIS1100 applies continuous on-chip calibration of all the sensors (accelerometer, gyroscope, and magnetometer) including scale, offset, and temperature calibration. When used in conjunction with a sensor fusion filter (such as the Fairchild XKF3) running on the host processor, estimated sensor errors can be updated in-use, allowing sensor calibration to be performed in the background without any host intervention. This offloads computationally expensive per-sample re-calibration from the host processor to the FIS1100.
- **Sample Synchronization**: FIS1100 automatically provides highly synchronous output between the various IMU accelerometer and gyroscope channels through the use of fully parallel ΣΔ-converters. The FIS1100 also provides time synchronization of data between the IMU and the external magnetometer.
- **Motion Encoder**: Performs 32-bit high-speed dead reckoning calculations at 1 kHz data rates allowing accurate capture of high frequency and coning effects. Orientation and velocity increments are calculated with full coning and sculling compensation and the magnetic field vector from the external magnetometer is rotated to the sensor frame of reference. This allows the lossless encoding (compression) of 6D motion to a low output data rate, while maintaining the accuracy provided by the 1 kHz input and data processing rate. Motion data encoded by the AttitudeEngine is available at a user programmable data rate (1 Hz to 64 Hz). The orientation and velocity increments from the AttitudeEngine are suitable for any 3D motion tracking application (orientation, velocity and position) and may be further fused by the user with information from other sources such as a GNSS receiver or barometer in an optimal estimator.
- **Motion on Demand (MoD)**: FIS1100 allows the host to access encoded motion data asynchronously (polling) and on demand. The motion data in the AttitudeEngine (AE) mode remains accurate even at very low output data rates. This allows easy integration and synchronization with other sensors for state-of-the-art applications such as rolling shutter camera stabilization, optical sensors software de-blurring, GNSS integration and augmented or virtual reality.

2.2 Advantages of the Attitude Engine Approach

The advantages of the AttitudeEngine (AE) approach over the traditional sensor approach are many and are briefly discussed below, for more detail see Application note AN-5083.

- **Low-Power Architecture**: Dead reckoning calculations are performed with the AE vector DSP which is designed to perform essential calculations while achieving high-accuracy and low power simultaneously. The AE approach enables a typical interrupt rate reduction to the host processor of 10x and can be up to 100x for some applications. This significantly enhances the operational life of battery powered devices without any compromises in 3D motion tracking accuracy.
- **High Performance**: The motion encoder and sample synchronizer enable highly accurate strap down integration that can be fully compensated for coning and sculling artifacts.

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2.3 9D Sensor Fusion and Auto-Calibration using XKF3

XKF3 is a sensor fusion algorithm, based on Extended Kalman Filter theory that fuses 3D inertial sensor data (orientation and velocity increments) and 3D magnetometer, also known as '9D', data to optimally estimate 3D orientation with respect to an Earth fixed frame.

A license to use XKF3 in a CMSIS compliant library form for Cortex M0+, M3, M4, M4F, for commercial purposes is provided with the FIS1100 Evaluation Kit (FEBFIS1100MEMS_IMU6D3X).

A restricted-use license for use of XKF3 for commercial purposes is also granted for certain applications when XKF3 is used with the FIS1100.

XKF3 is developed by Xsens™, a pioneering company in inertial based 3D motion tracking. The first generation 9D sensor fusion algorithms were developed by Xsens more than 15 years ago and have been proven in demanding 24/7 continuous use for a broad range of applications; from unmanned underwater robotics to accurate joint angle measurements for rehabilitation and sports. The XKF3 algorithm is wholly owned by Fairchild.

XKF3 only works with the FIS1100 and supported magnetometers. Refer to the FEBFIS1100 Evaluation Board document for further details.

For additional information, refer to *AN-5084* application note for more details on XKF3 and its benefits

XKF3 Features:

- Continuous Sensor Auto Calibration, No User Interaction Required
- High Accuracy, Real-Time, Low-Latency Optimal estimate of 3D Orientation, up to 1 kHz output data rate
- Ultra low system power for 3D Orientation enabled by AttitudeEngine, between 8 to 64 Hz output data rate without any degradation in accuracy
- Best-in-Class Immunity to Magnetic Distortions
- Best-in-Class Immunity to Transient Accelerations
- Flexible use Scenarios, North Referenced, Unreferenced
- Extensive Status Reporting for Smooth Integration in Applications
- Optimized Library for Popular Microcontrollers

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Figure 7. Chip Orientation Coordinate System

2.4 Frames of Reference and Conventions for Using FIS1100

FIS1100 uses a right-handed coordinate system as the basis for the sensor frame of reference. Acceleration (a_x, a_y, a_z) are given with respect to the X-Y-Z co-ordinate system shown above. Increasing accelerations along the positive X-Y-Z axis are considered positive. Angular Rate (ω_x, ω_y, ω_z) around the counter clockwise direction are considered positive. Magnetic fields (m_x, m_y, m_z) can be configured to be expressed in the sensor X-Y-Z coordinates as well. Care must be taken to make sure that FIS1100 and the magnetic sensor of choice are mounted on the board so that the coordinate systems of the two sensors are substantially orthogonal.

Figure 7 shows the various frames of reference and conventions for using FIS1100.

The accelerometer, gyroscope, and the optional external magnetometer are enabled or disabled using the aEN, gEN and mEN bits in the CTRL7 register respectively. AE Mode may be enabled or disabled using the sEN bit in CTRL7 register. The outputs available in Typical Sensor Mode and AttitudeEngine™ Modes are outlined below in Table 22 and Table 23. A list and description of FIS1100 Operational Modes is provided in Table 32. A FIFO buffer is also available to store sample history. The FIFO may be configured separately using FIFO_CTRL, FIFO_STATUS and FIFO_DATA. The FIFO control is described in detail in the FIFO Description section.

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3 System, Electrical and Electro-Mechanical Characteristics

3.1 Absolute Maximum Ratings

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions. Stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only.

Table 4. Absolute Maximum Ratings

Symbol	Parameter		Min.	Max.	Unit
T_{STG}	Storage Temperature		-40	+125	°C
T_{Pmax}	Lead Soldering Temperature, 10 Seconds			+260	°C
V_{DDa}	Supply Voltage		-0.3	3.6	V
V_{DDd}	I/O Pins Supply Voltage		-0.3	2.05	V
S_g (5)	Acceleration g for 0.2 ms (Un-powered)			10,000	g
ESD (6)	Electrostatic Discharge Protection Level	Human Body Model per JES001-2014	±2000		V
		Charged Device Model per JESD22-C101	±500		

Notes:

5. △This is a mechanical shock (g) sensitive device. Proper handling is required to prevent damage to the part.
6. ⁄This is an ESD-sensitive device. Proper handling is required to prevent damage to the part.

3.2 Recommended Operating Conditions

The Recommended Operating Conditions table defines the conditions for actual device operation. Recommended operating conditions are specified to ensure optimal performance. Fairchild does not recommend exceeding them or designing to Absolute Maximum Ratings.

Table 5. Recommended Operating Conditions

Symbol	Parameter	Min.	Typ.	Max.	Unit
V_{DDa}	Supply Voltage	2.4	2.7	3.47	V
V_{DDd}	I/O Pins Supply Voltage	1.62	1.80	1.98	V
V_{IL}	Digital Low Level Input Voltage			0.3 *V_{DDd}	V
V_{IH}	Digital High Level Input Voltage	0.7 *V_{DDd}			V
V_{OL}	Digital Low Level Output Voltage			0.1 *V_{DDd}	V
V_{OH}	Digital High Level Output Voltage	0.9 *V_{DDd}			V

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3.3 System Level Specifications

System level specifications are provided to give guidance on the system performance in a recommended and typical configuration. The recommended system configuration is the FIS1100 and optionally a supported 3D magnetometer used with a supported host processor, running the Fairchild XKF3 9D sensor fusion and having executed and stored the result of the "Board Level Calibration" routine (see AN-5085 application note). The system performance specifications assume that good engineering practices for the placement conditions of the FIS1100 and 3D magnetometer are taken into account. For example, take care not to place the FIS1100 where strong vibrations may occur or even be amplified; take care not to place the 3D magnetometer where magnetic fields other than the Earth magnetic field may be measured. Typical numbers are provided below unless otherwise noted.

Table 6. System Level 3D Orientation Accuracy Specifications

Subsystem	Parameter	Typical	Unit	Comments
FIS1100+XKF3 quaternion	Roll	±3	deg	Requires use of XKF3 software library on host processor.
	Pitch	±3	deg	Requires use of XKF3 software library on host processor.
	Yaw (Heading) Referenced to North	±5	deg	Requires use of XKF3 software library on host processor, using magnetometer, in a homogenous Earth magnetic field.
	Yaw (Heading) Unreferenced	5-25	deg/h	From Allan Variance bias instability. Does not require a magnetometer. *(See specification above for use with magnetometer.)* Fully immune to magnetic distortions.
FIS1100+XKF3 quaternion	Output Data Rate	8 - 1000	Hz	To benefit from the power saving using the AttitudeEngine, use a max ODR of 64 Hz.

3.4 Electro-Mechanical Specifications

V_{DDd} = 1.8 V, V_{DDa} = 2.7 V, T = 25°C unless otherwise noted.

Table 7. Accelerometer Electro-Mechanical Specifications

Subsystem	Parameter	Typical		Unit	Comments
Accelerometer	Noise Density	50		µg/√Hz	High-Resolution Mode
	Sensitivity Scale Factor	Scale Setting	Sensitivity	LSB/g	16-Bit Output
		±2 g	16,384		
		±4 g	8,192		
		±8 g	4,096		
	Cross-Axis Sensitivity	±2		%	
	Temperature Coefficient of Offset (TCO)	±1 (X and Y Axis)		mg/°C	Over-Temperature Range of -40°C to 85°C at Board Level
		±2.5 (Z-Axis)			
	Temperature Coefficient of Sensitivity (TCS)	±0.01 (X and Y Axis)		%/°C	
		±0.02 (Z Axis)			
	Initial Offset Tolerance	±50		mg	Component Level
	Initial Sensitivity Tolerance	±1 (X and Y Axis)		%	Board Level
		±3 (Z Axis)			
	Non-Linearity	±1		%	Best Fit Line
	System Turn On Time (VDDd and VDDa within 1% of Final Value)	1.75		s	From Hardware Reset, No Power, or Power Down to Power-on Default state. = t0 in Figure 8

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Table 7. Accelerometer Electro-Mechanical Specifications (Continued)

Subsystem	Parameter	Typical	Unit	Comments
	Accel Turn On Time	3ms + 3/ODR	ms	Accel Turn on from Power-On Default state or from Low Power state. = t2 + t5 in Figure 8.

Table 8. Gyroscope Electro-Mechanical Specifications

Subsystem	Parameter	Typical		Unit	Comments
Gyroscope	Sensitivity	Scale Setting	Sensitivity	LSB/dps	16-Bit Output
		±32 dps	1024		
		±64 dps	512		
		±128 dps	256		
		±256 dps	128		
		±512 dps	64		
		±1024 dps	32		
		±2048 dps	16		
		±2560 dps	8		
	Minimum Natural Frequency	> 19.3		kHz	
	Noise Density	10		mdps/√Hz	High-Resolution Mode
		10			OIS Mode with gLPF=1
		13.5			OIS LL Mode, 2 kHz BW
	Non-Linearity	< 0.2		%	FSO=2560 dps
	Cross-Axis Sensitivity	±2		%	
	System Turn On Time (VDDd and VDDa within 1% of Final Value)	1.75		s	From Hardware Reset, No Power, or Power Down to Power-on Default state. = t0 in Figure 8
	Gyro Turn On Time	60ms + 3/ODR		ms	Gyro Turn on from Power-On Default = t1 + t5 in Figure 8.
	Gyro Warm Start Turn On Time	5ms + 3/ODR		ms	From Gyro Warm-Start to Gyro Only or Accel + Gyro modes. = t4 + t5 in Figure 8.
	Temperature Coefficient of Offset (TCO)	X & Y Axis	±0.1	dps/°C	Over-Temperature Range of -40°C to 85°C
		Z Axis	±0.02		
	Temperature Coefficient of Sensitivity (TCS)	X & Y Axis	±0.07	%/°C	Over-Temperature Range of -40°C to 85°C
		Z Axis	±0.02		
	Initial Offset Tolerance	X & Y Axis	±10	dps	Board Level
		Z Axis	±1		
	Initial Sensitivity Tolerance	X & Y Axis	±3	%	Board Level
		Z Axis	±1		

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Table 9. Magnetometer and AttitudeEngine Range and Scale

Subsystem	Parameter	Typical		Unit	Comments
		Scale Setting	Sensitivity		
Typical Sensor Mode	Magnetometer Sensitivity Scale Factor	±16 gauss	2,048	LSB/gauss	16 Bit Output
AE Mode	Magnetometer Sensitivity Scale Factor	±16 gauss	2,048	LSB/gauss	
	Orientation Increment (quaternion) Sensitivity Scale Factor	±1	16,384	LSB/unit	
	Velocity Increment Sensitivity Scale Factor	±32	1,024	LSB/ms	

3.5 Accelerometer Programmable Characteristics

V_{DDd} = 1.8 V, V_{DDa} = 2.7 V, T = 25°C unless otherwise noted. Typical numbers are provided below unless otherwise noted. All frequencies are ±5% and are synchronized to the gyro oscillator (“drive”) frequency.

Table 10. Accelerometer Noise Density

Mode	High-Resolution				Low-Power				Unit
ODR	1000	250	125	31.25	125	62.5	25	3	Hz
Typical Noise Density	50	50	50	50	125	180	285	820	μg/√Hz

Table 11. Accelerometer Filter Characteristics(7)

Mode	High-Resolution				Low-Power				Unit
ODR	1000	250	125	31.25	125	62.5	25	3	Hz
Bandwidth	500	125	62.5	15.625	62.5	31.25	12.5	1.5	
Bandwidth with Low-Pass Filter Enabled (aLPF=1)	200	50	25	5	25	15	5	0.6	
Corner Frequency(f_c) with High-Pass Filter Enabled (aHPF=1)	2.50	0.60	0.30	0.08	0.30	0.15	0.10	0.013	

Note:

7. All frequencies are ±5% and are synchronized to the gyro oscillator (“drive”) frequency.

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3.6 Gyroscope Programmable Characteristics

V_{DDd} = 1.8 V, V_{DDa} = 2.7 V, T = 25°C, and represent typical numbers unless otherwise noted. All frequencies are ±5% and are synchronized to the gyro oscillator (“drive”) frequency.

Table 12. Gyroscope Filter Characteristics

Mode		High-Resolution				Snooze Warm-Start	OIS	OIS LL	Unit
ODR	**gHPF=0**	1000	250	125	31.25	Snooze	8100	8100	Hz
Bandwidth	**gLPF=0**	500	125	62.5	15.625	N/A	4050	2000	
	gLPF=1	200	50	25	6	N/A	345	N/A[8]	
Corner Frequency (f_c) with High-Pass Filter Enabled (gHPF=1)	**gHPF01=0**	2.5	0.625	0.3125	0.08	N/A	0.1	N/A[8]	
	gHPF01=1	0.1	0.025	0.0125	0.0032	N/A	0.1	N/A[8]	

Note:

8. For OIS LL mode, no filters can be enabled. gLPF=0 and gHPF=0 should be maintained.

Table 13. Optical Image Stabilization (OIS) Group Delay

	At Frequency (Hz)	Filter Bandwidth (Hz)	Typical	Unit
Group Delay	10	4050	0.11	ms
		2000 (OIS LL)	0.5	
		345	1.1	

3.7 Electrical Characteristics

V_{DDd} = 1.8 V; V_{DDa} = 2.7 V; T = 25°C unless otherwise noted.

Table 14. Electrical Subsystem Characteristics

Symbol	Parameter		Min.	Typ.	Max.	Unit
f_{SPC}	Host SPI Interface Speed			10		MHz
f_{SCL}	Host I^2C Interface Speed	Standard Mode		100		kHz
		Fast Mode		400		
f_{SCL2}	Master I^2C Interface Speed(9)	Standard Mode		25		kHz
		Fast Mode		300		

Note:

9. When only accelerometer is enabled, I^2C master operates at 25 kHz. When gyroscope is enabled, I^2C master operates at 300 kHz.

3.7.1 Current Consumption

V_{DDd} = 1.8 V, V_{DDa} = 2.7 V, T = 25°C unless otherwise noted. Typical numbers are provided below.

