



# 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:  $\pm 3^\circ$  Pitch and Roll,  $\pm 5^\circ$  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  $\mu\text{g}/\sqrt{\text{Hz}}$  Accelerometer and 10  $\text{mdps}/\sqrt{\text{Hz}}$  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  $\pm 32^\circ/\text{s}$  to  $\pm 2,560^\circ/\text{s}$  and  $\pm 2 \text{ g}$  to  $\pm 8 \text{ g}$
- Low Power and Warm-Start Modes for Effective Power Management
- Digitally Programmable Sampling Rate and Filters
- Host Serial Interface Supporting I<sup>2</sup>C or SPI
- I<sup>2</sup>C 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  $\pm 3^\circ$  pitch and roll orientation, and a  $\pm 5^\circ$  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<sup>2</sup>C 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

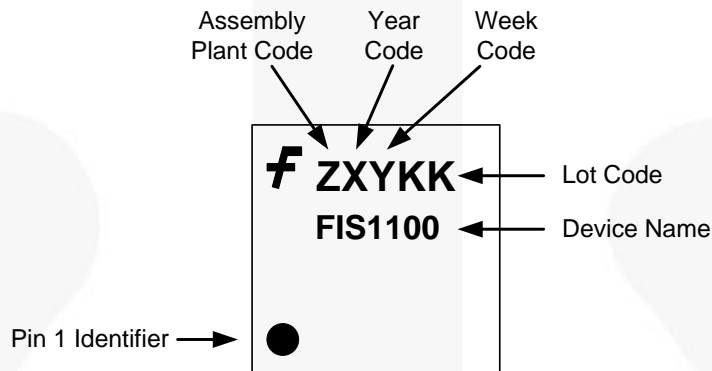


Figure 1. Top Mark

## 1.3 Internal Block Diagram

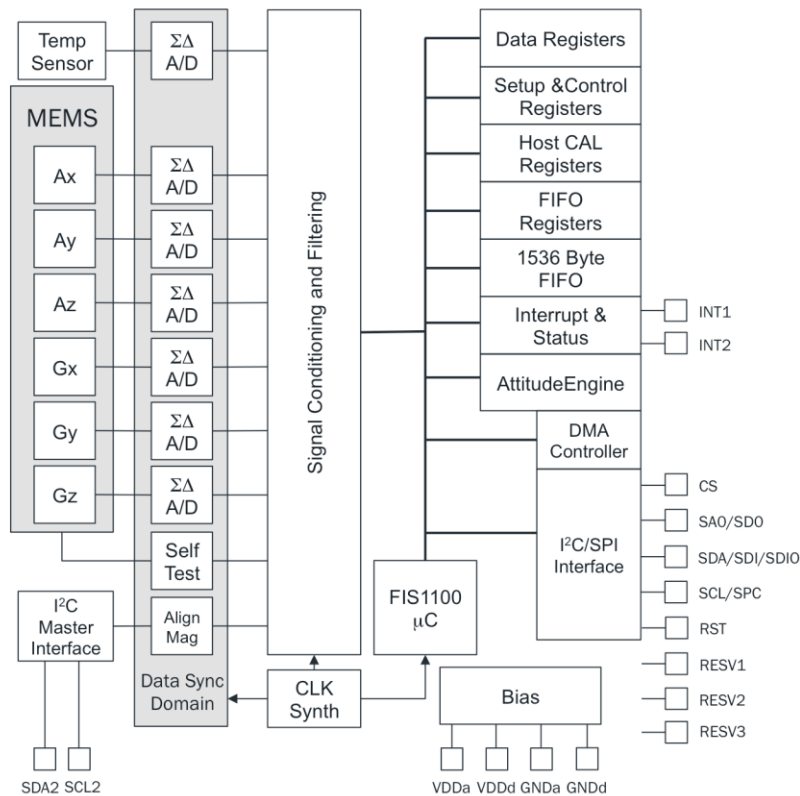
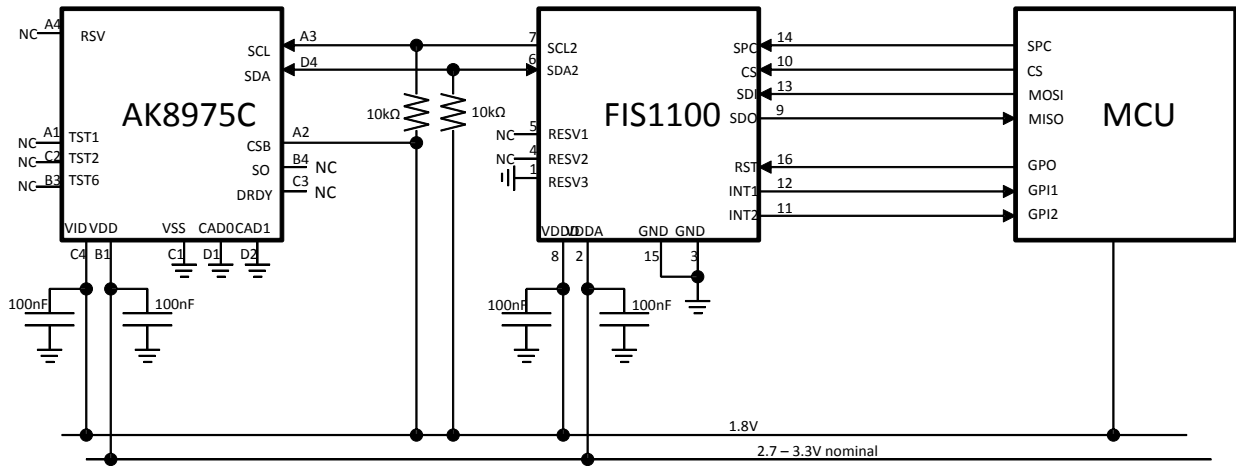


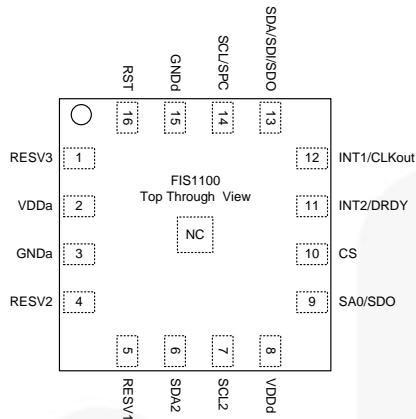
Figure 2. Internal Block Diagram

### 1.4 Application Diagram

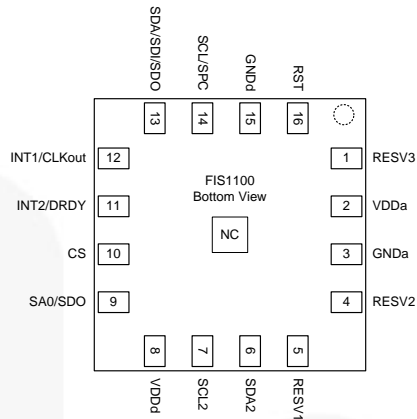


**Figure 3. Typical Application Diagram (Showing Magnetometer Connected through FIS1100 Master I<sup>2</sup>C and a SPI 4 Wire Interface Connected to the Host Processor)**

## 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 <sup>2</sup> C Serial Data  |
| 7                 | SCL2                  |                       |                        | Master I <sup>2</sup> C Serial Clock   |
| 8                 | VDDd                  |                       |                        | Power Supply for Digital and IO Pins   |
| 9                 | SA0 <sup>(1)(3)</sup> | SDO                   |                        | Host I <sup>2</sup> C Slave Address LSB (SA0);<br>Host 4-Wire SPI Serial Data Output (SDO)   |
| 10 <sup>(1)</sup> | CS                    |                       |                        | Host SPI Chip Select (1 = I <sup>2</sup> C Mode). <i>See SPI Mode Configuration section</i>  |
| 11                | INT2                  | DRDY                  |                        | Interrupt2. Data Ready/FIFO Interrupt  |
| 12                | INT1                  | CLKout                |                        | Interrupt1. General Purpose Interrupt. Clock out in OIS Mode   |
| 13                | SDA                   | SDI <sup>(2)(3)</sup> | SDIO <sup>(2)(3)</sup> | Host I <sup>2</sup> C Serial Data (SDA);<br>Host 4-Wire SPI Serial Data Input (SDI);<br>Host 3-Wire SPI Serial Data Output (SDIO)  |
| 14                | SCL                   | SPC <sup>(2)(3)</sup> |                        | Host I <sup>2</sup> C Serial Clock (SCL);<br>Host SPI Serial Clock (SPC)   |
| 15                | GNDd                  |                       |                        | Ground   |
| 16                | RST ***               |                       |                        | Reset Input. Assert for at least 5 $\mu$ s. Part ready for communication 50 $\mu$ s 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 K $\Omega$  pull up resistor.
2. In SPI mode (not in I<sup>2</sup>C Mode), there is an internal pull down 200 K $\Omega$  resistor.
3. Refer to Section 1 for detailed configuration information.

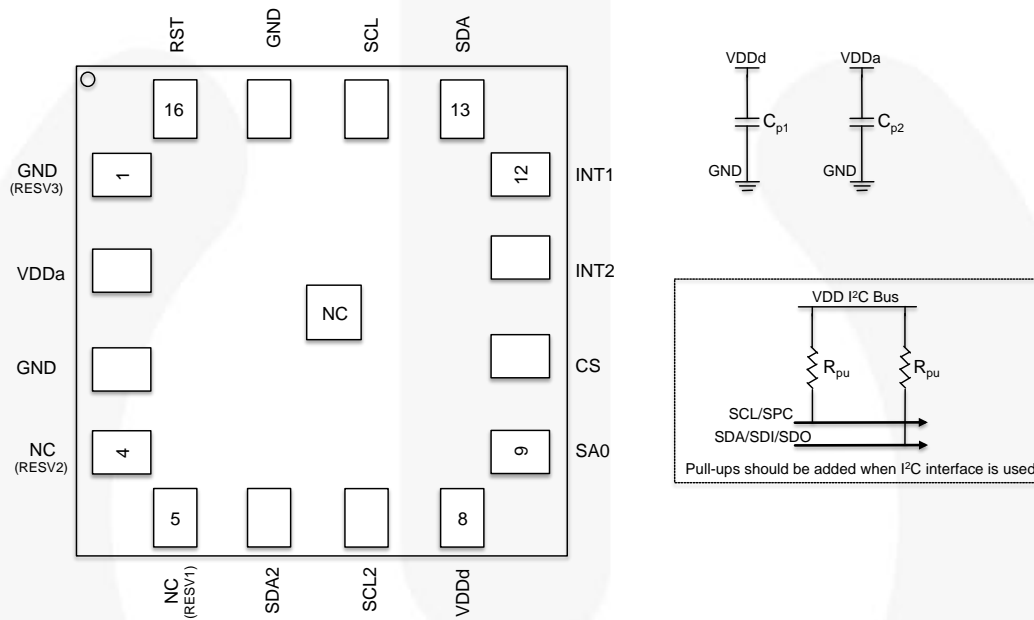
## 1.6 Recommended External Components

**Table 3. Recommended External Components**

| Component                      | Description | Parameter   | Typical |
|--------------------------------|-------------|-------------|---------|
| C <sub>p1</sub>                | Capacitor   | Capacitance | 100 nF  |
| C <sub>p2</sub>                | Capacitor   | Capacitance | 100 nF  |
| R <sub>pu</sub> <sup>(4)</sup> | Resistor    | Resistance  | 10 KΩ   |

**Note:**

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



**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  $\pm 3^\circ$  for pitch and roll and  $\pm 5^\circ$  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  $\Sigma\Delta$  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 recalibration 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  $\Sigma\Delta$ -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.



## 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

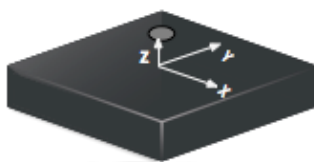


Figure 7. Chip Orientation Coordinate System

## 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 coordinate system shown above. Increasing accelerations along the positive X-Y-Z axis are considered positive. Angular Rate ( $\omega_x$ ,  $\omega_y$ ,  $\omega_z$ ) 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.

### 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 <sub>STG</sub>              | Storage Temperature                      | -40                                  | +125   | °C   |
| T <sub>Pmax</sub>             | Lead Soldering Temperature, 10 Seconds   |                                      | +260   | °C   |
| V <sub>DDa</sub>              | Supply Voltage                           | -0.3                                 | 3.6    | V    |
| V <sub>DDd</sub>              | I/O Pins Supply Voltage                  | -0.3                                 | 2.05   | V    |
| S <sub>g</sub> <sup>(5)</sup> | Acceleration g for 0.2 ms (Un-powered)   |                                      | 10,000 | g    |
| ESD <sup>(6)</sup>            | Electrostatic Discharge Protection Level | Human Body Model per JES001-2014     | ±2000  |      |
|                               |  | Charged Device Model per JESD22-C101 | ±500   |      |
|                               |  |                                      |        | V    |

**Notes:**

- △ This is a mechanical shock (g) sensitive device. Proper handling is required to prevent damage to the part.
- ↗ 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 <sub>DDa</sub> | Supply Voltage                    | 2.4                   | 2.7  | 3.47                  | V    |
| V <sub>DDd</sub> | I/O Pins Supply Voltage           | 1.62                  | 1.80 | 1.98                  | V    |
| V <sub>IL</sub>  | Digital Low Level Input Voltage   |                       |      | 0.3 *V <sub>DDd</sub> | V    |
| V <sub>IH</sub>  | Digital High Level Input Voltage  | 0.7 *V <sub>DDd</sub> |      |                       | V    |
| V <sub>OL</sub>  | Digital Low Level Output Voltage  |                       |      | 0.1 *V <sub>DDd</sub> | V    |
| V <sub>OH</sub>  | Digital High Level Output Voltage | 0.9 *V <sub>DDd</sub> |      |                       | V    |