Table 15. Current Consumption for Accelerometer Only Typical Sensor Mode (Gyroscope Disabled)

Mode		High-Resolution				Low-Power				Unit
ODR		1000	250	125	31.25	125	62.5	25	3	Hz
Typical Analog Current I_{DDa}(10)		220	220	220	220	35	35	20	7	μA
Typical Digital Current I_{DDd}(11)	Filters Disabled (aLPF=0; aHPF=0)	100	70	65	60	20	15	10	8	
	Filters Enabled (aLPF=1; aHPF=1)	108	71	66	61	21	16	10	8	

Table 16. Current Consumption for Gyroscope Only Typical Sensor Mode (Accelerometer Disabled)

Mode		High-Resolution				Snooze Warm-Start	OIS, OIS LL(8)	Unit
ODR		1000	250	125	31.25	Snooze	8100	Hz
Typical Analog Current I_{DDa}(10)		2540	2540	2540	2540	1240	2540	μA
Typical Digital Current I_{DDd}(11)	Filters Disabled (gLPF=0; gHPF=0; gHPF01=0)	740	710	705	700	570	1100	
	Filters Enabled (gLPF=1; gHPF=1; gHPF01=0)	740	710	705	700	570	1100	

Notes:

10. I_{DDa} is the current drawn from the analog supply V_{DDa}.
11. I_{DDd} is the current drawn from the digital supply V_{DDd}.

Table 17. Current Consumption for 6DOF Typical Sensor Mode (Accelerometer and Gyroscope Enabled)

Mode		High-Resolution				Unit
ODR		1000	250	125	31.25	Hz
Typical Analog Current I_{DDa}		2750	2750	2750	2750	μA
Typical Digital Current I_{DDd}	Filters Disabled (aLPF=0; gLPF=0; aHPF=0; gHPF=0; gHPF01=0)	815	780	780	780	
	Filters Enabled (aLPF=1; gLPF=1; aHPF=1; gHPF=1; gHPF01=0)	830	790	780	780	

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Table 18. Current Consumption for 6DOF Attitude Engine Mode (without Magnetometer)

Mode									Unit
ODR Setting		1	2	4	8	16	32	64	Hz
Typical Analog Current I_{DDa}		2750	2750	2750	2750	2750	2750	2750	µA
Typical Digital Current I_{DDd}	Filters Disabled (aLPF=0; gLPF=0)	930	930	930	930	930	930	930	
	Filters Enabled (aLPF=1; gLPF=1)	940	940	940	940	940	940	940	

Table 19. Current Consumption for 9DOF Attitude Engine Mode (with Magnetometer)

Mode								Unit
ODR		1	2	4	8	16	32	Hz
Typical Analog Current I_{DDa}		2750	2750	2750	2750	2750	2750	µA
Typical Digital Current I_{DDd}	With Magnetometer at 32 Hz	990	990	990	990	990	990	

3.8 Temperature Sensor

The FIS1100 is equipped with an internal 12-bit embedded temperature sensor that is automatically turned on by default whenever the accelerometer or gyroscope is enabled. The temperature sensor is used internally to correct the temperature dependency of calibration parameters of the accelerometer and gyroscope. The temperature compensation is optimal in the range of -40°C to 85°C with a resolution of 0.0625°C (1/16) or inversely, 16 LSB/°C.

The FIS1100 outputs the internal chip temperature that the HOST can read. This external output is truncated to an 8-bit resolution so that the HOST sees 1°C per LSB resolution. This is not representative of the accuracy used internally to model and compensate for temperature effects on calibration parameters. To read the temperature, the HOST needs to access the TEMP register *(see Data Output Registers in Table 21.* The HOST should synchronize to the interrupt, INT2, signal to get valid temperature readings.

Table 20. Temperature Sensor Specifications

Subsystem	Parameter	Typical	Unit
Digital Temperature Sensor	Range	-40 to +85	°C
	Internal Resolution	12	Bits
	Internal Sensitivity	16	LSB/°C
	Output Register Width	8	Bits
	Output Sensitivity	1	LSB/°C
	Refresh Rate	10	Hz

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4 Register Map Overview

The FIS1100 has various registers that enable programming and control of the inertial measurement unit and associated on-chip signal processing. The register map may be classified into the following register categories:

- General Purpose Registers
- Setup and Control Registers: Controls various aspects of the IMU.
- Host Controlled Calibration Registers: Controls and Configures various aspects of the IMU via Host Command interface called CTRL9
- Count Register for time stamping the sensor samples
- FIFO Registers: To setup the FIFO and detect data availability and over-run.
- Data Output Registers: Contains all data for 9D sensors.

FIS1100 registers are divided into two banks of 64 registers with the second register bank reserved for future use. Both register banks may be accessed from I^2C or SPI. A detailed description of each register including the register settings necessary to configure the FIS1100 operational modes is provided in Section 5.

Table 21. Register Overview

Name	Type	Register Address			Default	Comment
		Dec	Hex	Binary		
General Purpose Registers						
WHO_AM_I	r	0	00	00000000	11111100	Device Identifier
Setup and Control Registers						
CTRL1	rw	2	02	00000010	00000000	SPI Interface and Sensor Enable (for clock and power management)
CTRL2	rw	3	03	00000011	00000000	Accelerometer: Output Data Rate, Full Scale, Self Test
CTRL3	rw	4	04	00000100	00000000	Gyroscope: Output Data Rate, Full Scale, Self Test
CTRL4	rw	5	05	00000101	00000000	Magnetometer Settings: Output Data Rate, and Device Selection
CTRL5	rw	6	06	00000110	00000000	Data Processing Settings
CTRL6	rw	7	07	00000111	00000000	AttitudeEngine™ Settings: Output Data Rate, Motion on Demand
CTRL7	rw	8	08	00001000	00000000	Enable Sensors, syncSmpl
CTRL8	rw	9	09	00001001	00000000	Reserved: Not Used
CTRL9	rw	10	0A	00001010	00000000	Host commands
Host Controlled Calibration Registers (See CTRL9, Usage is Optional)						
CAL1_L	rw	11	0B	00001011	00000000	Calibration Register CAL1_L – lower 8 bits. CAL1_H – upper 8 bits.
CAL1_H	rw	12	0C	00001100	00000000	
CAL2_L	rw	13	0D	00001101	00000000	Calibration Register CAL2_L – lower 8 bits. CAL2_H – upper 8 bits.
CAL2_H	rw	14	0E	00001110	00000000	
CAL3_L	rw	15	0F	00001111	00000000	Calibration Register CAL3_L – lower 8 bits. CAL3_H – upper 8 bits.
CAL3_H	rw	16	10	00010000	00000000	
CAL4_L	rw	17	11	00010001	00000000	Calibration Register CAL4_L – lower 8 bits. CAL4_H – upper 8 bits.
CAL4_H	rw	18	12	00010010	00000000	
FIFO Registers						
FIFO_CTRL	rw	19	13	00010011	00000000	FIFO Setup
FIFO_DATA	r	20	14	00010100	00000000	FIFO Data
FIFO_STATUS	r	21	15	00010101	00000000	FIFO Status

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Table 21. Register Overview (Continued)

Name	Type	Register Address			Default	Comment
		Dec	Hex	Binary		
Status Registers						
STATUS0	r	22	16	00010110	00000000	Output Data Over Run and Data Availability
STATUS1	r	23	17	00010111	00000000	Miscellaneous Status: Wake on Motion, FIFO ready, CmdDone (CTRL9 protocol bit)
Count Register						
CNT_OUT	r	24	18	00011000	00000000	Sample Time Stamp (Count Output)
Data Output Registers (16 bits 2'compliment except self test sensor data, AE-REG1 and AE_REG2)						
AX_L	r	25	19	00011001	00000000	X-axis Acceleration AX_L – lower 8 bits. AX_H – upper 8 bits.
AX_H	r	26	1A	00011010	00000000	
AY_L	r	27	1B	00011011	00000000	Y-axis Acceleration AY_L – lower 8 bits. AY_H – upper 8 bits.
AY_H	r	28	1C	00011100	00000000	
AZ_L	r	29	1D	00011101	00000000	Z-axis Acceleration AZ_L – lower 8 bits. AZ_H – upper 8 bits.
AZ_H	r	30	1E	00011110	00000000	
GX_L	r	31	1F	00011111	00000000	X-axis Angular Rate GX_L – lower 8 bits. GX_H – upper 8 bits.
GX_H	r	32	20	00100000	00000000	
GY_L	r	33	21	00100001	00000000	Y-axis Angular Rate GY_L – lower 8 bits. GY_H – upper 8 bits.
GY_H	r	34	22	00100010	00000000	
GZ_L	r	35	23	00100011	00000000	Z-axis Angular Rate GZ_L – lower 8 bits. GZ_H – upper 8 bits.
GZ_H	r	36	24	00100100	00000000	
MX_L	r	37	25	00100101	00000000	X-axis Magnetic Field MX_L – lower 8 bits. MX_H – upper 8 bits.
MX_H	r	38	26	00100110	00000000	
MY_L	r	39	27	00100111	00000000	Y-axis Magnetic Field . MY_L – lower 8 bits. MY_H – upper 8 bits.
MY_H	r	40	28	00101000	00000000	
MZ_L	r	41	29	00101001	00000000	Z-axis Magnetic Field. MZ_L – lower 8 bits. MZ_H – upper 8 bits.
MZ_H	r	42	2A	00101010	00000000	
dQW_L	r	45	2D	00101101	00000000	Quaternion Increment dQW. dQW_L – lower 8 bits. dQW_H – upper 8 bits.
dQW_H	r	46	2E	00101110	00000000	
dQX_L	r	47	2F	00101111	00000000	Quaternion Increment dQX. dQX_L – lower 8 bits. dQX_H – upper 8 bits.
dQX_H	r	48	30	00110000	00000000	
dQY_L	r	49	31	00110001	00000000	Quaternion Increment dQY. dQY_L – lower 8 bits. dQY_H – upper 8 bits.
dQY_H	r	50	32	00110010	00000000	
dQZ_L	r	51	33	00110011	00000000	Quaternion Increment dQZ dQZ_L – lower 8 bits. dQZ_H – upper 8 bits.
dQZ_H	r	52	34	00110100	00000000	
dVX_L	r	53	35	00110101	00000000	Velocity Increment along X-axis, or X-axis Angular Rate for OIS LL mode, or Self test sensor data dVX_L – lower 8 bits. dVX_H – upper 8 bits.
dVX_H	r	54	36	00110110	00000000	
dVY_L	r	55	37	00110111	00000000	Velocity Increment along Y-axis, or Y-axis Angular Rate for OIS LL mode, or Self test sensor data dVY_L – lower 8 bits. dVY_H – upper 8 bits.
dVY_H	r	56	38	00111000	00000000	
dVZ_L	r	57	39	00111001	00000000	Velocity Increment along Z-axis, or Z-axis Angular Rate for OIS LL mode, or Self test sensor data dVZ_L – lower 8 bits. dVZ_H – upper 8 bits.
dVZ_H	r	58	3A	00111010	00000000	

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Table 21. Register Overview (Continued)

Name	Type	Register Address			Default	Comment
		Dec	Hex	Binary		
Data Output Registers (Continued)						
TEMP	r	59	3B	00111011	00000000	Temperature Output Data
AE_REG1	r	60	3C	00111100	00000000	AttitudeEngine Register 1
AE_REG2	r	61	3D	00111101	00000000	AttitudeEngine Register 2

5 Sensor Configuration Settings and Output Data

5.1 Typical Sensor Mode Configuration and Output Data

In Typical Sensor Mode, FIS1100 outputs raw sensor values. The sensors are configured and read using the registers described below. The accelerometer, gyroscope and magnetometer can be independently configured. Table 22 summarizes these pertinent registers.

Table 22. Typical Sensor Mode Configuration and Output Data

Typical Sensor Configuration and Output Data			
Description	**Registers**	**Unit**	**Comments**
Sensor Enable, SPI 3 or 4 Wire	CTRL1		Control power states, configure SPI communications
Enable Sensor, Configure Data Reads	CTRL7		Enable sensor mode (sEN = 0). Configure data reads from Sensor Data Output Registers with syncSmpl. Individually enable/disable the Accelerometer, Gyroscope and Magnetometer using aEN, gEN, and mENbits, respectively.
Configure Accelerometer, Enable Self Test	CTRL2		Configure Full Scale and Output Data Rate; Enable Self Test
Configure Gyroscope, Enable Self Test	CTRL3		Configure Full Scale and Output Data Rate; Enable Self Test
Configure Magnetometer	CTRL4		Configure Output Data Rate and choose device
Sensor Filters	CTRL5		Configure and Enable/Disable High Pass and Low Pass Filters
Status	STATUS0, STATUS1		Data Availability, Data Overrun, FIFO ready to be read, CTRL9 Protocol Bit
Time Stamp	CNT_OUT		Sample Time Stamp (circular register 0-FF)
Acceleration	A[X,Y,Z]_[H,L]	g	In Sensor Frame of Reference, Right-handed Coordinate System
Angular Rate	G[X,Y,Z]_[H,L]	dps	In Sensor Frame of Reference, Right-handed Coordinate System
Magnetic Field	M[X,Y,Z]_[H,L]	gauss	In Sensor Frame of Reference, Right-handed Coordinate System
Temperature	TEMP	°C	Temperature of the sensor
FIFO Based Output	FIFO_DATA		See FIFO Description section for more details on using the FIFO to store and access multiple samples

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5.2 AttitudeEngine Mode Configuration and Output Data

In AE Mode, FIS1100 outputs orientation (quaternion) and velocity increments.

Orientation increments are expressed in unit quaternion format. dQ = [QW, QX, QY, QZ]^T where QW is the scalar component of the quaternion increment and QX, QY and QZ are the (imaginary) vector components of the unit quaternion. Velocity increments are expressed in vector format dV = [VX, VY, VZ].

Table 23 summarizes the operation of the AttitudeEngine mode.

Table 23. AttitudeEngine Mode Configuration and Output Registers

AttitudeEngine Mode			
Configuration	**Registers**	**Unit**	**Comments**
Sensor Enable, SPI 3 or 4 Wire	CTRL1		Control power states, SPI communications
Enable AttitudeEngine	CTRL7		Enable the AttitudeEngine (CTRL7, sEN =1, aEN=1, gEN=1, optionally mEN=1 if external magnetometer is available)
Configure	CTRL6		AttitudeEngine Output Data Rate and Motion on Demand
Configure Accelerometer, Enable Self Test	CTRL2		Configure Full Scale; Enable Self Test
Configure Gyroscope, Enable Self Test	CTRL3		Configure Full Scale; Enable Self Test
Configure Magnetometer	CTRL4		Configure Output Data Rate and choose device
Sensor Filters	CTRL5		Configure and Enable/Disable High Pass and Low Pass Filters
Quaternion Increment	dQ[W,X,Y,Z]_[H,L]		Unit Quaternion format in sensor frame
Velocity Increment	dV[X,Y,Z]_[H,L]	ms^{-1}	Rotation compensated velocity increment (based on specific force), rotated to sensor frame of reference
Magnetic Field	M[X,Y,Z]_[H,L]	gauss	Rotation compensated magnetic field (rotated to sensor frame of reference)
Status	STATUS0, STATUS1		Data Availability, Data Overrun, Wake on Motion detected
Bias Update, Clipping, Overflow	AE_REG1, AEREG_2		Magnetometer and Gyroscope bias update acknowledgement, Sensor clipping acknowledgement, Velocity increment overflow
Temperature	TEMP	°C	Temperature of the sensor

5.3 General Purpose Register

Table 24. General Purpose Register Description

Register Name			
WHO_AM_I		**Register Address: 0 (0x00)**	
Bits	**Name**	**Default**	**Description**
7:0	WHO_AM_I	0xFC	Device identifier FC - to identify the device is a Fairchild sensor

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5.4 Configuration Registers

This section describes the various operating modes and register configurations of the FIS1100.

Table 25. Configuration Registers Description

<table>
<tr><th colspan="2">Register Name</th><th colspan="2"></th></tr>
<tr><td colspan="2">CTRL1</td><td colspan="2">SPI Interface and Sensor Enable. Register Address: 2 (0x02)</td></tr>
<tr><th>Bits</th><th>Name</th><th>Default</th><th>Description</th></tr>
<tr><td>7</td><td>SIM</td><td>1’b0</td><td>0: Enables 4-wire SPI interface
1: Enables 3-wire SPI interface</td></tr>
<tr><td>6:1</td><td>Reserved</td><td>6’b0</td><td>Reserved</td></tr>
<tr><td>0</td><td>sensorDisable</td><td>1’b0</td><td>0: Enables internal 1 MHz oscillator
1: Disables internal 1 MHz oscillator
For more detail, see Table 32 and see Figure 8</td></tr>
<tr><td colspan="2">CTRL2</td><td colspan="2">Accelerometer Settings: Address: 3 (0x03)</td></tr>
<tr><th>Bits</th><th>Name</th><th>Default</th><th>Description</th></tr>
<tr><td>7:6</td><td>Reserved</td><td>2’b0</td><td>Reserved</td></tr>
<tr><td>5</td><td>aST</td><td>1’b0</td><td>Enable Accelerometer Self Test. For more detail, see Section 9.1</td></tr>
<tr><td>4:3</td><td>aFS<1:0></td><td>2’b0</td><td>Set Accelerometer Full-scale:
00 - Accelerometer Full-scale = ±2 g
01 - Accelerometer Full-scale = ±4 g
10 - Accelerometer Full-scale = ±8 g
11 - Accelerometer Full-scale = ±8 g</td></tr>
<tr><td>2:0</td><td>aODR<2:0>[12]</td><td>3’b0</td><td>Set Accelerometer Output Data Rate (ODR):
<table>
<tr><th>Setting</th><th>ODR Rate (Hz)</th><th>Mode</th><th>LPF Bandwidth (Hz), aLPF=0</th><th>LPF Bandwidth (Hz), aLPF=1</th></tr>
<tr><td>000</td><td>1000</td><td>High Resolution</td><td>500</td><td>200</td></tr>
<tr><td>001</td><td>250</td><td>High Resolution</td><td>125</td><td>50</td></tr>
<tr><td>010</td><td>125</td><td>High Resolution</td><td>62.5</td><td>25</td></tr>
<tr><td>011</td><td>31.25</td><td>High Resolution</td><td>15.625</td><td>5</td></tr>
<tr><td>100</td><td>125</td><td>Low Power</td><td>62.5</td><td>25</td></tr>
<tr><td>101</td><td>62.5</td><td>Low Power</td><td>31.25</td><td>15</td></tr>
<tr><td>110</td><td>25</td><td>Low Power</td><td>12</td><td>5</td></tr>
<tr><td>111</td><td>3</td><td>Low Power</td><td>2</td><td>0.6</td></tr>
</table></td></tr>
</table>

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Table 25 Configuration Register Description (Continued)

<table>
<tr><td colspan="2">Register Name</td><td colspan="2"></td></tr>
<tr><td colspan="2">CTRL3</td><td colspan="2">Gyroscope Settings: Address 4 (0x04)</td></tr>
<tr><td>Bits</td><td>Name</td><td>Default</td><td>Description</td></tr>
<tr><td>7</td><td>Reserved</td><td>1’b0</td><td></td></tr>
<tr><td>6</td><td>gST</td><td>1’b0</td><td>Enable Gyro Self-Test. For more detail, see Section 9.2, Gyroscope Self Test</td></tr>
<tr><td>5:3</td><td>gFS<2:0></td><td>3’b0</td><td>Set Gyroscope Full-scale:
000 - ±32 dps
001 - ±64 dps
010 - ±128 dps
011 - ±256 dps
100 - ±512 dps
101 - ±1024 dps
110 - ±2048 dps
111 - ±2560 dps</td></tr>
<tr><td>2:0</td><td>gODR<2:0> (12)</td><td>3’b0</td><td>Set Gyroscope Output Data Rate (ODR):
<table>
<tr><th>Setting</th><th>ODR Rate (Hz)</th><th>Mode</th><th>LPF Bandwidth (Hz). gLPF=0</th><th>LPF Bandwidth (Hz), gLPF=1</th></tr>
<tr><td>000</td><td>1000</td><td>High-Resolution</td><td>500</td><td>200</td></tr>
<tr><td>001</td><td>250</td><td>High-Resolution</td><td>125</td><td>50</td></tr>
<tr><td>010</td><td>125</td><td>High-Resolution</td><td>62.5</td><td>25</td></tr>
<tr><td>011</td><td>31.25</td><td>High-Resolution</td><td>15.625</td><td>6</td></tr>
<tr><td>10X</td><td>0</td><td>Gryo Warm-Start (“Snooze”)</td><td>NA</td><td>NA</td></tr>
<tr><td>110</td><td>8100</td><td>OIS</td><td>4050</td><td>345</td></tr>
<tr><td>111</td><td>8100</td><td>OIS LL(13)</td><td>2000</td><td>N/A(14)</td></tr>
</table></td></tr>
<tr><td colspan="2">CTRL4</td><td colspan="2">Magnetometer Settings: Address: 5 (0x05)</td></tr>
<tr><td>Bits</td><td>Name</td><td>Default</td><td>Description</td></tr>
<tr><td>7:6</td><td>Reserved</td><td>2’b0</td><td></td></tr>
<tr><td>5:4</td><td>mDEV<1:0></td><td>2’b0</td><td>Designate External Magnetometer Device:
<table>
<tr><th>Setting</th><th>Vendor</th><th>Part Number</th></tr>
<tr><td>00</td><td>AKM</td><td>AK8975</td></tr>
</table></td></tr>
<tr><td>3:2</td><td>Reserved</td><td>2’b0</td><td></td></tr>
<tr><td>1:0</td><td>mODR<1:0></td><td>2’b0</td><td>Set Recommended Magnetometer Output Data Rate (ODR):
<table>
<tr><th>Setting</th><th>ODR Rate (Hz)</th><th>Description</th></tr>
<tr><td>10</td><td>31.25</td><td>AKM8975</td></tr>
</table></td></tr>
</table>

Note:

12. When both the accelerometer and the gyroscope are enabled, it is typical to set the ODR rates for each sensor to be identical, such as when output rates are chosen in the range of 1kHz to 32Hz. In case the host requires different ODRs (for example, as with OIS mode) then, the gyroscope output rate should be chosen to be greater than or equal to the accelerometer output rate. NOTE: The accelerometer low power mode is only available when the gyroscope is disabled
13. When gODR<2:0>=111 (OIS LL mode) is selected, the gyro data will be written to dVX_L, dVX_H, dVY_L, dVY_H, dVZ_L and dVZ_H registers. See register #53 through #58 for additional details.

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Table 25 Configuration Register Description (Continued)

<table>
<tr><th colspan="2">Register Name</th><th colspan="2"></th></tr>
<tr><td colspan="2">CTRL5</td><td colspan="2">Sensor Data Processing Settings. Register Address: 6 (0x06)</td></tr>
<tr><th>Bits</th><th>Name</th><th>Default</th><th>Description</th></tr>
<tr><td>7:5</td><td>Reserved</td><td>3’b0</td><td></td></tr>
<tr><td>4</td><td>gHPF01</td><td>1’b0</td><td>Set HPF corner frequency. See Table associated with gHPF bit below.</td></tr>
<tr><td>3</td><td>gLPF</td><td>1’b0</td><td>0: Disable Gyroscope Low-Pass Filter.
1: Enable Gyroscope Low-Pass Filter.</td></tr>
<tr><td>2</td><td>gHPF</td><td>1’b0</td><td>0: Disable Gyroscope High-Pass Filter.
1: Enable Gyroscope High-Pass Filter (see Table below).
High-Pass Filter corner frequency (f_c) with gHPF = 1
<table>
<tr><th>ODR Rate (Hz)</th><th>gHPF01=1 (Hz)</th><th>gHPF01=0 (Hz)</th></tr>
<tr><td>1000</td><td>0.1</td><td>2.5</td></tr>
<tr><td>250</td><td>0.0250</td><td>0.6250</td></tr>
<tr><td>125</td><td>0.0125</td><td>0.3125</td></tr>
<tr><td>31.25</td><td>0.0032</td><td>0.0800</td></tr>
<tr><td>8100 (gODR=110)</td><td>0.1000</td><td>0.1000</td></tr>
<tr><td>8100 (gODR=111)</td><td>N/A(14)</td><td>N/A(14)</td></tr>
</table></td></tr>
<tr><td>1</td><td>aLPF</td><td>1’b0</td><td>0: Disable Accelerometer Low-Pass Filter.
1: Enable Accelerometer Low-Pass Filter.</td></tr>
<tr><td>0</td><td>aHPF</td><td>1’b0</td><td>0: Disable Accelerometer High-Pass Filter
1: Enable Accelerometer High-Pass Filter.</td></tr>
<tr><td colspan="2">CTRL6</td><td colspan="2">Attitude Engine ODR and Motion on Demand: Address: 7 (0x07)</td></tr>
<tr><th>Bits</th><th>Name</th><th>Default</th><th>Description</th></tr>
<tr><td>7</td><td>sMoD</td><td>1’b0</td><td>0: Disables Motion on Demand.
1: Enables Motion on Demand (Requires sEN=1).</td></tr>
<tr><td>6:3</td><td>Reserved</td><td>4’b0</td><td></td></tr>
<tr><td>2:0</td><td>sODR<2:0></td><td>3’b0</td><td>Attitude Engine Output Data Rate (ODR)
<table>
<tr><th>Setting</th><th>ODR Rate (Hz)</th></tr>
<tr><td>000</td><td>1</td></tr>
<tr><td>001</td><td>2</td></tr>
<tr><td>010</td><td>4</td></tr>
<tr><td>011</td><td>8</td></tr>
<tr><td>100</td><td>16</td></tr>
<tr><td>101</td><td>32</td></tr>
<tr><td>110</td><td>64(15)</td></tr>
<tr><td>111</td><td>NA</td></tr>
</table></td></tr>
</table>

Notes:

14. For OIS LL mode, no filters can be enabled. gLPF=0 and gHPF=0 should be maintained.
15. This ODR should not be used if magnetometer is enabled

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Table 25 Configuration Register Description (Continued)

Register Name			
CTRL7		**Enable Sensors and Configure Data Reads. Register Address: 8 (0x08)**	
Bits	**Name**	**Default**	**Description**
7	syncSmpl	1'b0	This bit determines how data are read out of Sensor Data Output Registers of the FIS1100. 0: INT2 is placed into edge trigger mode: the Sensor Data Output Registers are updated at the Output Data Rate (ODR), and INT2 is pulsed at the ODR rate 1: INT2 is placed into level mode: the Sensor Data Output Registers are updated at the ODR until the STATUS0 register is read by the host. Reading STATUS0 causes the Sensor Data Output Registers register to stop updating and causes INT2 to be brought low. The Sensor Data Output Registers are not updated until the last byte has been read from them. Once this read is complete, the FIS1100 resumes updating the Sensor Data Output Registers and INT2 will be brought high when new data is available.
6:4	Reserved	3'b0	
3	sEN	1'b0	0: Disable AttitudeEngine orientation and velocity increment computation 1: Enable AttitudeEngine orientation and velocity increment computation
2	mEN	1'b0	0: Magnetometer placed in Standby or Power-down Mode. 1: Enable Magnetometer
1	gEN	1'b0	0: Gyroscope placed in Standby or Power-down Mode. 1: Enable Gyroscope.
0	aEN	1'b0	0: Accelerometer placed in Standby or Power-down Mode. 1: Enable Accelerometer.
CTRL8		**Reserved – Special Settings. Register Address: 9 (0x09)**	
Bits	**Name**	**Default**	**Description**
7:0	Reserved	0x00	Not Used
Register Name			
CTRL9		**Host Commands. Register Address: 10 (0x0A)** (See Section 5.7, CTRL 9 Functionality (Executing Pre-defined Commands))	

5.5 Status and Count Registers

Table 27. Status and Time Stamp Registers

Register Name			
STATUS0		**Output Data Status Register Address: 22 (0x16)**	
Bits	**Name**	**Default**	**Description**
7	aeOVRN	1'b0	0: No overrun 1: AE data overrun. Previous data overwritten before it was read.
6	mOVRN	1'b0	0: No overrun 1: Magnetometer data overrun. Previous data overwritten before it was read.
5	gOVRN	1'b0	0: No overrun 1: Gyroscope data overrun. Previous data overwritten before it was read.
4	aOVRN	1'b0	0: No overrun 1: Accelerometer data overrun. Previous data overwritten before it was read.
3	aeDA	1'b0	AE new data available 0: No updates since last read. 1: New data available.
2	mDA	1'b0	Valid Magnetometer data available 0: Magnetometer data is NOT Valid 1: Valid Magnetometer data is available at every ODR. If Mag ODR is lower than accelerometer and gyroscope ODR previous valid Magnetometer data will be repeated until new data is available
1	gDA	1'b0	Gyroscope new data available 0: No updates since last read. 1: New data available.
0	aDA	1'b0	Accelerometer new data available 0: No updates since last read. 1: New data available.
STATUS1		**Miscellaneous Status. Register Address 23 (0x17)**	
Bits	**Name**	**Default**	**Description**
7:3	Reserved	5'b0	
2	WoM	1'b0	Wake on Motion detected (see Section 8 for more details)
1	FIFO_rddy	1'b0	FIFO ready to be read.
0	CmdDone	1'b0	Bit read by Host Processor as part of CTRL9 register protocol. See Section 5.7 for more information.
CNT_OUT		**Sample Time Stamp – Output Count. Register Address: 24 (0x18)**	
Bits	**Name**	**Default**	**Description**
7:0	CNT_OUT<7:0>	0x00	Sample time stamp. Count incremented by one for each sample (x, y, z data set) from sensor with highest ODR (circular register 0x00-0xFF).

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5.6 Sensor Data Output Registers

Table 28. Sensor Data Output Registers Description

Register Name			
A[X,Y,Z]_[H,L]		**Acceleration Output. Register Address: 25 – 30, (0x19 – 0x1E)**	
Bits	**Name**	**Default**	**Description**
7:0	AX_L<7:0>	0x00	X-axis acceleration in two's complement. AX_L – lower 8 bits. AX_H – upper 8 bits.
7:0	AX_H<15:8>	0x00	
7:0	AY_L<7:0>	0x00	Y-axis acceleration in two's complement. AY_L – lower 8 bits. AY_H – upper 8 bits.
7:0	AY_H<15:8>	0x00	
7:0	AZ_L<7:0>	0x00	Z-axis acceleration in two's complement. AZ_L – lower 8 bits. AZ_H – upper 8 bits.
7:0	AZ_H<15:8>	0x00	
Register Name			
G[X,Y.Z]_[H,L]		**Angular Rate Output. Register Address: 31 – 36 (0x1F – 0x24)**	
Bits	**Name**	**Default**	**Description**
7:0	GX_L<7:0>	0x00	X-axis angular rate in two's complement. GX_L – lower 8 bits. GX_H – upper 8 bits.
7:0	GX_H<15:8>	0x00	
7:0	GY_L<7:0>	0x00	Y-axis angular rate in two's complement. GY_L – lower 8 bits. GY_H – upper 8 bits.
7:0	GY_H<15:8>	0x00	
7:0	GZ_L<7:0>	0x00	Z-axis angular rate in two's complement. GZ_L – lower 8 bits. GZ_H – upper 8 bits.
7:0	GZ_H<15:8>	0x00	
Register Name			
M[X,Y,Z]_[H,L]		**Magnetometer Output. Register Address: 37 - 42. (0x25 – 0x2A)**	
Bits	**Name**	**Default**	**Description**
7:0	MX_L<7:0>	0x00	X-axis magnetic field data in two's complement. MX_L – lower 8 bits. MX_H – upper 8 bits.
7:0	MX_H<15:8>	0x00	
7:0	MY_L<7:0>	0x00	Y-axis magnetic field data in two's complement. MY_L – lower 8 bits. MY_H – upper 8 bits.
7:0	MY_H<15:8>	0x00	
7:0	MZ_L<7:0>	0x00	Z-axis magnetic field data in two's complement. MZ_L – lower 8 bits. MZ_H – upper 8 bits.
7:0	MZ_H<15:8>	0x00	

Continued on the following page…

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Table 28 Sensor Data Output Registers Description (Continued)

Register Name			
dQ[1,2,3,4]_[H,L]		**Quaternion Output. Register Addresses: 45 – 52 (0x2D – 0x34)**	
Bits	**Name**	**Default**	**Description**
7:0	dQW_L<7:0>	0x00	Quaternion Increment dQW in two's complement. dQW_L – lower 8 bits. dQW_H – upper 8 bits.
7:0	dQW_H<15:8>	0x00	
7:0	dQX_L<7:0>	0x00	Quaternion Increment dQX in two's complement. dQX_L – lower 8 bits. dQX_H – upper 8 bits.
7:0	dQX_H<15:8>	0x00	
7:0	dQY_L<7:0>	0x00	Quaternion Increment dQY in two's complement. dQY_L – lower 8 bits. dQY_H – upper 8 bits.
7:0	dQY_H<15:8>	0x00	
7:0	dQZ_L<7:0>	0x00	Quaternion Increment dQZ in two's complement. dQZ_L – lower 8 bits. dQZ_H – upper 8 bits.
7:0	dQZ_H<15:8>	0x00	
dV[X,Y,Z]_[H,L]		**Delta Velocity Output. Register Address: 53 – 58 (0x35– 0x3A)**	
Bits	**Name**	**Bits**	**Name**
7:0	dVX_L<7:0>	0x00	X-axis Velocity Increment in two's complement. dVX_L – lower 8 bits. dVX_H – upper 8 bits. When gODR=111, OIS LL Gyro X-axis data in two's complement Also used for accelerometer or gyro self test data
7:0	dVX_H<15:8>	0x00	
7:0	dVY_L<7:0>	0x00	Y-axis Velocity Increment in two's complement. dVY_L – lower 8 bits. dVY_H – upper 8 bits. When gODR=111, OIS LL Gyro Y-axis data in two's complement Also used for accelerometer or gyro self test data
7:0	dVY_H<15:8>	0x00	
7:0	dVZ_L<7:0>	0x00	Z-axis Velocity Increment in two's complement. dVZ_L – lower 8 bits. dVZ_H – upper 8 bits. When gODR=111, OIS LL Gyro Z-axis data in two's complement Also used for accelerometer or gyro self test data
7:0	dVZ_H<15:8>	0x00	
TEMP		**Temperature Output. Register Address: 59. (0x3B)**	
Bits	**Name**	**Default**	**Description**
7:0	TEMP<7:0>	0x00	Temperature output (°C) in two's complement.
AE_REG1		**AttitudeEngine Register 1, Address: 60 (0x3C)**	
Bits	**Name**	**Default**	**Description**
7	MagBiasAck	1'b0	Acknowledgement that Mag Bias was updated during this time period.
6	GyroBiasAck	1'b0	Acknowledgement that Gyro Bias was updated during this time period.
5	wz_clip	1'b0	Gyroscope Z-axis data was clipped during the dQ calculation.
4	wy_clip	1'b0	Gyroscope Y-axis data was clipped during the dQ calculation.
3	wx_clip	1'b0	Gyroscope X-axis data was clipped during the dQ calculation.
2	az_clip	1'b0	Accelerometer Z-axis data was clipped during the dQ calculation.
1	ay_clip	1'b0	Accelerometer Y-axis data was clipped during the dQ calculation.
0	ax_clip	1'b0	Accelerometer X-axis data was clipped during the dQ calculation.