### 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)<br>Referenced to North | ±5       | deg   | Requires use of XKF3 software library on host processor, using magnetometer, in a homogenous Earth magnetic field.  |
|                         | Yaw (Heading)<br>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<sub>DDd</sub> = 1.8 V, V<sub>DDa</sub> = 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 (V <sub>DDd</sub> and V <sub>DDa</sub> within 1% of Final Value) | 1.75   | s                    | From Hardware Reset, No Power, or Power Down to Power-on Default state. = t <sub>0</sub> in Figure 8 |  |               |

**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   |
|--|--|---------------|-------------|---|--|
|  |  | Scale Setting | Sensitivity |   |  |
| Gyroscope                                    | Sensitivity  | ±32 dps       | 1024        | LSB/dps                                 | 16-Bit Output  |
|  |  | ±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            |             |   |  |

**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

$V_{DDd} = 1.8\text{ V}$ ,  $V_{DDa} = 2.7\text{ V}$ ,  $T = 25^{\circ}\text{C}$  unless otherwise noted. Typical numbers are provided below unless otherwise noted. All frequencies are  $\pm 5\%$  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 | $\mu\text{g}/\sqrt{\text{Hz}}$ |

**Table 11. Accelerometer Filter Characteristics<sup>(7)</sup>**

| 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  $\pm 5\%$  and are synchronized to the gyro oscillator (“drive”) frequency.

### 3.6 Gyroscope Programmable Characteristics

$V_{DDd} = 1.8\text{ V}$ ,  $V_{DDa} = 2.7\text{ V}$ ,  $T = 25^{\circ}\text{C}$ , and represent typical numbers unless otherwise noted. All frequencies are  $\pm 5\%$  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 <sup>(8)</sup> |      |
| 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 <sup>(8)</sup> |      |
|   | gHPF01=1 | 0.1             | 0.025 | 0.0125 | 0.0032 | N/A               | 0.1  | N/A <sup>(8)</sup> |      |

**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**

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

### 3.7 Electrical Characteristics

$V_{DDd} = 1.8\text{ V}$ ;  $V_{DDa} = 2.7\text{ V}$ ;  $T = 25^\circ\text{C}$  unless otherwise noted.

**Table 14. Electrical Subsystem Characteristics**

| Symbol            | Parameter  | Min.          | Typ. | Max. | Unit |
|-------------------|--|---------------|------|------|------|
| $f_{\text{SPC}}$  | Host SPI Interface Speed                               |               | 10   |      | MHz  |
| $f_{\text{SCL}}$  | Host I <sup>2</sup> C Interface Speed                  | Standard Mode | 100  |      | kHz  |
|                   |  | Fast Mode     | 400  |      |      |
| $f_{\text{SCL2}}$ | Master I <sup>2</sup> C Interface Speed <sup>(9)</sup> | Standard Mode | 25   |      | kHz  |
|                   |  | Fast Mode     | 300  |      |      |

**Note:**

9. When only accelerometer is enabled, I<sup>2</sup>C master operates at 25 kHz. When gyroscope is enabled, I<sup>2</sup>C master operates at 300 kHz.

#### 3.7.1 Current Consumption

$V_{DDd} = 1.8\text{ V}$ ,  $V_{DDa} = 2.7\text{ V}$ ,  $T = 25^\circ\text{C}$  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 $I_{DDa}$ <sup>(10)</sup>  |                                   | 220             | 220 | 220 | 220   | 35        | 35   | 20 | 7 | $\mu\text{A}$ |
| Typical Digital Current $I_{DDd}$ <sup>(11)</sup> | 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 <sup>(8)</sup> | Unit          |
|---|--|-----------------|------|------|-------|-------------------|----------------------------|---------------|
| ODR   |  | 1000            | 250  | 125  | 31.25 | Snooze            | 8100                       | Hz            |
| Typical Analog Current $I_{DDa}$ <sup>(10)</sup>  |  | 2540            | 2540 | 2540 | 2540  | 1240              | 2540                       | $\mu\text{A}$ |
| Typical Digital Current $I_{DDd}$ <sup>(11)</sup> | Filters Disabled (gLPF=0; gHPF=0; gHPF0=0) | 740             | 710  | 705  | 700   | 570               | 1100                       |               |
|   | Filters Enabled (gLPF=1; gHPF=1; gHPF0=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  | $\mu\text{A}$ |
| Typical Digital Current $I_{DDd}$ | Filters Disabled (aLPF=0; gLPF=0; aHPF=0; gHPF=0; gHPF0=0) | 815             | 780  | 780  | 780   |               |
|                                   | Filters Enabled (aLPF=1; gLPF=1; aHPF=1; gHPF=1; gHPF0=0)  | 830             | 790  | 780  | 780   |               |



**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 <sub>DDa</sub>  |                                   | 2750 | 2750 | 2750 | 2750 | 2750 | 2750 | 2750 | μA   |
| Typical Digital Current I <sub>DDd</sub> | 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 <sub>DDa</sub>  |                            | 2750 | 2750 | 2750 | 2750 | 2750 | 2750 | μA |      |
| Typical Digital Current I <sub>DDd</sub> | 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     |

## 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<sup>2</sup>C 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   |          |  |
| <b>General Purpose Registers</b>  |      |                  |     |          |          |  |
| WHO_AM_I  | r    | 0                | 00  | 00000000 | 11111100 | Device Identifier  |
| <b>Setup and Control Registers</b>  |      |                  |     |          |          |  |
| 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  |
| <b>Host Controlled Calibration Registers (See CTRL9, Usage is Optional)</b> |      |                  |     |          |          |  |
| CAL1_L  | rw   | 11               | 0B  | 00001011 | 00000000 | Calibration Register   |
| CAL1_H  | rw   | 12               | 0C  | 00001100 | 00000000 | CAL1_L – lower 8 bits. CAL1_H – upper 8 bits.                    |
| CAL2_L  | rw   | 13               | 0D  | 00001101 | 00000000 | Calibration Register   |
| CAL2_H  | rw   | 14               | 0E  | 00001110 | 00000000 | CAL2_L – lower 8 bits. CAL2_H – upper 8 bits.                    |
| CAL3_L  | rw   | 15               | 0F  | 00001111 | 00000000 | Calibration Register   |
| CAL3_H  | rw   | 16               | 10  | 00010000 | 00000000 | CAL3_L – lower 8 bits. CAL3_H – upper 8 bits.                    |
| CAL4_L  | rw   | 17               | 11  | 00010001 | 00000000 | Calibration Register   |
| CAL4_H  | rw   | 18               | 12  | 00010010 | 00000000 | CAL4_L – lower 8 bits. CAL4_H – upper 8 bits.                    |
| <b>FIFO Registers</b>   |      |                  |     |          |          |  |
| 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  |