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Table 28 Sensor Data Output Registers Description (Continued)

Register Name			
AE_REG2		**AttitudeEngine Register 2, Address: 61 (0x3D)**	
Bits	**Name**	**Default**	**Description**
7	Reserved	1'b0	
6	Reserved	1'b0	
5	mz_clip	1'b0	Mag Z-axis data was clipped.
4	my_clip	1'b0	Mag Y-axis data was clipped.
3	mx_clip	1'b0	Mag X-axis data was clipped.
2	dvz_of	1'b0	Velocity Increment overflow along dvz.
1	dvy_of	1'b0	Velocity Increment overflow along dvy.
0	dvx_of	1'b0	Velocity Increment overflow along dvx.

Table 29. AttitudeEngine Modes and Output Table

Mode/Outputs		dQ	dV	M	CNT_OUT	Comments on CNT_OUT
AttitudeEngine in ODR Mode (Accelerometer and Gyroscope Enabled)						
CTRL6 Register	sEN=1	Quaternion Increment	Velocity Increment	No Data	AttitudeEngine Sample count	8-bit data. Count starts at 1, 256 count wraps to 0, i.e. Mod(256)
	sMoD=0					
CTRL7 Register	aEN=1					
	gEN=1					
	mEN=0					
AttitudeEngine in Motion on Demand (MoD) mode (Accelerometer and Gyroscope enabled)						
CTRL6 Register	sEN=1	Quaternion Increment	Velocity Increment	No Data	Gyroscope Samples in Integration Window	8-bit data. Count starts at 1, 256 count wraps to 0, i.e. Mod(256)
	sMoD=1					
CTRL7 Register	aEN=1					
	gEN=1					
	mEN=0					
AttitudeEngine with Raw Magnetometer in ODR Mode (Accelerometer, Gyroscope and Magnetometer Enabled)						
CTRL6 Register	sEN=1	Quaternion Increment	Velocity Increment	Initial Raw Mag Data	AttitudeEngine Sample Count	8-bit data. Count starts at 1, 256 count wraps to 0, i.e. Mod(256)
	sMoD=0					
CTRL7 Register	aEN=1					
	gEN=1					
	mEN=1					

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5.7 CTRL 9 Functionality (Executing Pre-defined Commands)

5.7.1 CTRL 9 Description

The protocol for executing predefined commands from an external host processor on the FIS1100 is facilitated by the using the Control 9 (CTRL9) register on the FIS1100. The register is available to the host via the SPI /I^2C bus. It operates by the host writing a pre-defined value (Command) to the CTRL9 register. The firmware of the FIS1100 evaluates this Command and if a match is found it executes the corresponding pre-defined function. Once the function has been executed, the FIS1100 signals the completion of this by raising INT1 interrupt. The host must acknowledge this by reading STATUS1 register bit 0. This is the CmdDone bit. After this read, the FIS1100 pulls down the INT1 interrupt. This command presentation from the host to the FIS1100 and the subsequent execution and handshake between the host and the FIS1000 will be referred to as the "*CTRL9 Protocol*".

There are three types of interactions between the host and FIS1100 that follow the CTRL9 Protocol.

WCtrl9: The host needs to supply data to FIS1100 prior to the Ctrl9 protocol. (**Write – Ctrl9 Protocol**)

Ctrl9R: The host gets data from FIS1100 following the Ctrl9 protocol. (**Ctrl9 protocol – Read**)

Ctrl9: No data transaction is required prior to or following the Ctrl9 protocol. (**Ctrl9**).

Table 30. CAL Register Addresses

Register Name	Register Address	
	Dec	Hex
CAL1_H	11	0x0B
CAL1_L	12	0x0C
CAL2_H	13	0x0D
CAL2_L	14	0x0E
CAL3_H	15	0x0F
CAL3_L	16	0x10
CAL4_H	17	0x11
CAL4_L	18	0x12

5.7.2 WCtrl9 (Write – CTRL9 Protocol)

1. The host needs to provide the required data for this command to the FIS1100. The host typically does this by placing the data in a set of registers called the CAL buffer. Currently 8 CAL registers are used the following table provides the name and addresses of these registers.
2. Write Ctrl9 register 0x0a with the appropriate Command value.
3. The Device will raise INT1 and set Bit 0 in STATUS1 reg, to 1 once it have executed the appropriate function based on the command value.
4. The host must acknowledge this by reading STATUS1 register bit 0 (CmdDone) which is reset to 0 on reading the register. Also INT1 is pulled low, completing the CTRL9 transaction.
5. If any data is expected from the device it will be available at this time. The location of the data is specified separately for each of the Commands.

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5.7.3 Ctrl9R (CTRL9 Protocol - Read)

1. Write Ctrl9 register 0x0A with the appropriate Command value.
2. The Device will raise INT1 and set Bit 0 in STATUS1 register to 1 once it has executed the appropriate function based on the command value.
3. The host must acknowledge this by reading STATUS1 register bit 0 (CmdDone) which is then reset to 0 upon reading the register. Also INT1 is pulled low upon the register read, completing the CTRL9 transaction.
   Data is available from the device at this time. The location of the data is specified separately for each of the Commands (see Section 5.7.5, CTRL9 Commands in Detail).

5.7.4 Ctrl9 (CTRL9 Protocol Acknowledge)

1. Write CTRL9 register 0x0a with the appropriate Command value.
2. The Device will raise INT1 and set Bit 0 in STATUS1 register to 1 once it has executed the appropriate function based on the command value.
3. The host must acknowledge this by reading STATUS1 register bit 0 (CmdDone) which is then reset to 0 upon reading the register. Also INT1 is pulled low, upon the register read, completing the CTRL9 transaction.

Table 31. CTRL9 Register CMND Values:

CMND Name	CTRL9 Command Value	Protocol Type	Description
CTRL_CMD_RST_AHPF	0x03	Ctrl9	Reset Accelerometer High Pass Filter from Host
CTRL_CMD_RST_GHPF	0x04	Ctrl9	Reset Gyroscope High Pass Filter from Host
CTRL_CMD_AE_MAG_OFFSET	0x0b	WCtrl9	Set Magnetometer Offset from Host
CTRL_CMD_AE_GYRO_OFFSET	0x0e	WCtrl9	Set Gyroscope Offset from Host for most accurate computation of dQ by AE
CTRL_CMD_REQ_MoD	0x0c	Ctrl9R	Get AE Data from Device in MoD Mode
CTRL_CMD_HOST_ACCEL_OFFSET	0x12	WCtrl9	Set Accelerometer Offset from Host Dynamically
CTRL_CMD_HOST_GYRO_OFFSET	0x13	WCtrl9	Set Gyroscope Offset from Host Dynamically
CTRL_CMD_MAG_SKOR_X	0x06	WCtrl9	Set X Magnetometer, Offset and Skew from Host
CTRL_CMD_MAG_SKOR_Y	0x07	WCtrl9	Set Y Magnetometer, Offset and Skew from Host
CTRL_CMD_MAG_SKOR_Z	0x08	WCtrl9	Set Z Magnetometer, Offset and Skew from Host
CTRL_CMD_GET_TCYCLE	0x18	Ctrl9R	Get TCYCLE time from Device
CTRL_CMD_REQ_FIFO	0x0d	Ctrl9R	Get FIFO data from Device
CTRL_CMD_RST_FIFO	0x02	Ctrl9	Reset FIFO from Host
CTRL_CMD_WRITE_WoM_SETTING	0x19	WCtrl9	Set up and enable Wake on Motion

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5.7.5 CTRL9 Commands in Detail

CTRL_CMD_RST_AHPF
This CTRL command of writing 0x03 to the CTRL9 register 0x0A allows the host to instruct the device to reset the accelerometer high-pass filter.

CTRL_CMD_RST_GHPF
This CTRL9 command of writing 0x04 to the CTRL9 register 0x0A allows the host to instruct the device to reset the gyroscope high-pass Filter.

CTRL_CMD_AE_MAG_OFFSET
This CTRL9 Command is issued to configure the AE with specific magnetometer offset data. The X,Y & Z magnetometer offset are provided to the device from the host. They are 16 bit each and programmed into the CAL1 to CAL3 registers respectively.

CTRL_CMD_AE_GYRO_OFFSET
This CTRL9 Command is issued to configure the AE with specific Gyro offset data required for dQ computations. The X,Y & Z gyro bias specific for AE engine are provided to the device from the host. They are 16 bit each and programmed into the CAL1 to CAL3 registers respectively.

CTRL_CMD_REQ_MoD
This CTRL9 command is used to retrieve motion data from the FIS1100 when Motion on Demand mode (MoD) is enabled. To enable MoD the device should have the AttitudeEngine orientation enabled. This can be done by enabling the AttitudeEngine by setting CTRL7 Bit 3 (sEN) to 1. Then the MoD mode can be enabled by setting CTRL6 Bit 7 (sMoD) to 1. The CTRL_CMD_REQ_MoD command is then issued by writing 0x0C to CTRL9 register 0x0A. This indicates to the FIS1100 that it is required to supply the motion data to the host. The device immediately makes available the orientation and velocity increments it has computed so far to the host by making it available at output registers 0x25 to 0x3D and raise the INT1 to indicate to the host that valid data is available.

CTRL_CMD_HOST_ACCEL_OFFSET
This CTRL9 command is issued when the host wants to tune the accelerometer offset. The incremental value of the offset should be 16 bit 2's complement format with 5 bits for signed integer and 11 bits fraction. The value should be placed into the CAL1 to CAL3 register for X, Y, and Z, respectively. The new value provided here will be subtracted from the accelerometer base offset value. The new value is used for dynamic calibration. There will be a delay of up to 3 output samples before this takes effect. Once the host has loaded the offset values in the CALx registers it needs to issue the CTRL9 command by writing the 0x12 to CTRL9 register 0x0A.

CTRL_CMD_HOST_GYRO_OFFSET
This CTRL9 command is issued when the host wants to tune the gyroscope offset. The incremental value of the offset should be 16 bit 2's complement format with 10 bits for signed integer and 6 bits fraction. The value should be placed into the CAL1 to CAL3 registers for X, Y, and Z, respectively. The new value provided here is subtracted from the gyroscope base offset value. The new value is used for dynamic calibration. There will be a delay of up to 3 output samples before this takes effect. Once the host has loaded the offset values in the CALx registers it needs to issue the CTRL9 command by writing 0x13 to CTRL9 register 0x0A.

CTRL_CMD_MAG_SKOR_X
This CTRL9 Command is issued to configure the Magnetometer device calibration value. The X Offset, Scale and 2 skew values are provided to the device from the host. They are 16 bits each and programmed into the CAL1 to CAL4 registers. Once the host has loaded the offset values in the CALx registers it needs to issue the CTRL9 command by writing the 0x06 to CTRL9 register 0x0a.

CTRL_CMD_MAG_SKOR_Y
This CTRL9 Command is issued to configure the magnetometer device with the calibration value. The Y offset, scale and 2 skew values are provided to the device from the host. They are 16 bits each and programmed into the CAL1 to CAL4 registers. Once the host has loaded the offset values in the CALx registers it needs to issue the CTRL9 command by writing 0x07 to CTRL9 register 0x0A.

CTRL_CMD_MAG_SKOR_Z
This CTRL9 Command is issued to configure the magnetometer device with the calibration value. The Z offset, scale and 2 skew values are provided to the device from the host. They are 16 bits each and programmed into the CAL1 to CAL4 registers. Once the host has loaded the offset values in the CALx registers it needs to issue the CTRL9 command by writing 0x08 to CTRL9 register 0x0A.

CTRL_CMD_GET_TCYCLE
This CTRL9 Command can only be issued when the FIS1100 is in the AE Mode. The Host can issue this command to get the exact time in milliseconds between samples (for example 1 Hz ODR may not be exactly 1 sec but could be 0.998 seconds). This command is issued by writing 0x18 to CTRL9 register 0x0A.

CTRL_CMD_REQ_FIFO
This CTRL9 Command is issued when the host wants to get data from the FIFO. When the FIFO is enabled it will be indicated to the host by asserting INT2 and thus signaling that a flag condition (like FIFO full) has been reached and that data is available to be read by the host. This Command is issued by writing 0x0D to the CTRL9 register 0x0A. The device will raise INT1 to indicate that it is ready for a FIFO transaction. The host must read the STATUS1 register bit 0 (CmdDone). At this point the host should set the FIFO_rd_mode Bit to 1 (FIFO_CTRL register 0x13 bit 7). The device will direct the FIFO data to the FIFO_DATA register 0x14 until the FIFO is empty. The host must now set FIFO_rd_mode to 0 which will cause the INT2 to be de-asserted.

CTRL_CMD_RST_FIFO
This CTRL9 command of writing 0x02 to the Ctrl9 register 0x0a allows the host to instruct the device to reset the FIFO.

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CTRL_CMD_WRITE_WOM_SETTING

This CTRL9 Command is issued when the host wants to enable/modify the trigger thresholds or blanking interval of the Wake on Motion Feature of the device. Please refer to Section 8 for details for setting up this feature. Once the specified CALx registers are loaded with the appropriate data, the Command is issued by writing 0x19 to CTRL9 register 0x0A.

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5.8 Interrupts

The FIS1100 has two Interrupt lines; INT1 and INT2. INT1 is used as a general purpose interrupt. The details are described in the specific sections where INT1 and INT2 are used. The following provides a summary of the INT1 and INT2 usage.

5.8.1 Interrupt 1 (INT1)

The following summarizes the use of INT1:

Set high for ~4 ms after reset to indicate that the chip is ready for normal operation.

If any operation has set INT1 it will always be cleared by reading STATUS1 register

Used as part of the CTRL9 handshake protocol (*see section 5.7)*

During gyroscope OIS mode INT1 is driven by the gyroscope ODR clock (~8 MHz). In this mode all normal INT1 functions are disabled.

When Wake on Motion (WoM) is enabled, INT1 can be selected to indicate WoM *(see section* 8*).*

5.8.2 Interrupt 2 (INT2)

INT2 generally indicates data availability. The following indicates when INT2 will be asserted.

Register-Read Mode (FIFO Bypass Mode)

In Register-Read mode the accelerometer, gyroscope and magnetometer data are available in the Sensor Data Output registers (A[X,Y,Z]_[H,L]). The updating of these output registers and the functionality of the INT2 interrupt is controlled by the syncSmpl bit as described below.

With syncSmpl = 0 (refer to Table 25, CTRL7 register bit 7), INT2 is placed into edge trigger mode: the Sensor Data Output Registers are updated at the Output Data Rate (ODR), and INT2 is pulsed at the ODR. A rising edge on INT2 indicates that data is available and INT2 is cleared automatically after a short duration. It is the responsibility of the host to detect the rising edge and to latch the data before the next sample occurs. Note that the INT2 pulse width is dependent on the ODR and the sensor. It is not recommended to depend on the level to determine if INT2 has occurred.

With syncSmpl = 1 (refer to Table 25, CTRL7 register bit 7), INT2 is placed into level mode: The INT2 is asserted when data is available and remains asserted until the host reads STATUS0 register.

The device continues to refresh the output data until the STATUS0 register is read by host.

Once the STATUS0 is read by host the FIS1100 will de-assert INT2 and stop refreshing the output data. Once the host detects INT2 has been de-asserted it can start reading the output data.

Once the last byte of data is read by the host (FIS1100 keeps track) the FIS1100 will start updating the output register and setup the next INT2 when data is available in the output registers.

FIFO Enabled Mode *(see Section* 7*)*

When the FIFO is enabled in the **FIFO mode** (the mode bits in FIFO_CTRL register set to 01), INT2 is asserted when the FIFO is full or when the watermark is reached.

When the FIFO is enabled in the **Streaming Mode** (the mode bits in FIFO_CTRL register set to 10), INT2 is asserted when the watermark is reached but not when the FIFO is full because in the stream mode the FIFO will continue to fill by overwriting the oldest data in the FIFO.

INT2 is cleared in both the FIFO Mode and the Streaming Mode by clearing the FIFO_rd_mode bit in the FIFO_CTRL register. This is done as part of the CTRL9 command CTRL_CMD_REQ_FIFO (see Section 5.7.5 for details).

Accelerometer and Gyroscope Self Test Modes *(see Section* 9*)*

INT2 is asserted to indicate availability of self-test data and is cleared by resetting the aST and gST bits in CTRL2 and CTRL3 registers, respectively.

AE Mode

In AE Mode, INT2 is asserted when data is available.

OIS LL Mode

In this mode, the gyroscope operates in a high data rate Optical Image Stability (OIS) mode with Low Latency (LL). Data is transmitted through the SPI interface at 8.1 kHz. The SPI bus can be operated using a 3-wire or 4-wire interface by setting the CTRL1 SIM bit. Data is clocked out on the rising edge of INT2. The accelerometer may be used in this mode with a 1 kHz ODR.

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6 Operating Modes

The FIS1100 offers a large number of operating modes that may be used to operate the device in a power efficient manner. These modes are described in Table 32 and are shown in Figure 8; they may be configured using the control (CTRL) registers.

Table 32. Operating Modes

Mode	Description	Suggested Configuration
Sensor Modes		
Power-On Default	All sensors off, clock is turned on. The current in this mode is typically 15 µA. Note this mode is the default state upon initial power up or after a reset.	CTRL1 sensorDisable = 0 CTRL7 aEN = 0, gEN = 0, mEN = 0, sEN=0. CTRL2 aODR=000
Low Power	Same as Power-On Default mode, except in this mode the 125 kHz clock is turned on instead of the 1 MHz clock. The current in this mode is typically 5 µA. To enter this mode requires host interaction to set CTRL2 aODR=1xxx.	CTRL1 sensorDisable =0 CTRL7 aEN = 0, gEN = 0, mEN = 0, sEN=0. CTRL2 aODR=1xx
Power-Down	All FIS1100 functional blocks are switched off to minimize power consumption. Digital interfaces remain on allowing communication with the device. All configuration register values are preserved and output data register values are maintained. The current in this mode is typically 2 µA. Host must initiate this mode by setting sensorDisable=1	CTRL1 sensorDisable =1 CTRL7 aEN = 0, gEN = 0, mEN = 0, sEN=0. CTRL2 aODR=xxx
Accel Only	Device configured as an accelerometer only.	CTRL7 aEN =1, gEN =0, mEN =0 CTRL2 aODR=0xx
Low Power Accel Only	Device configured in low power accelerometer mode	CTRL7 aEN =1, gEN =0, mEN =0 CTRL2 aODR=1xx
Gyro Only	Device configured as a gyroscope only.	CTRL7 aEN =0, gEN =1, mEN =0 CTRL2 aODR=000
Mag Only	Device configured as a magnetometer only.	CTRL7 aEN =0, gEN =0, mEN =1 CTRL2 aODR=000
Accel + Mag	Device configured as an accelerometer and magnetometer combination only. Device can be used as a (stabilized) compass.	CTRL7 aEN =1, gEN =0, mEN =1 CTRL2 aODR=0xx
Accel + Gyro (IMU)	Device configured as an Inertial Measurement Unit, i.e. an accelerometer and gyroscope combination sensor.	CTRL7 aEN =1, gEN =1, mEN =0 CTRL2 aODR=0xx
Accel + Gyro + Mag (9DOF)	Accelerometer and gyroscope are enabled and combined with an external magnetometer and the device can be used as a 9D orientation sensor (Attitude and Heading Reference).	CTRL7 aEN =1, gEN =1, mEN =1 CTRL2 aODR=0xx
Wake on Motion (WoM)	Very low power mode used to wake-up the host by providing an interrupt upon detection of device motion. WoM Mode enabled - see CTRL_CMD_WRITE_WOM_SETTING in Section 5.7.5 and see Section 8, Wake On Motion (WoM)	CTRL7 aEN =1, gEN =0, mEN =0 CTRL2 aODR = 111
Gyro Warm Start	This mode turns on the gyroscope drive and shuts off the sense path of the gyroscope. This mode can be used as a low-power mode to quickly turn on the gyroscope without needing to wake-up the gyroscope from the Power On Default state (see Figure 8 and Section 6.2).	CTRL3 gODR = 100 CTRL2 aODR = 0xx

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Table 32 Operating Modes (Continued)

Mode	Description	Suggested Configuration
Sensor Modes		
OIS	In this mode, the gyroscope operates in a high data rate Optical Image Stability (OIS) mode. Data is transmitted through the SPI interface at 8.1 kHz. The SPI bus can be operated using a 3-wire or 4-wire interface by setting the CTRL1 SIM bit. Data is clocked out on the falling edge of INT1. The accelerometer is not available in this mode.	CTRL3 gODR = 110 CTRL2 aODR = 0xx
OIS LL	In this mode, the gyroscope operates in a high data rate Optical Image Stability (OIS) mode with Low Latency. Data is transmitted through the SPI interface at 8.1 kHz. The SPI bus can be operated using a 3-wire or 4-wire interface by setting the CTRL1 SIM bit. Data is clocked out on the rising edge of INT2. The accelerometer may be used in this mode with a 1kHz ODR.	CTRL3 gODR = 111 CTRL2 aODR = 000
Hardware Reset	RST pin asserted	
No Power	VDDd and VDDa low	
Attitude Engine Modes		
6DOF AttitudeEngine Mode	Attitude Engine Mode with Accel and Gyro. Note that velocity increments and orientation (quaternion) increments will be output rather than sensor values	CTRL7 aEN = 1, gEN = 1, sEN = 1 CTRL2 aODR=0xx
9DOF AttitudeEngine Mode	AttitudeEngine Mode with Accel, Gyro, and Mag. Note that velocity increments, orientation (quaternion) increments and magnetic field values will be output rather than sensor values	CTRL7 aEN = 1, gEN = 1, sEN = 1, mEN = 1 CTRL4 (configure magnetometer as needed)
Motion On Demand Mode	This mode allows Host to sample AttitudeEngine data asynchronously by polling	CTRL7 aEN = 1, gEN = 1, sEN = 1 CTRL6 sMOD = 1

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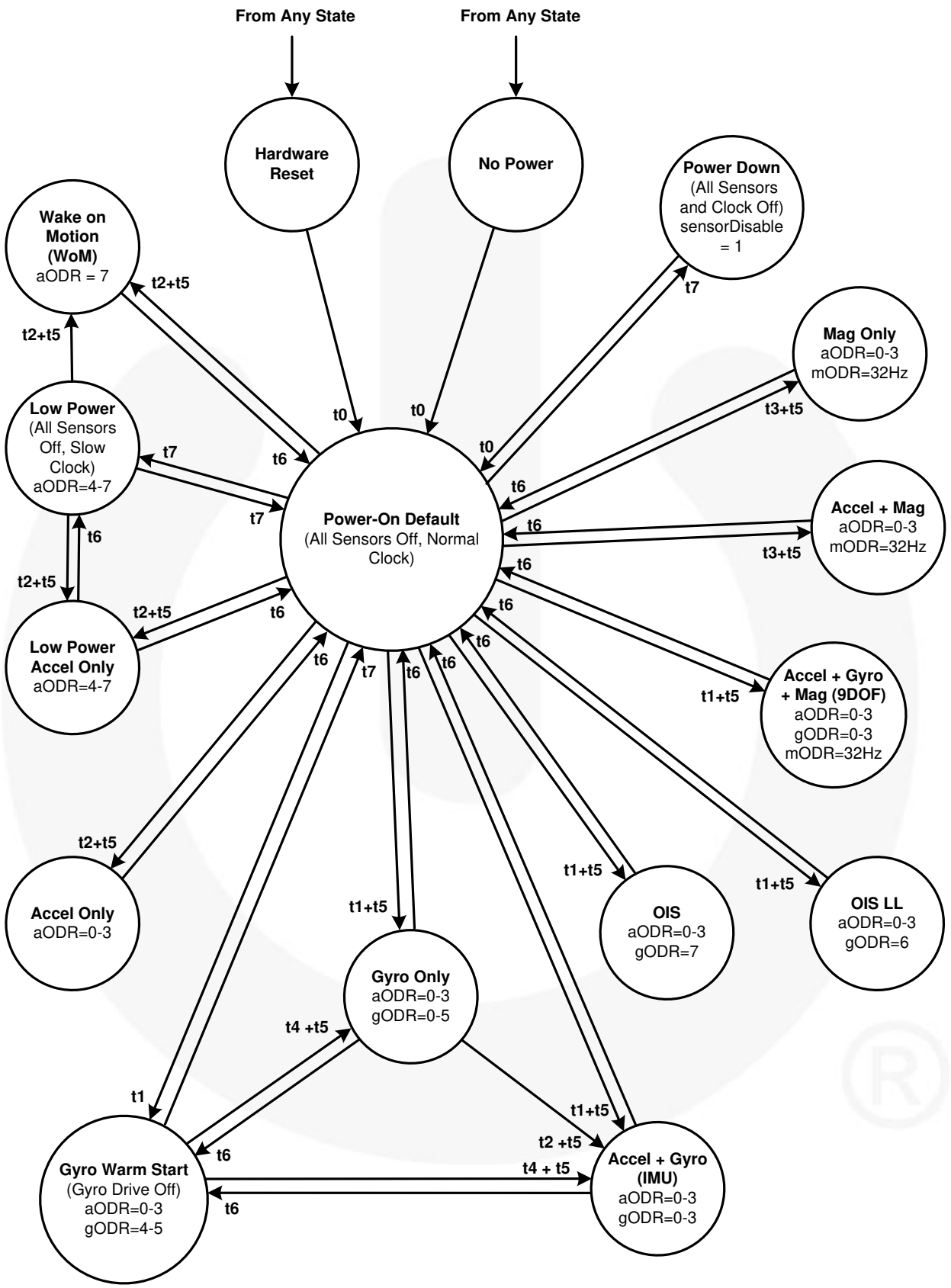


Figure 8. Operating Mode Transition Diagram

6.1 General Mode Transitioning

Upon exiting the No Power state (i.e. on first applying power to the part) or exiting a Hardware Reset state, the part will enter the Power-On Default state. From there, the sensor can be configured in the various modes described in Table 32 and as shown in Figure 8. The figure illustrates the timing associated with various mode transitions, and values for these times are given in the section below and in Table 7 and Table 8.

6.2 Transition Times

The time it takes for data to be present after a mode switch will vary and depends on which mode has been selected. For example, the time it takes for retrieving data from the accelerometer after a mode switch is less than any mode that involves the gyroscope. The times t1, t2, t3 and t4, are defined as the time it takes from INT2 going high to data being present. The time, t5 is the time it takes to have a correct representation of the inertial state. t5 is variable and is associated with the user selected Output Data Rate (ODR). We have defined t5 = (3/ODR) to generally represent that time.

t6 is the time it takes to go from a sensor powered state to a state where the sensors are off. This time depends on the Output Data Rate (ODR) and ranges from 1/ODR to 2/ODR.

t7 is the transition time between various states where the sensors are off.

t0 is the *System Turn On Time*, and is the time to enter the Power-On Default state from Hardware Reset, No Power, or Power down.

- Time t0 is the *System Turn on Time* and is 1.75 seconds. This time only needs to be done once, upon transitioning from either a No Power or Power Down state, or whenever a RST (reset) is issued, which should not be done unless the intent is to have the device to go through its entire boot sequence (see the specification *System Turn On Time* in both Table 7 and Table 8).
- The *Gyro Turn on Time* (see Table 8) is comprised of t1 (the gyroscope wakeup time) and t5 (the part's filter settling time). t1 is typically 60 ms and t5 is defined as 3/ODR, where ODR is the output data rate in Hertz.
- The *Accel Turn on Time* (see Table 7) is comprised of t2 (the accel wakeup time) and t5 (the part's filter settling time). t2 is typically 3 ms, and t5 is defined as 3/ODR, where ODR is the output data rate in Hertz.
- Time t3 is the magnetometer wakeup time, which is typically 12 ms. Transitioning from the Power-On Default state to a Mag Only state or a Mag + Accel state takes the time t3 + t5, where t5 is defined as 3/ODR, where ODR is the output data rate in Hertz.
- The *Gyro Warm Start Turn On Time* (see Table 8) is comprised of t4 (the gyroscope wakeup time from warm-start) and t5 (the part's filter settling time). T4 is typically 5 ms, and t5 is defined as 3/ODR, where ODR is the output data rate in Hertz.
- The t7 transition is dependent on data transfer rates and is for I2C at 400 kHz is <100 µs for SPI at 11 Mbps is around 40 µs.

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7 FIFO Description

7.1 Using the FIFO

The FIS1100 contains a programmable 1536 byte data buffer which can be used as a FIFO buffer. The FIFO's operating mode and configuration are set via the FIFO_CTRL register. FIFO data may consist of gyroscope, accelerometer and magnetometer data and is accessible via the serial interfaces. The FIFO also supports burst reads. The host must complete its burst read prior to the next sensor data period. This time period is defined by the ODR selected. Depending on how many sensors are enabled, the host will need to read increments of 6, 12 or 18 bytes, corresponding to one, two and three sensors active at the same time. This feature helps reduce overall system power consumption by enabling the host processor to read and process the sensor data in bursts and then enter a low-power mode. The interrupt function may be used to alert when new data is available.

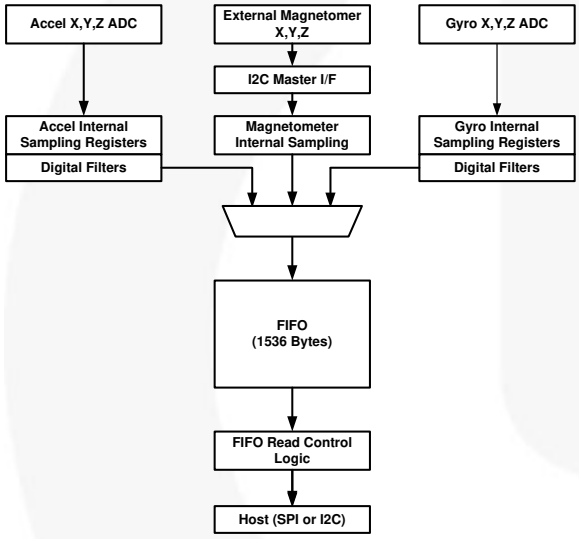


Figure 9. FIFO Data Flow

The FIFO size is configured using the FIFO_CTRL register. When the FIFO is enabled for two or more sensors, as is true for all modes that have multiple sensors active, the sensors must be set at the same Output Data Rate (ODR).

The FIFO is read through the I2C/SPI interface by reading the FIFO_DATA register. Any time the Output Registers are read, data is erased from the FIFO memory.

The FIFO has multiple operating modes: Bypass, FIFO, and Streaming. The operating modes are set using the mode<1:0> bits in the FIFO_CTRL register.

Enabling FIFO

The FIFO is configured by writing to the FIFO_CTRL register and is enabled after the accelerometer and/or gyroscope are enabled. If the watermark function is enabled in the FIFO_CTRL register, pin INT2 is asserted when the FIFO watermark level is reached.

Reading Sensor Data from FIFO

Sensor data is read from the FIFO through the following command sequence. (For additional information, see the Section 5.7.1 for CTRL9 description).

- Request access to FIFO data buffer by sending CTRL9 command 0x0D.
- Set FIFO_rd_mode bit to 1 in FIFO_CTRL.
- Read FIFO_DATA register to empty the FIFO.
- After FIFO is emptied, set FIFO_rd_mode bit to 0.

Note that when only the accelerometer or gyroscope is enabled, the sensor data format at the host interface is:

AX_L[0] →AX_H[0]] →AY_L[0] →AY_H[0] →AZ_L [0] →AZ_H[0] →AX_L[1] →…

When 2 sensors are enabled, the sensor data format is:

AX_L[0] →AX_H[0] →AY_L[0] →AY_H[0] →

AZ_L[0] →AZ_H[0] →GX_L[0] →GX_H[0] →

GY_L[0] →GY_H[0] →GZ_L[0] →GZ_H[0] →

AX_L[1] →AX_H[1] →…

When 3 sensors are enabled, the sequence will be extended to include the 6 corresponding magnetometer samples.