Table 21. Register Overview (Continued)

| Name  | Type | Register Address |     |          | Default  | Comment   |
|---|------|------------------|-----|----------|----------|---|
|   |      | Dec              | Hex | Binary   |          |   |
| <b>Status Registers</b>   |      |                  |     |          |          |   |
| 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)  |
| <b>Count Register</b>   |      |                  |     |          |          |   |
| CNT_OUT   | r    | 24               | 18  | 00011000 | 00000000 | Sample Time Stamp (Count Output)  |
| <b>Data Output Registers (16 bits 2's complement except self test sensor data, AE-REG1 and AE_REG2)</b> |      |                  |     |          |          |   |
| AX_L  | r    | 25               | 19  | 00011001 | 00000000 | X-axis Acceleration<br>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<br>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<br>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<br>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<br>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<br>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<br>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 .<br>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.<br>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.<br>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.<br>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.<br>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<br>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<br>OIS LL mode, or Self test sensor data<br>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<br>OIS LL mode, or Self test sensor data<br>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<br>OIS LL mode, or Self test sensor data<br>dVZ_L – lower 8 bits. dVZ_H – upper 8 bits. |
| dVZ_H   | r    | 58               | 3A  | 00111010 | 00000000 |   |

**Table 21. Register Overview** (Continued)

| Name                                     | Type | Register Address |     |          | Default  | Comment                   |
|--|------|------------------|-----|----------|----------|---------------------------|
|  |      | Dec              | Hex | Binary   |          |                           |
| <b>Data Output Registers</b> (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).<br>Configure data reads from Sensor Data Output Registers with syncSmpl.<br>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   |

## 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 <sup>-1</sup> | 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 |

## 5.4 Configuration Registers

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

**Table 25. Configuration Registers Description**

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

Table 25 Configuration Register Description (Continued)

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

**Note:**

- 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
- 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.

Table 25 Configuration Register Description (Continued)

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

**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



Table 25 Configuration Register Description (Continued)

| Register Name        |          |   |  |
|----------------------|----------|---|--|
| <b>CTRL7</b>         |          | <b>Enable Sensors and Configure Data Reads. Register Address: 8 (0x08)</b>  |  |
| Bits                 | Name     | Default   | Description  |
| 7                    | syncSmpl | 1'b0  | This bit determines how data are read out of Sensor Data Output Registers of the FIS1100.<br>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<br>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<br>1: Enable AttitudeEngine orientation and velocity increment computation  |
| 2                    | mEN      | 1'b0  | 0: Magnetometer placed in Standby or Power-down Mode.<br>1: Enable Magnetometer  |
| 1                    | gEN      | 1'b0  | 0: Gyroscope placed in Standby or Power-down Mode.<br>1: Enable Gyroscope.   |
| 0                    | aEN      | 1'b0  | 0: Accelerometer placed in Standby or Power-down Mode.<br>1: Enable Accelerometer.   |
| <b>CTRL8</b>         |          | <b>Reserved – Special Settings. Register Address: 9 (0x09)</b>  |  |
| Bits                 | Name     | Default   | Description  |
| 7:0                  | Reserved | 0x00  | Not Used   |
| <b>Register Name</b> |          |   |  |
| <b>CTRL9</b>         |          | <b>Host Commands. Register Address: 10 (0x0A)</b><br>(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  |              |  |  |
|----------------|--------------|--|--|
| <b>STATUS0</b> |              | <b>Output Data Status Register Address: 22 (0x16)</b>                |  |
| Bits           | Name         | Default  | Description  |
| 7              | aeOVRN       | 1'b0   | 0: No overrun<br>1: AE data overrun. Previous data overwritten before it was read.   |
| 6              | mOVRN        | 1'b0   | 0: No overrun<br>1: Magnetometer data overrun. Previous data overwritten before it was read.   |
| 5              | gOVRN        | 1'b0   | 0: No overrun<br>1: Gyroscope data overrun. Previous data overwritten before it was read.  |
| 4              | aOVRN        | 1'b0   | 0: No overrun<br>1: Accelerometer data overrun. Previous data overwritten before it was read.  |
| 3              | aeDA         | 1'b0   | AE new data available<br>0: No updates since last read.<br>1: New data available.  |
| 2              | mDA          | 1'b0   | Valid Magnetometer data available<br>0: Magnetometer data is NOT Valid<br>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<br>0: No updates since last read.<br>1: New data available.   |
| 0              | aDA          | 1'b0   | Accelerometer new data available<br>0: No updates since last read.<br>1: New data available.   |
| <b>STATUS1</b> |              | <b>Miscellaneous Status. Register Address 23 (0x17)</b>              |  |
| 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.   |
| <b>CNT_OUT</b> |              | <b>Sample Time Stamp – Output Count. Register Address: 24 (0x18)</b> |  |
| 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).   |

## 5.6 Sensor Data Output Registers

Table 28. Sensor Data Output Registers Description

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

Continued on the following page...

Table 28 Sensor Data Output Registers Description (Continued)

| Register Name            |             |  |   |
|--------------------------|-------------|--|---|
| <b>dQ[1,2,3,4]_[H,L]</b> |             | <b>Quaternion Output. Register Addresses: 45 – 52 (0x2D – 0x34)</b>  |   |
| Bits                     | Name        | Default  | Description   |
| 7:0                      | dQW_L<7:0>  | 0x00   | Quaternion Increment dQW in two's complement.<br>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.<br>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.<br>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.<br>dQZ_L – lower 8 bits. dQZ_H – upper 8 bits.  |
| 7:0                      | dQZ_H<15:8> | 0x00   |   |
| <b>dV[X,Y,Z]_[H,L]</b>   |             | <b>Delta Velocity Output. Register Address: 53 – 58 (0x35– 0x3A)</b> |   |
| Bits                     | Name        | Bits   | Name  |
| 7:0                      | dVX_L<7:0>  | 0x00   | X-axis Velocity Increment in two's complement.<br>dVX_L – lower 8 bits. dVX_H – upper 8 bits.<br>When gODR=111, OIS LL Gyro X-axis data in two's complement<br>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.<br>dVY_L – lower 8 bits. dVY_H – upper 8 bits.<br>When gODR=111, OIS LL Gyro Y-axis data in two's complement<br>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.<br>dVZ_L – lower 8 bits. dVZ_H – upper 8 bits.<br>When gODR=111, OIS LL Gyro Z-axis data in two's complement<br>Also used for accelerometer or gyro self test data |
| 7:0                      | dVZ_H<15:8> | 0x00   |   |
| <b>TEMP</b>              |             | <b>Temperature Output. Register Address: 59. (0x3B)</b>              |   |
| Bits                     | Name        | Default  | Description   |
| 7:0                      | TEMP<7:0>   | 0x00   | Temperature output (°C) in two's complement.  |
| <b>AE_REG1</b>           |             | <b>AttitudeEngine Register 1, Address: 60 (0x3C)</b>                 |   |
| 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.  |

**Table 28 Sensor Data Output Registers Description** (Continued)

| Register Name  |          |  |  |
|----------------|----------|--|--|
| <b>AE_REG2</b> |          | <b>AttitudeEngine Register 2, Address: 61 (0x3D)</b> |  |
| 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  |
|---|--------|----------------------|--------------------|----------------------|---|--|
| <b>AttitudeEngine in ODR Mode (Accelerometer and Gyroscope Enabled)</b>                                     |        |                      |                    |                      |   |  |
| 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  |                      |                    |                      |   |  |
| <b>AttitudeEngine in Motion on Demand (MoD) mode (Accelerometer and Gyroscope enabled)</b>                  |        |                      |                    |                      |   |  |
| 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  |                      |                    |                      |   |  |
| <b>AttitudeEngine with Raw Magnetometer in ODR Mode (Accelerometer, Gyroscope and Magnetometer Enabled)</b> |        |                      |                    |                      |   |  |
| 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  |                      |                    |                      |   |  |

## 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<sup>2</sup>C 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.