Bypass Mode

In Bypass mode (set in FIFO_CTRL), the FIFO is not operational and, therefore, remains empty. Sampled data from the gyroscope and/or Accelerometer are stored directly in the Sensor Data Output Registers (see Table 28). When new data is available, the old data is over-written.

FIFO Mode

In FIFO mode, data from the sensors are stored in the FIFO. The watermark interrupt, if enabled in FIFO_CTRL, is triggered when the FIFO is filled to the level specified by the value of wtm<1:0> in the FIFO_CTRL register. The FIFO continues filling until it is full. When full, the FIFO stops collecting data from the input channels. Data collection restarts when FIFO is emptied.

Streaming Mode

In Streaming mode (set in FIFO_CTRL), data from the gyroscope and accelerometer are stored in the FIFO. A watermark interrupt can be enabled and set as in FIFO mode. The FIFO continues filling until full. In this mode, the FIFO acts as a circular buffer, when full, the FIFO discards the older data as the new data arrives. Programmable watermark level events can be enabled to generate dedicated interrupts on the DRDY/INT2 pin (configured through the FIFO_CTRL register).

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7.2 FIFO Register Description

Table 33. FIFO Registers Description

Register Name			
FIFO_CTRL		**Configure FIFO. Register Address: 19 (0x13)**	
Bits	**Name**	**Default**	**Description**
7	FIFO_rd_mode	1'b0	0: Disable FIFO read via FIFO_DATA register. 1: Enable FIFO read via FIFO_DATA register.
6	Reserved	1'b0	Reserved
5:4	wtm<1:0>	2'b0	Set Watermark level. 00 – Do not use. 01 – Set watermark at ¼ of FIFO size. 10 – Set watermark at ½ of FIFO size. 11 – Set watermark at ¾ of FIFO size.
3:2	size<1:0>	2'b0	Set FIFO size. (See Table 34 for more details.) 00 – Set FIFO size at 16 samples for each enabled sensor 01 – Set FIFO size at 32 samples for each enabled sensor 10 – Set FIFO size at 64 samples for each enabled sensor 11 – Set FIFO size at 128 samples for each enabled sensor (up to 2 sensors enabled only)
1:0	mode<1:0>	1'b0	Set FIFO Mode. 00 – Bypass (FIFO disable). 01 – FIFO. 10 – Streaming. 11 – Not Used
FIFO_DATA		**FIFO Data Register. Register Address: 20 (0x14)**	
Bits	**Name**	**Default**	**Description**
7:0	data<7:0>	8'b0	Read this register to read sensor data out of FIFO.
FIFO_STATUS		**FIFO Status. Register Address: 21 (0x15)**	
Bits	**Name**	**Default**	**Description**
7	resv	1'b0	Reserved
6	wtm	1'b0	Watermark level hit.
5	overflow	1'b0	FIFO over-flow condition.
4	not_empty	1'b0	FIFO not empty.
3:0	fss<3:0>	4'b0	Indicates FIFO storage level. For more information, see Table 34

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Table 34. FIFO Storage Level Indicator fss<3:0> Description

fss<3:0> Description		Comments	
		The FIFO storage level is indicated by the bits fss<3:0> in the FIFO_STATUS register. The value of fss<3:0> represents a coarse value of the FIFO storage level. The coarseness or granularity varies based on the TOTAL FIFO size, as set by the bits size<1:0> in the FIFO_CTRL register. Total FIFO size is the sum of the Accelerometer, Gyroscope and Magnetometer FIFO samples. Each sample for each sensor uses 6 bytes in the FIFO (2 bytes per axis x 3 axes). For example, with 2 sensors active and the bits size<1:0> = [11], the FIFO size is 256 samples (=2x128), which in bytes is 1536 bytes (=6*2*128). In the table below, the Total FIFO Size lists the total number of sensor samples. Note that this value varies based upon the number of sensors enabled and upon the bits size<1:0> in the FIFO CTRL register . The value of the bits fss<3:0> in the FIFO_STATUS register, represents a coarse sample count, whose granularity is given by the number of sensor samples per LSB, as shown below.	
FIFO_CTRL register, bits size<1:0>	**No. of Sensors Enabled (A, G, or M)**	**Total FIFO Size (Total Number of Samples)**	**fss<3:0> Granularity (Number of Sensor Samples per LSB)**
00	1	16	2
01	1	32	4
00	2		
00	3	48	4
10	1	64	8
01	2		
01	3	96	8
11	1	128	16
10	2		
10	3	192	16
11	2	256	32

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8 Wake On Motion (WoM)

8.1 Wake on Motion Introduction

The purpose of the Wake on Motion (WoM) functionality is to allow a system to enter a low power sleep state while the system is static and then to automatically awaken when moved. In this mode the system should use very little power, yet still respond quickly to motion.

It is assumed that the system host processor is responsible for configuring the FIS1100 correctly to place it into Wake on Motion mode, and that the system host processor will reconfigure the FIS1100 as necessary following a WoM interrupt.

Wake on Motion is configured through the CTRL9 command interface (see write-up for CTRL_CMD_WRITE_WOM_SETTING in Section 5.7.5 CTRL9 Commands in Detail).

Table 35. Registers used for WoM

Register (bits)	Function
CAL1_L (0:7)	WoM Threshold: absolute value in mg (with 1mg/LSB resolution) 0x00 must be used to indicate that WoM mode is disabled
CAL1_H (7;6)	WoM interrupt select 01 – INT2 (with initial value 0) 11 – INT2 (with initial value 1) 00 – INT1 (with initial value 0) 10 - INT2 (with initial value 1)
CAL1_H (0:5)	Interrupt blanking time (in number of accelerometer samples)

The threshold value is configurable to make the amount of motion required to wake the device controllable by the host application. The special threshold value of 0x00 can be used to disable the WoM mode, returning the interrupt pins to their normal functionality.

The interrupt initial value (1 or 0) and the interrupt pin used for signaling (INT1 or INT2) are selectable to make it easy for system integrators to use the WoM motion mode to wake the host processor from its deepest sleep level. Using the lowest power mode on many microcontrollers requires the use of special wake up pins that may have only a single polarity setting, and thus may not be useable for other special purposes such as timer captures.

The interrupt blanking time is a programmable number of accelerometer samples to ignore when starting WoM mode so that no spurious wake-up events are generated by startup transients.

8.2 Accelerometer Configuration

For additional tuning of the WoM responsiveness, the precise configuration of the accelerometer is left to the host. This gives the host processor the ability to program the desired sample rate and full-scale range.

8.3 Wake on Motion Event

When a Wake on Motion event is detected the FIS1100 will set bit 2 (WoM) in the STATUS1 register. Reading STATUS1 by the host will clear the WoM bit and will reset the chosen interrupt line (INT1 or INT2, see previous section) to the value given by the WoM interrupt initial value (see previous section).

For each WoM event, the state of the selected interrupt line is toggled. This ensures that while the system is moved, the host processor will receive wakeup interrupts regardless of whether it uses high, low, positive- or negative-edge interrupts.

The FIS1100 stays in WoM mode until commanded to enter a new mode by the host processor.

8.4 Configuration Procedure

The host processor is responsible for all configurations necessary to put the FIS1100 into WoM mode. The specific sequence of operations performed by the host processor to enable WoM is shown in Figure 10.

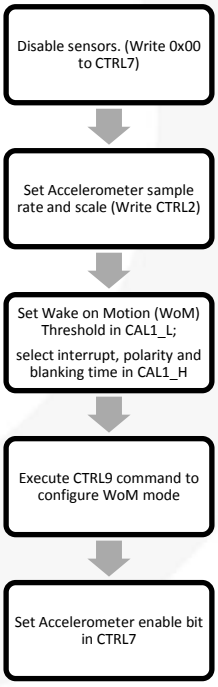


Figure 10. WoM Configuration Commands and Sequence

The WoM bit is cleared upon setting the WoM threshold to a non-zero value, and the selected interrupt pin is configured according to the settings. Special care has been taken that the WoM interrupt does not activate due to any transients when the accelerometer is first enabled. An interrupt blanking time is included that prevents such spurious interrupts to propagate.

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8.5 Wake on Motion Control Registers

The WoM configuration is controlled by values written to the CAL1_x registers, as shown in Table 35.

8.6 Exiting Wake on Motion Mode

To exit WoM mode the host processor must first clear CTRL7 to disable all sensors, and then write a threshold value of 0x0 for the WoM Threshold (see Table 35, Registers used for WoM)and execute the WoM configuration CTRL9 command (see write-up for CTRL_CMD_WRITE_WOM_SETTING in Section 5.7.5 CTRL9 Commands in Detail). On doing this the interrupt pins will return to their normal function. After zeroing the WoM Threshold the host processor may proceed to reconfigure the FIS1100 as normal, as in the case following a reset event.

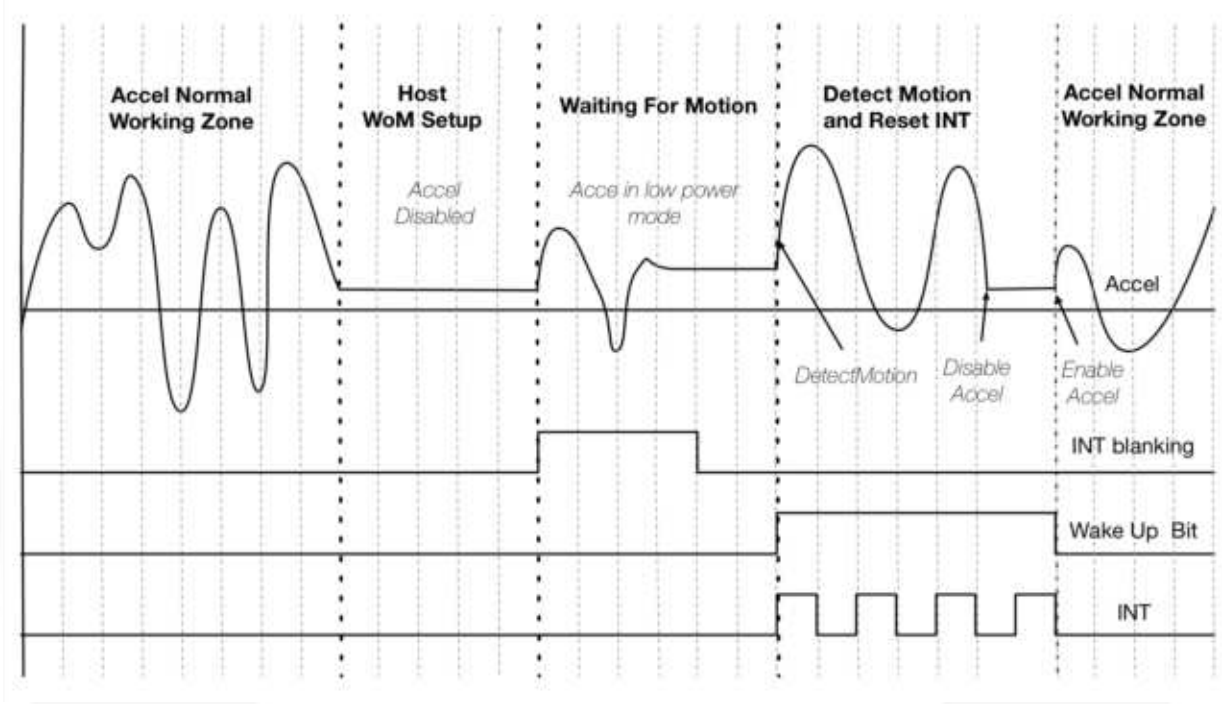


Figure 11. WoM Example Diagram

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9 Performing Device Self Test

9.1 Accelerometer Self Test

The accelerometer Self Test is used to determine if the accelerometer is functional and working within acceptable parameters. It does this by using an electrostatic force to actuate the inputs of each axis, AX, AY, and AZ. If the accelerometer mechanical structure responds to this input stimulus by sensing 50 mg or greater we can conclude that the accelerometer is functional. The accelerometer Self Test data is available to be read at registers dVX_L, dVX_H, dVY_L, dVY_H, dVZ_L and dVZ_H. The Host can initiate the Self Test at anytime by using the following procedure.

Procedure for accelerometer Self Test:

1. Set CTRL7 register to 0x00.
2. Wait 1 msec.
3. Set CTRL2 register to 0x10 (aFS =2, aODR= 0).
4. Wait 1 msec .
5. Set CTRL2 register to 0x30. This enables aST (accelerometer Self Test enable bit).
6. Wait for the device to drive INT2 high.
7. Read DVX_L, DVX_H, DVY_ L, DVY_H, DVZ_L & DVZ_H registers for the Self Test data.
8. Set CTRL2 register to 0x10 to disable aST.
9. INT2 will be pulled low by the FIS1100.
10. Set CTRL2 register to 0x00 (back to default value at power up)
11. Based on the data the host processor determines if the accelerometer response is greater or equal to 50 mg.
12. If “yes”, then the accelerometer Self Test has passed.

9.2 Gyroscope Self Test

The gyroscope Self Test is used to determine if the gyroscope is functional and working within acceptable parameters. It does this by applying an electrostatic force to actuate each of the three X, Y, and Z axis of the gyroscope and measures the mechanical response on the corresponding X, Y, and Z axis. If the equivalent magnitude of the output is greater than 300 dps for each axis then we can assume that the gyroscope is functional within acceptable parameters. The gyroscope Self Test data is available to be read at output registers dVX_L, dVX_H, dVY_L, dVY_H, dVZ_L & dVZ_H.

The Host can initiate the self test at anytime by using the following procedure.

Procedure for gyroscope Self Test:

1. Set CTRL7 reg. to 0x00;
2. Wait 1 msec
3. Set CTRL3 to 0x38 (gFS = 7, gODR= 0) (full scale = 4096 dps)
4. Wait 1 msec
5. Set CTRL3 register to 0x78. This enables gST (gyroscope Self Test enable bit).
6. Wait for the device to drive INT2 high.
7. Read DVX_L, DVX_H, DVY_ L, DVY_H, DVZ_L & DVZ_H registers for the self test Data.
8. Set CTRL3 register to 0x38 to disable gST.
9. INT2 will be pulled low by device.
10. Set CTRL3 register to 0x00 (back to default value at power up)
11. Based on the data the host processor determines if the gyroscope response is greater or equal to 300 dps.
12. If “yes” then the gyroscope Self Test has passed.

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10 Magnetometer Setup

10.1 Magnetometer Description

The FIS1100 provides an I^2C master interface to connect with an external magnetometer. Currently the FIS1100 offers support for an AKM AK8975 magnetometer *(see Figure 3)*. The FIS1100 supports the AK8975 in the 31.25 Hz Output Data Rate (ODR) mode only.

The FIS1100 is used to:

1. Calibrate the magnetometer data as per the equations described below and to time align magnetometer samples with the gyroscope and accelerometer samples.
2. When FIS1100 is used in the AttitudeEngine (AE) mode the magnetometer data along with the accelerometer and gyroscope data is fused to generate the AE data and is available to the host at a significantly reduced ODR without loss of accuracy.

10.2 Magnetometer Calibration

The raw data from the magnetometer is calibrated as per the follow equations. Values for the different S, K, O, and R variables are provided in the FIS1100 SDK sample code.

$$M_x = S_{TG}(S_xM_{xr} + O_x + K_{xy}M_{yr} + K_{xz}M_{zr})$$

$$M_y = S_{TG}(S_yM_{yr} + O_y + K_{yx}M_{xr} + K_{yz}M_{zr})$$

$$M_z = S_{TG}(S_zM_{zr} + O_z + K_{zx}M_{xr} + K_{zy}M_{yr})$$

where
M_{xr}, M_{yr}, M_{zr} are the available uncalibrated (raw) magnetometer values from AK8975.

M_x, M_y, M_z are the calibrated values available in the magnetometer output register.

S_x ,S_y, S_z are the scale factors
O_x,O_y, O_z are the offsets
K_{xy}, K_{xz}, y and z cross axis scale factor for M_x
K_{yx}, K_{yz}, x and z cross axis scale factor for M_y
K_{zx}, K_{zy}, x and y cross axis scale factor for M_z

S_{TG} is a conversion factor to convert from micro-Tesla format to Gauss format. S_{TG} = 1.536

The S, O, and K values are provided by the user as the SKOR values

SKOR_X -> {Sx, Ox, Kxy, Kxz}
SKOR_Y -> {Sy, Oy, Kyx, Kyz}
SKOR_Z -> {Sz, Oz, Kzx, Kzy}

Table 36. **Magnetometer Scale and Sensitivity Settings**

SKOR	Scale Setting	Sensitivity	Unit
Scale	+8	8192	lsb/unit
Offset	±16	2048	lsb/unit
Skew1	±4	8192	lsb/unit
Skew2	±4	8192	lsb/unit

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11 Host Serial Interface

FIS1100 Host Serial Interface supports I2C and SPI slave interfaces. For SPI, it supports both 3-wire and 4-wire modes. The basic timing characteristics for each interface are described below. Through the FIS1100 Host Serial Interface, the host can access, setup and control the FIS1100 Configuration Registers *(see Table 25).*

11.1 Serial Peripheral Interface (SPI)

FIS1100 supports both 3- and 4-wire modes in the SPI slave interface. The SPI 4-wire mode uses two control lines (CS, SPC) and two data lines (SDI, SDO). The SPI 3-wire mode uses the same control lines and one bi-directional data line (SDIO). The SDI /SDIO pin is used for both 3- and 4-wire modes and is configured based on the mode selected. The SPI interface has been validated at 10 MHz and the timing parameters are measured at that interface frequency.