### 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   |

## 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.



**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.



## 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.

## 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   |
|----------------------------------|---|---|
| <b>Sensor Modes</b>              |   |   |
| <b>Power-On Default</b>          | All sensors off, clock is turned on. The current in this mode is typically 15 $\mu$ A. Note this mode is the default state upon initial power up or after a reset.  | CTRL1 sensorDisable = 0<br>CTRL7 aEN = 0, gEN = 0,<br>mEN = 0, sEN=0.<br>CTRL2 aODR=000 |
| <b>Low Power</b>                 | 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 $\mu$ A. To enter this mode requires host interaction to set CTRL2 aODR=1xx.  | CTRL1 sensorDisable =0<br>CTRL7 aEN = 0, gEN = 0,<br>mEN = 0, sEN=0.<br>CTRL2 aODR=1xx  |
| <b>Power-Down</b>                | 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 $\mu$ A. Host must initiate this mode by setting sensorDisable=1 | CTRL1 sensorDisable =1<br>CTRL7 aEN = 0, gEN = 0,<br>mEN = 0, sEN=0.<br>CTRL2 aODR=xxx  |
| <b>Accel Only</b>                | Device configured as an accelerometer only.   | CTRL7 aEN =1, gEN =0,<br>mEN =0<br>CTRL2 aODR=0xx                                       |
| <b>Low Power Accel Only</b>      | Device configured in low power accelerometer mode   | CTRL7 aEN =1, gEN =0,<br>mEN =0<br>CTRL2 aODR=1xx                                       |
| <b>Gyro Only</b>                 | Device configured as a gyroscope only.  | CTRL7 aEN =0, gEN =1,<br>mEN =0<br>CTRL2 aODR=000                                       |
| <b>Mag Only</b>                  | Device configured as a magnetometer only.   | CTRL7 aEN =0, gEN =0,<br>mEN =1<br>CTRL2 aODR=000                                       |
| <b>Accel + Mag</b>               | Device configured as an accelerometer and magnetometer combination only. Device can be used as a (stabilized) compass.  | CTRL7 aEN =1, gEN =0,<br>mEN =1<br>CTRL2 aODR=0xx                                       |
| <b>Accel + Gyro (IMU)</b>        | Device configured as an Inertial Measurement Unit, i.e. an accelerometer and gyroscope combination sensor.  | CTRL7 aEN =1, gEN =1,<br>mEN =0<br>CTRL2 aODR=0xx                                       |
| <b>Accel + Gyro + Mag (9DOF)</b> | 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,<br>mEN =1<br>CTRL2 aODR=0xx                                       |
| <b>Wake on Motion (WoM)</b>      | Very low power mode used to wake-up the host by providing an interrupt upon detection of device motion.<br><br>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,<br>mEN =0<br>CTRL2 aODR = 111                                     |
| <b>Gyro Warm Start</b>           | 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<br>CTRL2 aODR = 0xx  |

Table 32 Operating Modes (Continued)

| Mode                            | Description  | Suggested Configuration   |
|---------------------------------|--|---|
| <b>Sensor Modes</b>             |  |   |
| <b>OIS</b>                      | 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<br>CTRL2 aODR = 0xx  |
| <b>OIS LL</b>                   | 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<br>CTRL2 aODR = 000  |
| <b>Hardware Reset</b>           | RST pin asserted   |   |
| <b>No Power</b>                 | VDDd and VDDa low  |   |
| <b>Attitude Engine Modes</b>    |  |   |
| <b>6DOF AttitudeEngine Mode</b> | 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<br>CTRL2 aODR=0xx                                       |
| <b>9DOF AttitudeEngine Mode</b> | 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,<br>mEN = 1<br>CTRL4 (configure magnetometer as needed) |
| <b>Motion On Demand Mode</b>    | This mode allows Host to sample AttitudeEngine data asynchronously by polling  | CTRL7 aEN = 1, gEN = 1, sEN = 1<br>CTRL6 sMOD = 1                                       |

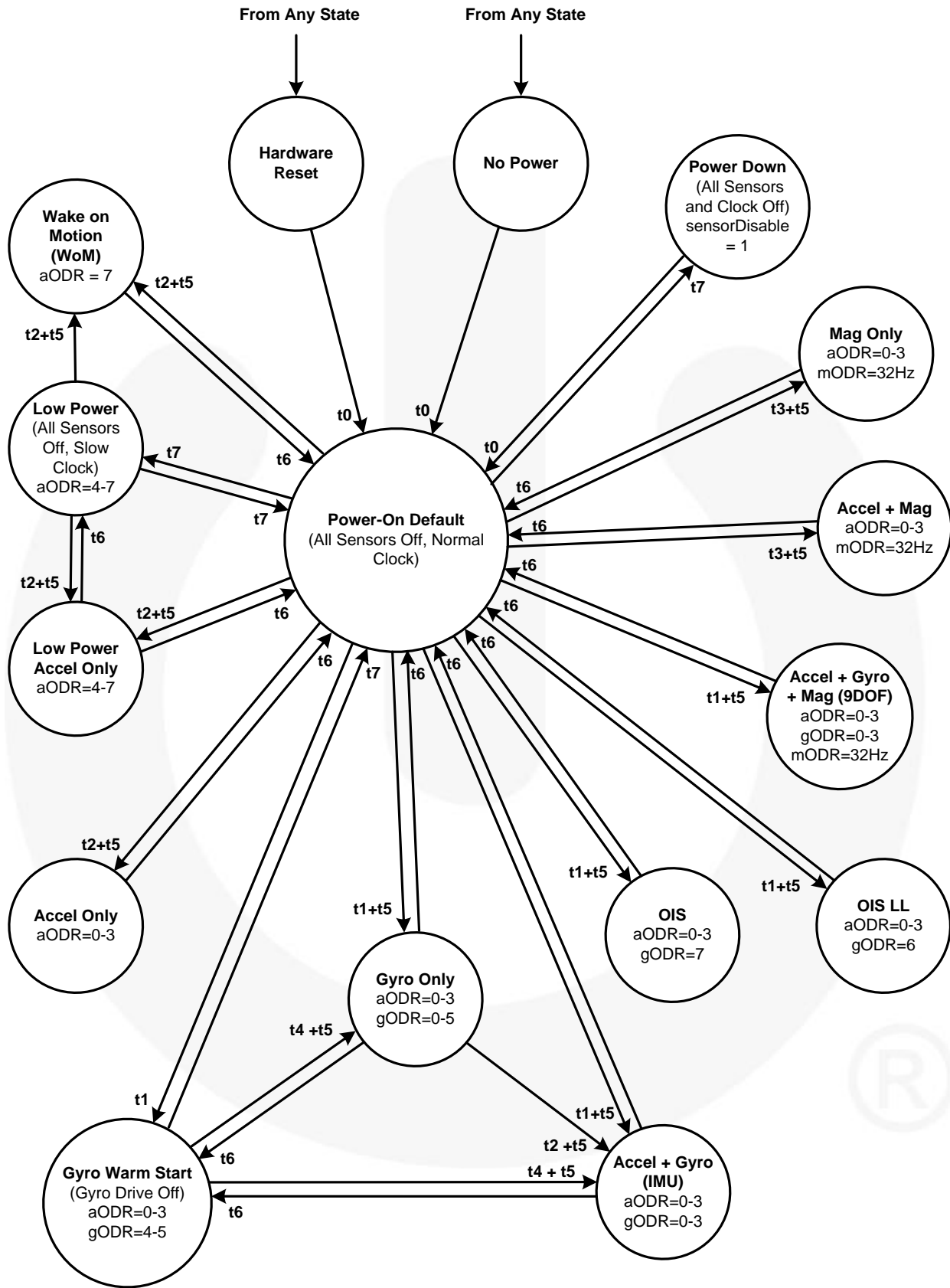


Figure 8. Operating Mode Transition Diagram

## 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  $t_1$ ,  $t_2$ ,  $t_3$  and  $t_4$ , are defined as the time it takes from INT2 going high to data being present. The time,  $t_5$  is the time it takes to have a correct representation of the inertial state.  $t_5$  is variable and is associated with the user selected Output Data Rate (ODR). We have defined  $t_5 = (3/ODR)$  to generally represent that time.

$t_6$  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  $2/ODR$ .

$t_7$  is the transition time between various states where the sensors are off.

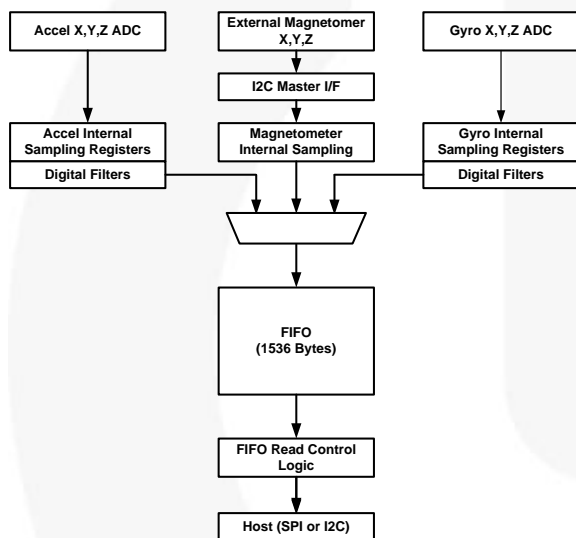
$t_0$  is the *System Turn On Time*, and is the time to enter the Power-On Default state from Hardware Reset, No Power, or Power down.

- Time  $t_0$  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  $t_1$  (the gyroscope wakeup time) and  $t_5$  (the part's filter settling time).  $t_1$  is typically 60 ms and  $t_5$  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  $t_2$  (the accel wakeup time) and  $t_5$  (the part's filter settling time).  $t_2$  is typically 3 ms, and  $t_5$  is defined as  $3/ODR$ , where ODR is the output data rate in Hertz.
- Time  $t_3$  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  $t_3 + t_5$ , where  $t_5$  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  $t_4$  (the gyroscope wakeup time from warm-start) and  $t_5$  (the part's filter settling time).  $t_4$  is typically 5 ms, and  $t_5$  is defined as  $3/ODR$ , where ODR is the output data rate in Hertz.
- The  $t_7$  transition is dependent on data transfer rates and is for I2C at 400 kHz is  $<100 \mu\text{s}$  for SPI at 11 Mbps is around 40  $\mu\text{s}$ .

## 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).

## 7.2 FIFO Register Description

Table 33. FIFO Registers Description

| Register Name      |              |  |   |
|--------------------|--------------|--|---|
| <b>FIFO_CTRL</b>   |              | <b>Configure FIFO. Register Address: 19 (0x13)</b>     |   |
| Bits               | Name         | Default  | Description   |
| 7                  | FIFO_rd_mode | 1'b0   | 0: Disable FIFO read via FIFO_DATA register.<br>1: Enable FIFO read via FIFO_DATA register.   |
| 6                  | Reserved     | 1'b0   | Reserved  |
| 5:4                | wtm<1:0>     | 2'b0   | Set Watermark level.<br>00 – Do not use.<br>01 – Set watermark at ¼ of FIFO size.<br>10 – Set watermark at ½ of FIFO size.<br>11 – Set watermark at ¾ of FIFO size.   |
| 3:2                | size<1:0>    | 2'b0   | Set FIFO size. (See Table 34 for more details.)<br>00 – Set FIFO size at 16 samples for each enabled sensor<br>01 – Set FIFO size at 32 samples for each enabled sensor<br>10 – Set FIFO size at 64 samples for each enabled sensor<br>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.<br>00 – Bypass (FIFO disable).<br>01 – FIFO.<br>10 – Streaming.<br>11 – Not Used   |
| <b>FIFO_DATA</b>   |              | <b>FIFO Data Register. Register Address: 20 (0x14)</b> |   |
| Bits               | Name         | Default  | Description   |
| 7:0                | data<7:0>    | 8'b0   | Read this register to read sensor data out of FIFO.   |
| <b>FIFO_STATUS</b> |              | <b>FIFO Status. Register Address: 21 (0x15)</b>        |   |
| 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  |



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

| <b>fss&lt;3:0&gt; Description</b>               |  | <b>Comments</b>  |  |
|---|--|--|--|
|   |  | <p>The FIFO storage level is indicated by the bits fss&lt;3:0&gt; in the FIFO_STATUS register. The value of fss&lt;3:0&gt; 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&lt;1:0&gt; in the FIFO_CTRL register.</p> <p>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&lt;1:0&gt; = [11], the FIFO size is 256 samples (=2x128), which in bytes is 1536 bytes (=6*2*128).</p> <p>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&lt;1:0&gt; in the FIFO_CTRL register .</p> <p>The value of the bits fss&lt;3:0&gt; 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.</p> |  |
| <b>FIFO_CTRL register, bits size&lt;1:0&gt;</b> | <b>No. of Sensors Enabled (A, G, or M)</b> | <b>Total FIFO Size (Total Number of Samples)</b>   | <b>fss&lt;3:0&gt; Granularity (Number of Sensor Samples per LSB)</b> |
| 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   |

## 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)<br>0x00 must be used to indicate that WoM mode is disabled   |
| CAL1_H (7:6)    | WoM interrupt select<br>01 – INT2 (with initial value 0)<br>11 – INT2 (with initial value 1)<br><br>00 – INT1 (with initial value 0)<br>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

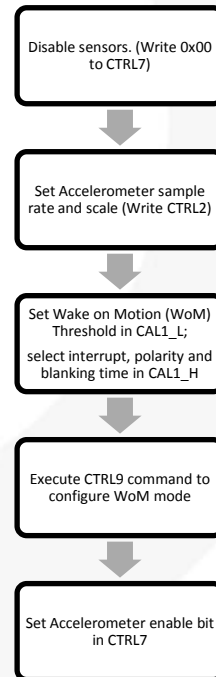
When a Wake on Motion event is detected the FIS1100 will set bit 2 (WoM) in the STATUS1 register. Reading STATUS1 by the host will clear the WoM bit and will reset the chosen interrupt line (INT1 or INT2, see previous section) to the value given by the WoM interrupt initial value (see previous section).