SPI 3- or 4-wire modes are configured by writing to bit-7 of CTRL1 register. 3-wire mode is selected when bit-7 is 1. The default configuration is 4-wire mode, i.e. bit-7 of CTRL1 is 0.

Figure 12 shows the SPI address and data formats.

SPI Features

- Data is latched on the rising edge of the clock
- Data should change on falling edge of clock
- Maximum frequency is 10 MHz
- Data is delivered MSB first
- Support single read/writes and multi cycle (Burst) read/writes***. NOTE:*** *burst writes to Configuration registers are NOT supported. These registers should be written in single cycle mode only.*
- Supports 6-bit Address format and 8-bit data format

Address Format

MSB							LSB
read	inc	A5	A4	A3	A2	A1	A0

read — indicates a read(1) or a write(0) transaction relative to the SPI master

inc — data from consecutive incremental address(1) during burst read/write cycles

Data Format

MSB							LSB
D7	D6	D5	D4	D3	D2	D1	D0

Figure 12. SPI Address and Data Form

In a single cycle read or write transaction, the inc address bit should be set to 0. During a burst read, the master indicates to the slave that the master expects data from the incremented address locations during a read by setting inc to 1. During a burst write, if the inc bit is set to 1, the master indicates to the slave that it is providing data from incremented address locations. Similarly, when the inc bit is set to 0, the master indicates that data is expected from or is available from the same address respectively during a burst read or write cycle.

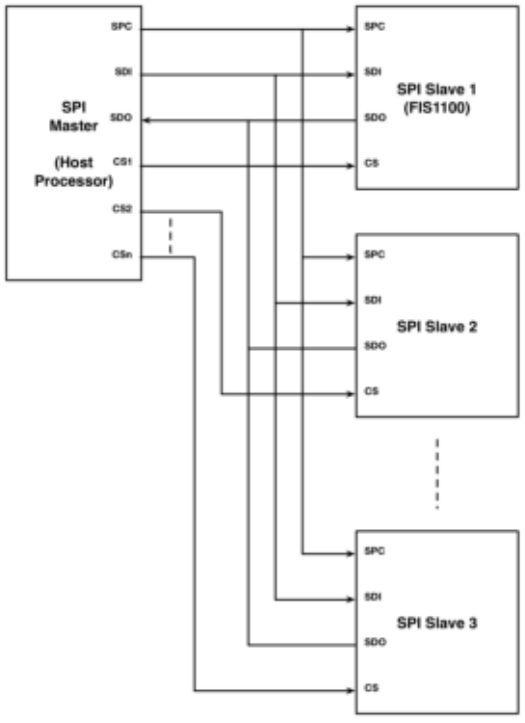


Figure 13. Typical SPI 4-Wire Multi-Slave

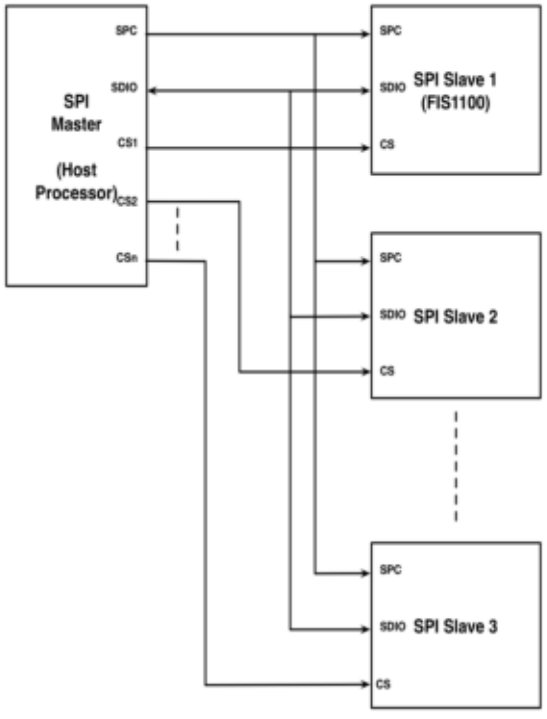


Figure 14. Typical SPI 3-Wire Multi-Slave

In a typical SPI Master/Slave configuration the SPI master shares the SPI clock (SPC), the serial data input (SDI), and the Serial Data Output (SDO) with all the connected SPI slaves devices. Unique Chip Select (CS) lines connect each SPI slave to the master.

Figure 13 and Figure 14 show typical multi-slave 4- and 3-wire configurations. The primary difference between the two configurations is that the SDI and SDO lines are replaced by the bi-directional SDIO line. The SDIO line is driven by the master with both address and data when it is configured for write mode. During read mode, the SDIO line is driven by the master with the address, and subsequently driven by the "addressed" slave with data.

Figure 15 and Figure 16 illustrate the waveforms for both 4-wire and 3-wire SPI read and write transactions. Note that CS is active during the entire transaction.

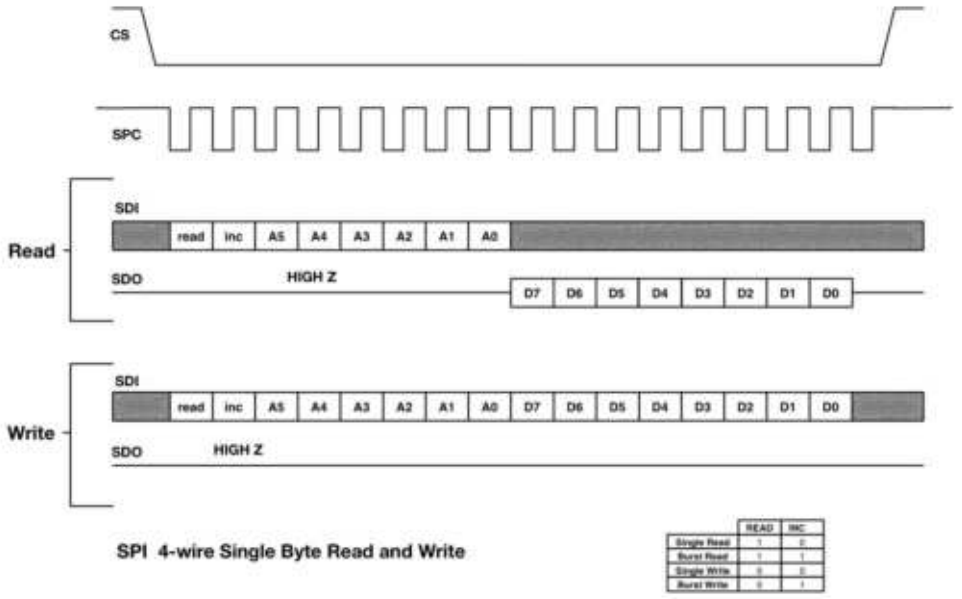


Figure 15. SPI 4-Wire Single Byte Read and Write

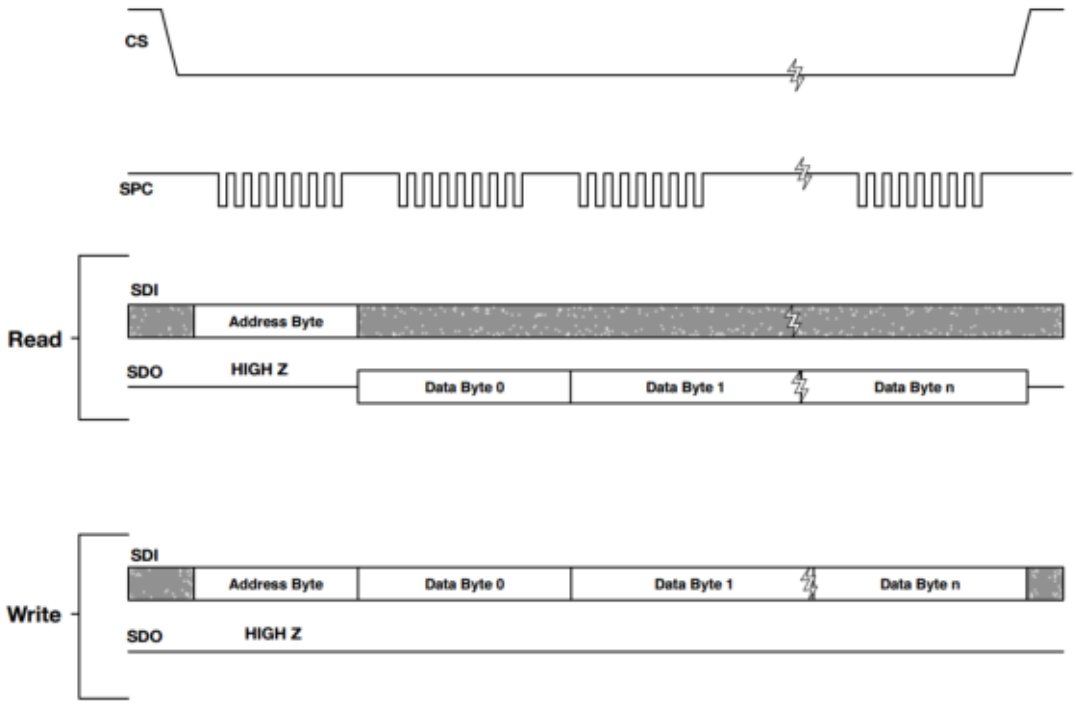
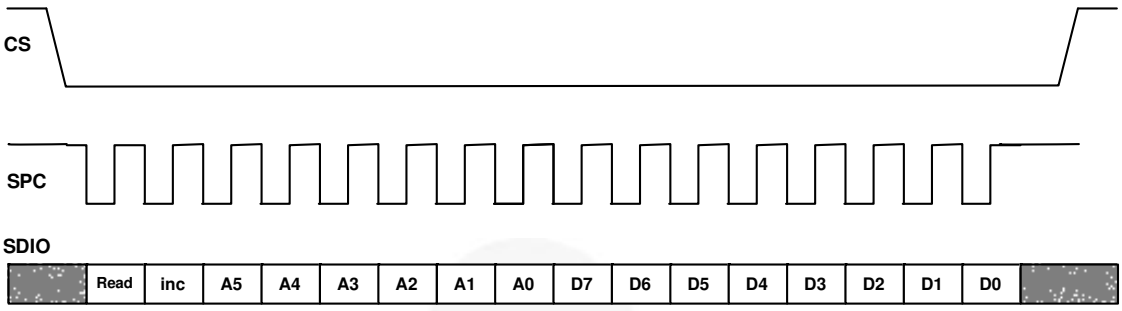


Figure 16. SPI 4-Wire Multi-Byte Read and Write Transactions

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SPI 3-wire Single Byte Read and Write

	READ	INC
Single Read	1	0
Burst Read	1	1
Single Write	0	0
Burst Write	0	1

Figure 17. SPI 3-Wire Single Byte Read and Write Transactions

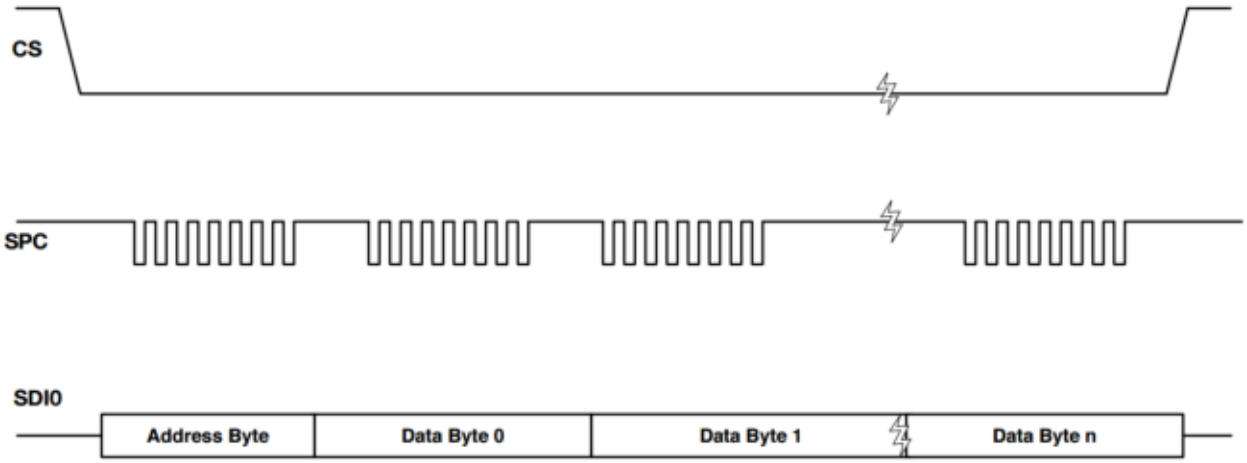


Figure 18. SPI 3-Wire Multi-Byte Read and Write Transactions

11.1.1 SPI Timing Characteristics

The typical operating conditions for the SPI interface are provided in Table 37

V_{DDd} = 1.8 V, T = 25°C unless otherwise noted.

Table 37. SPI Interface Timing Characteristics

Symbol	Parameter	Min.	Max.	Unit
t_{SPC}	SPI Clock Cycle	100		ns
f_{SPC}	SPI Clock Frequency		10	MHz
ts_{CS}	CS Setup Time	6		ns
th_{CS}	CS Hold Time	8		ns
ts_{SDI}	SDI Input Setup Time	5		ns
th_{SDI}	SDI Input Hold Time	15		ns
tv_{SDO}	SDO Time for Valid Output		50	ns
th_{SDO}	SDO Hold Time for Output	9		ns
td_{SDO}	SDO Disable Time for Output		50	ns
ts_{SDIO}	SDIO Address Setup Time	5		ns
th_{SDIO}	SDIO Address Hold Time	15		ns
tv_{SDIO}	SDIO Time for Valid Data		50	ns
tcz_{SDIO}	SDIO Time from SPC to High Z		50	ns
tz_{SDIO}	SDIO Time from CS to High Z		50	ns

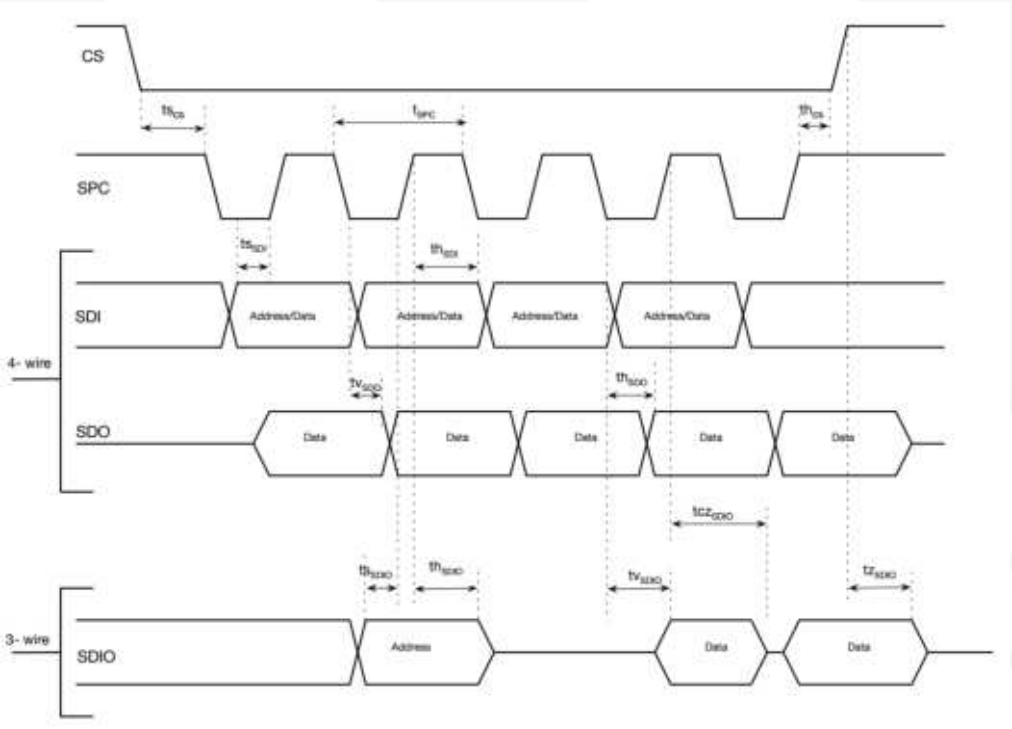


Figure 19. Timing Characteristics for SPI 3- and 4-Wire Interfaces

11.2 I²C Interface

Table 38 provides the I²C interface timing characteristics while Figure 20 and Figure 21 illustrate the I²C timing for both fast and standard modes, respectively.