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.

### 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.

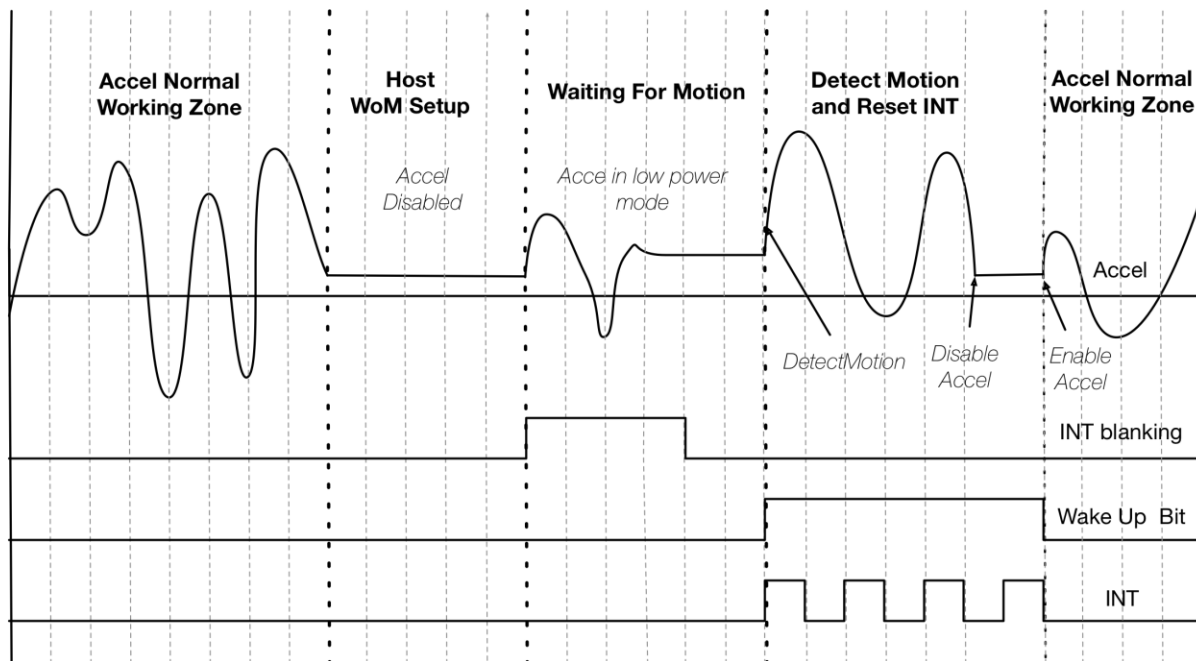


Figure 11. WoM Example Diagram

## 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.

## 10 Magnetometer Setup

### 10.1 Magnetometer Description

The FIS1100 provides an I<sup>2</sup>C 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.

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

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

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

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 -> { $S_x$ ,  $O_x$ ,  $K_{xy}$ ,  $K_{xz}$ }

SKOR\_Y -> { $S_y$ ,  $O_y$ ,  $K_{yx}$ ,  $K_{yz}$ }

SKOR\_Z -> { $S_z$ ,  $O_z$ ,  $K_{zx}$ ,  $K_{zy}$ }

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 |

# 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.

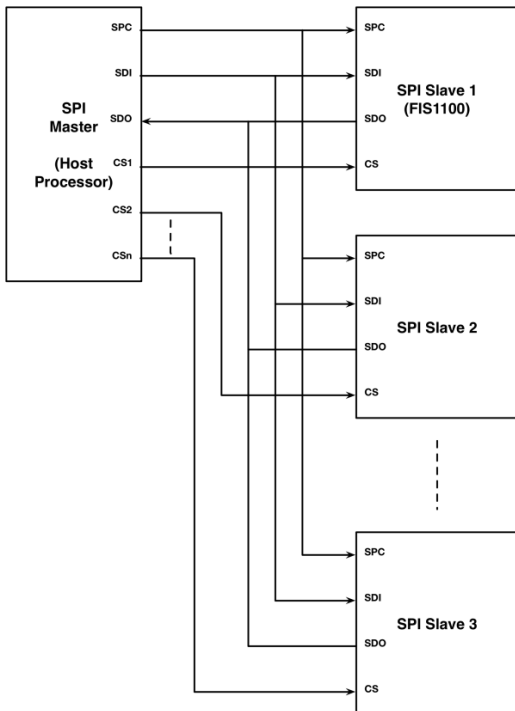


Figure 13. Typical SPI 4-Wire Multi-Slave

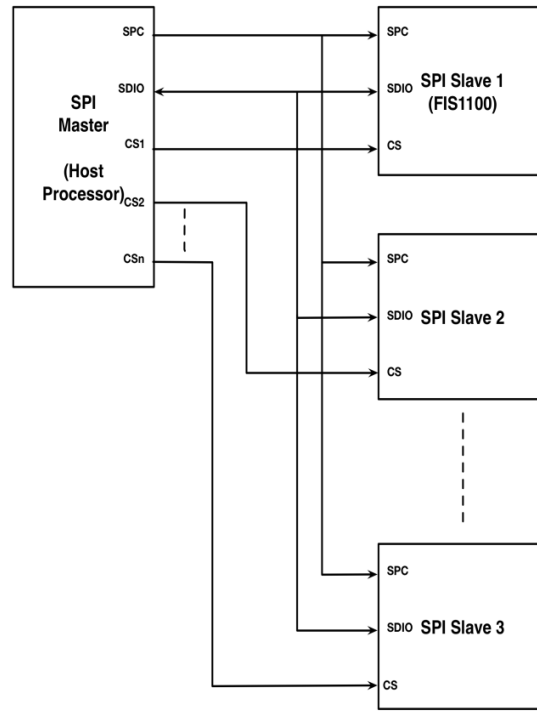


Figure 14. Typical SPI 3-Wire Multi-Slave

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 slave 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.