During the slave device selection phase, the I²C master supplies the 7-bit I²C slave device address to enable the FIS1100. The 7-bit device address for the FIS1100 is 0x6a (0b1101010) if SA0 is left unconnected, internally there is a weak pull-down of 200 kΩ thereby selecting bit-0=0. In case of a slave device ID conflict, SA0 may be used to change bit-0 of the device address. When SA0 is pulled up externally, the 7-bit device address becomes 0x6b (0b1101011).

During the slave register address phase bit-7 of the address is used to enable auto-increment of the target address. When bit-7 is set to 1 the target address is automatically incremented by one.

For additional technical details about the I²C standard, such as pull-up resistor sizing the user is referred to "UM10204 I²C-bus specification and user manual" published by NXP B.V.

Table 38. I2C Timing Characteristics

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
f_{SCL}	SCL Clock Frequency	Standard Mode			100	kHz
		Fast Mode			400	
t_{BUF}	Bus-Free Time between STOP and START Conditions	Standard Mode		4700		ns
		Fast Mode		1300		
$t_{HD;STA}$	START or Repeated START Hold Time	Standard Mode		4000		ns
		Fast Mode		600		
t_{LOW}	SCL LOW Period	Standard Mode		4700		ns
		Fast Mode		1300		
t_{HIGH}	SCL HIGH Period	Standard Mode		4000		ns
		Fast Mode		600		
$t_{SU;STA}$	Repeated START Setup Time	Standard Mode		4700		ns
		Fast Mode		600		
$t_{SU;DAT}$	Data Setup Time	Standard Mode		250		ns
		Fast Mode		100		
$t_{HD;DAT}$	Data Hold Time	Standard Mode	0		3450	ns
		Fast Mode	0		900	
t_{RCL}, t_R	SCL Rise Time	Standard Mode			1000	ns
		Fast Mode	$20 + 0.1 * C_B$[16]		300	
t_{FCL}	SCL Fall Time	Standard Mode			300	ns
		Fast Mode	$20 + 0.1 * C_B$[16]		300	
t_{RDA}, t_{RCL1}	SDA Rise Time. Rise Time of SCL after a Repeated START Condition and after ACK Bit	Standard Mode			1000	ns
		Fast Mode	$20 + 0.1 * C_B$[16]		300	
t_{FDA}	SDA Fall Time	Standard Mode			300	ns
		Fast Mode	$20 + 0.1 * C_B$[16]		300	
$t_{SU;STO}$	Stop Condition Setup Time	Standard Mode		4000		ns
		Fast Mode		600		

Note:

16. C_B is the bus capacitance.

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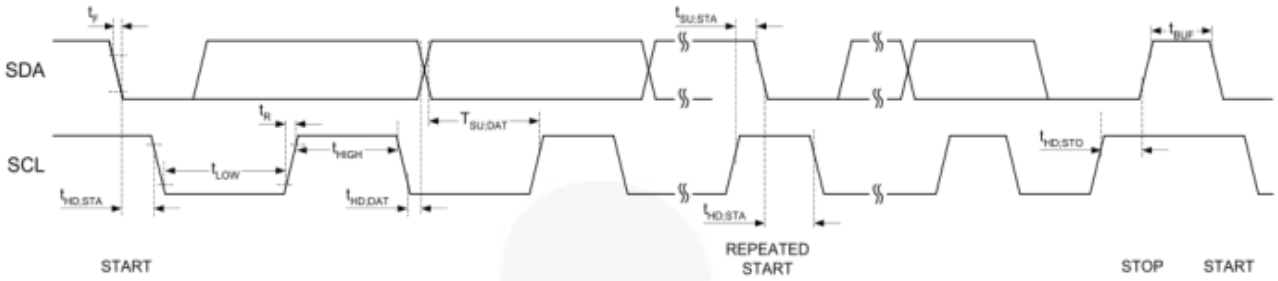
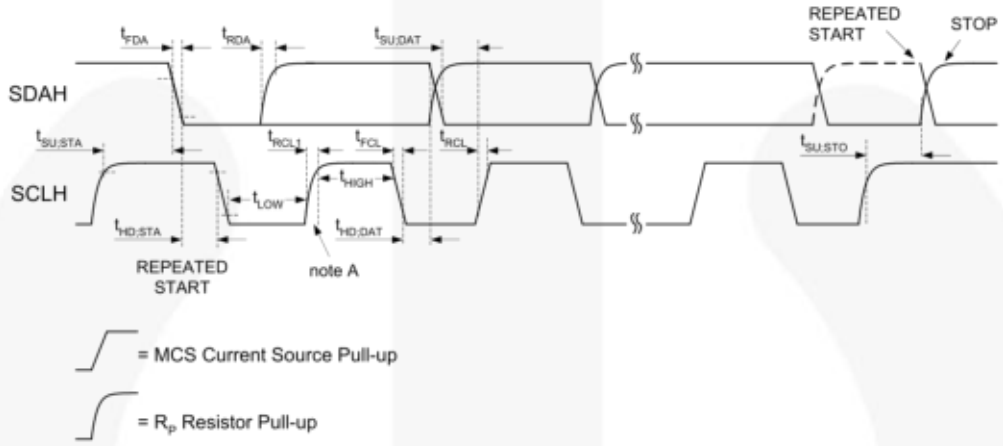


Figure 20. I²C Standard Mode Interface Timing

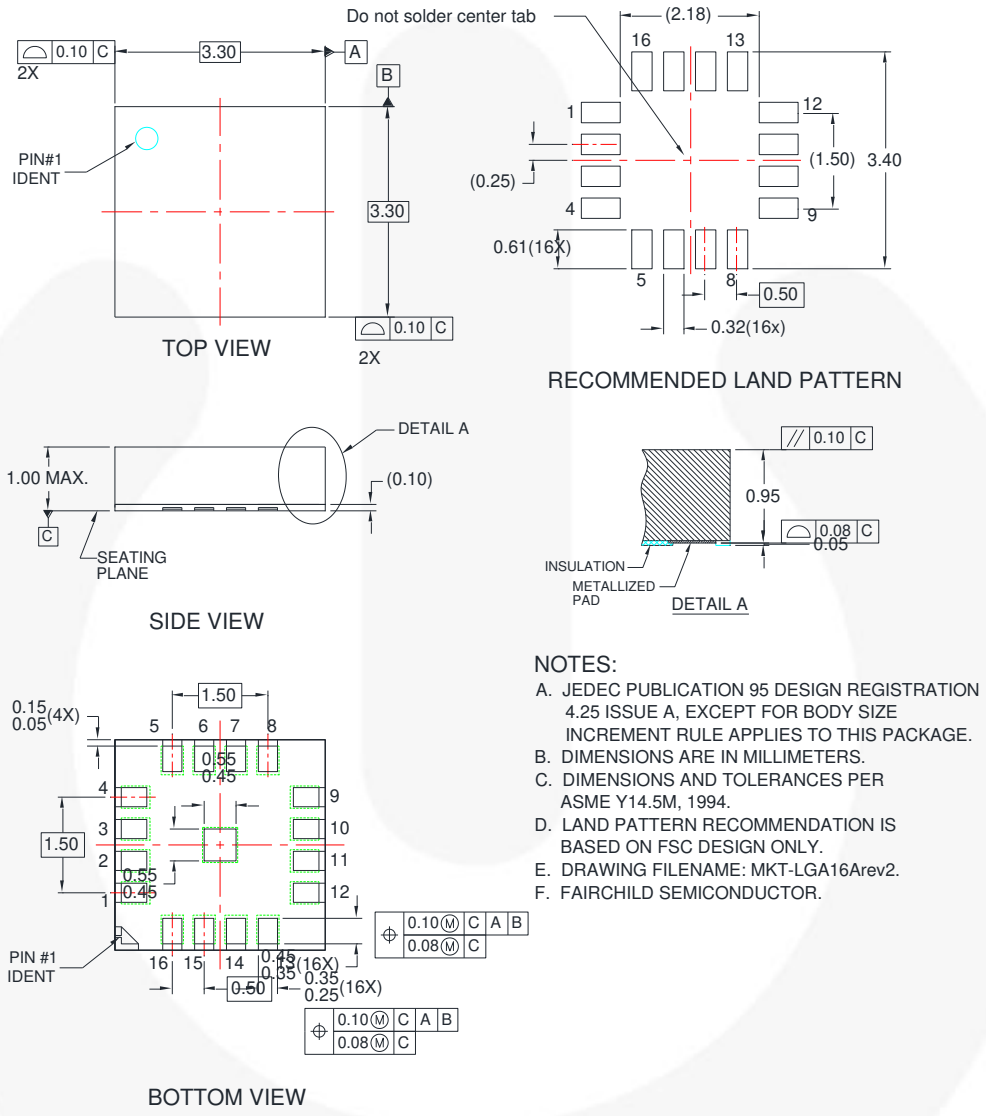


Note A: First rising edge of SCLH after Repeated Start and after each ACK bit.

Figure 21. I²C Fast Mode Interface Timing

12 Package and Handling

12.1 Package Drawing

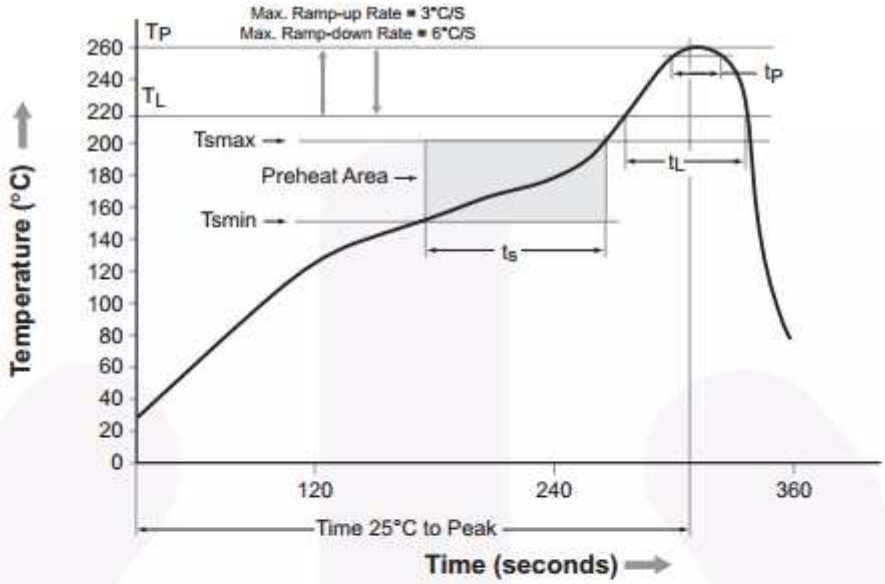


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Figure 22. 16 Pin LGA 3.3 x 3.3 x 1 mm Package

12.2 Reflow Specification



Profile Freature	Pb-Free Assembly Profile
Temperature Min. (Tsmin)	150°C
Temperature Max. (Tsmax)	200°C
Time (t_S) from (Tsmin to Tsmax)	60–120 seconds
Ramp-up Rate (t_L to t_P)	3°C/second max.
Liquidous Temperature (T_L)	217°C
Time (t_L) Maintained Above (T_L)	60–150 seconds
Peak Body Package Temperature	260°C +0°C / –5°C
Time (t_P) within 5°C of 260°C	30 seconds
Ramp-down Rate (T_P to T_L)	6°C/second max.
Time 25°C to Peak Temperature	8 minutes max.

Figure 23. Reflow Profile

12.3 Storage Specifications

FIS1100 storage specification conforms to IPC/JEDEC J-STD-020D.01 Moisture Sensitivity Level (MSL) 3. Floor life after opening the moisture-sealed bag is 168 hours with storage conditions: Temperature: ambient to ≤30°C and Relative Humidity: 60%RH.

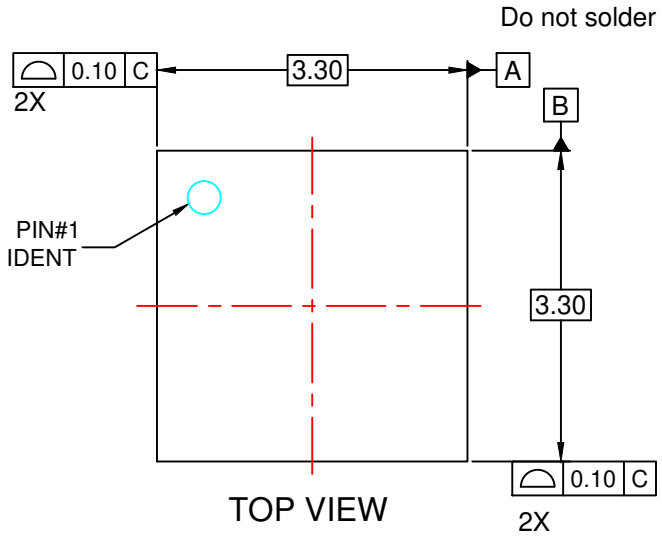
13 Related Resources

AN-5083 — Low Power Motion Co-Processor for High Accuracy Tracking Applications

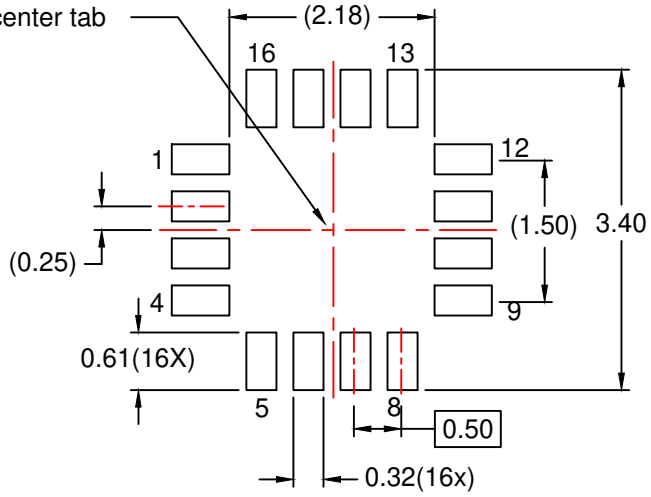
AN-5084 — XKF3 Low-Power, Optimal Estimation of 3D Orientation using Inertial and Magnetic Sensing

AN-5085 — FIS1100 Board Level Calibration

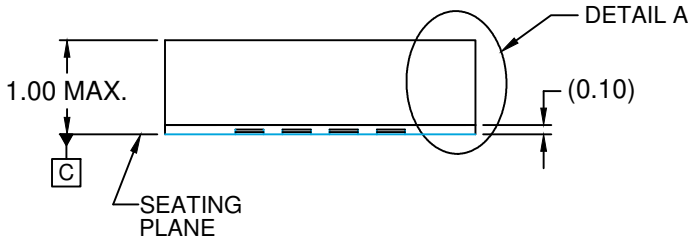
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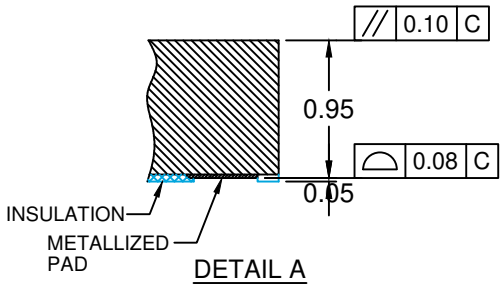
TOP VIEW

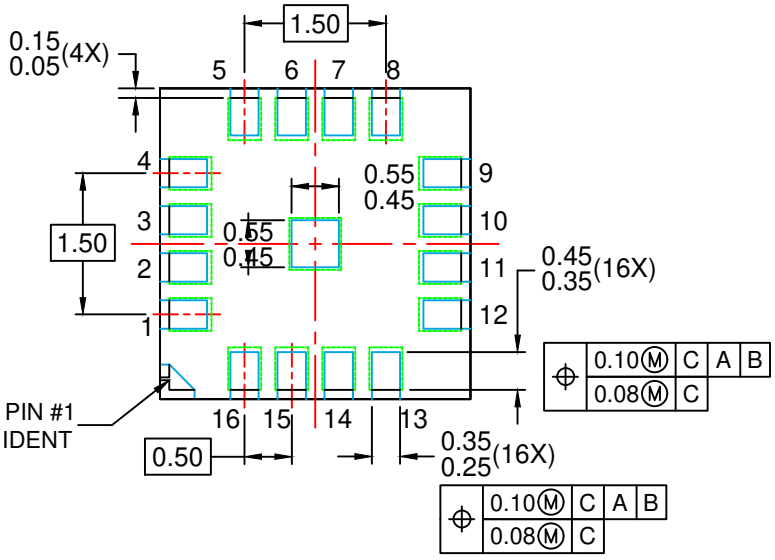


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SIDE VIEW





BOTTOM VIEW

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