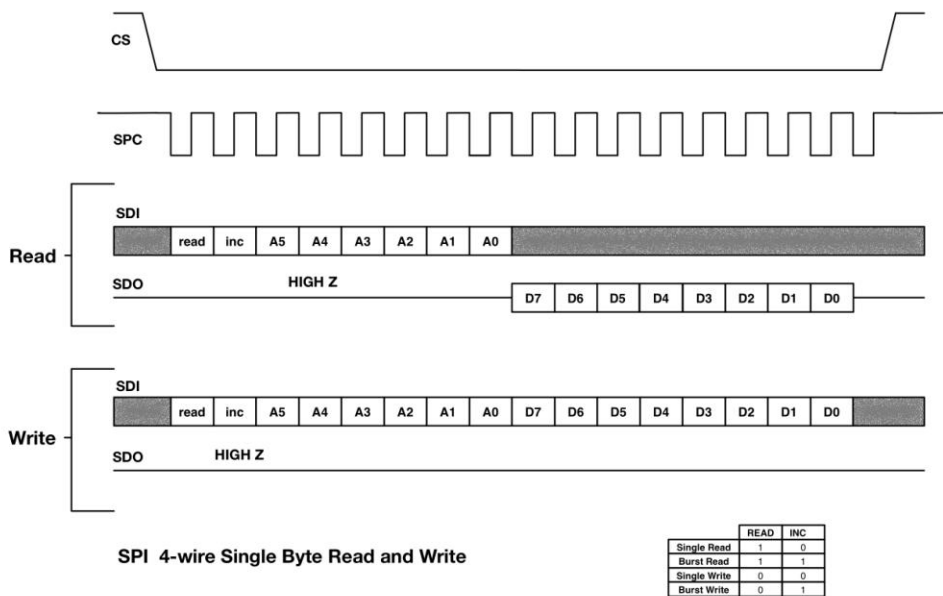


Figure 15. SPI 4-Wire Single Byte Read and Write

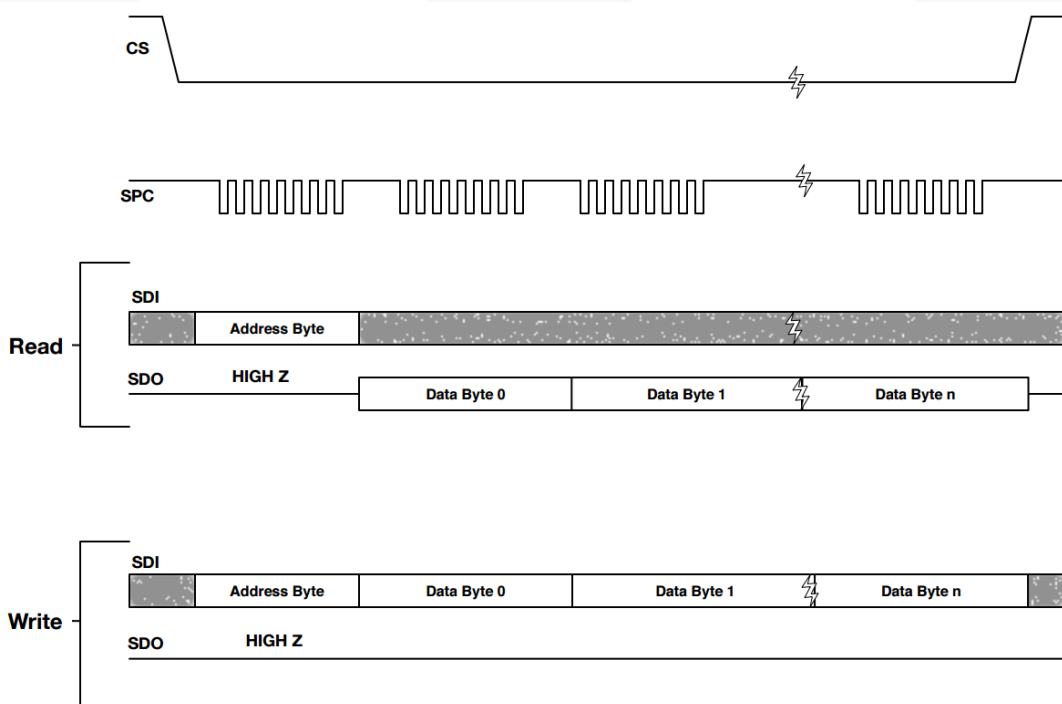
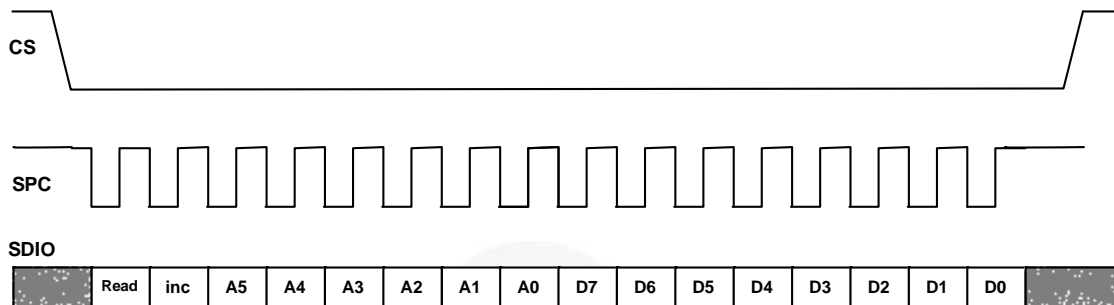


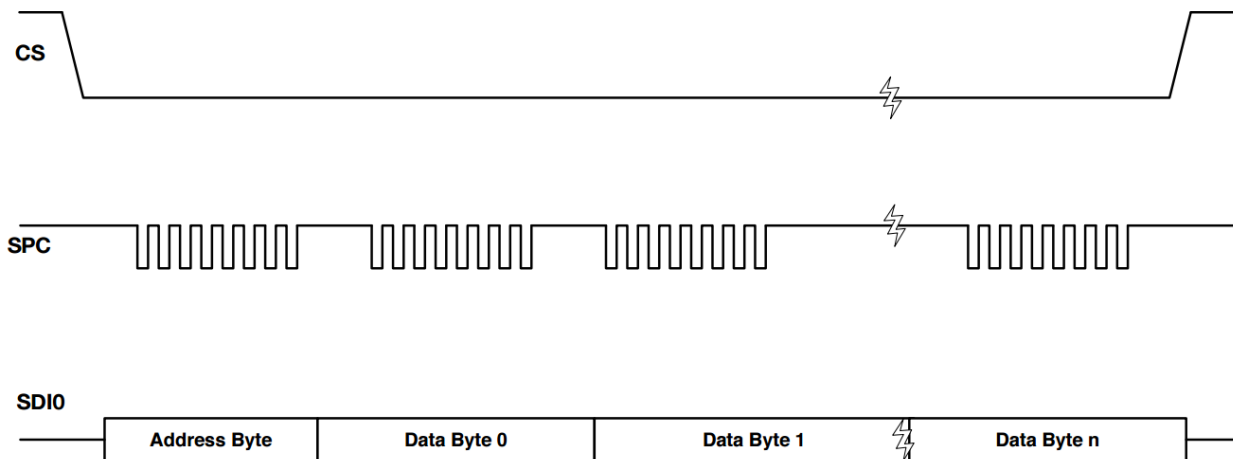
Figure 16. SPI 4-Wire Multi-Byte Read and Write Transactions



**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**



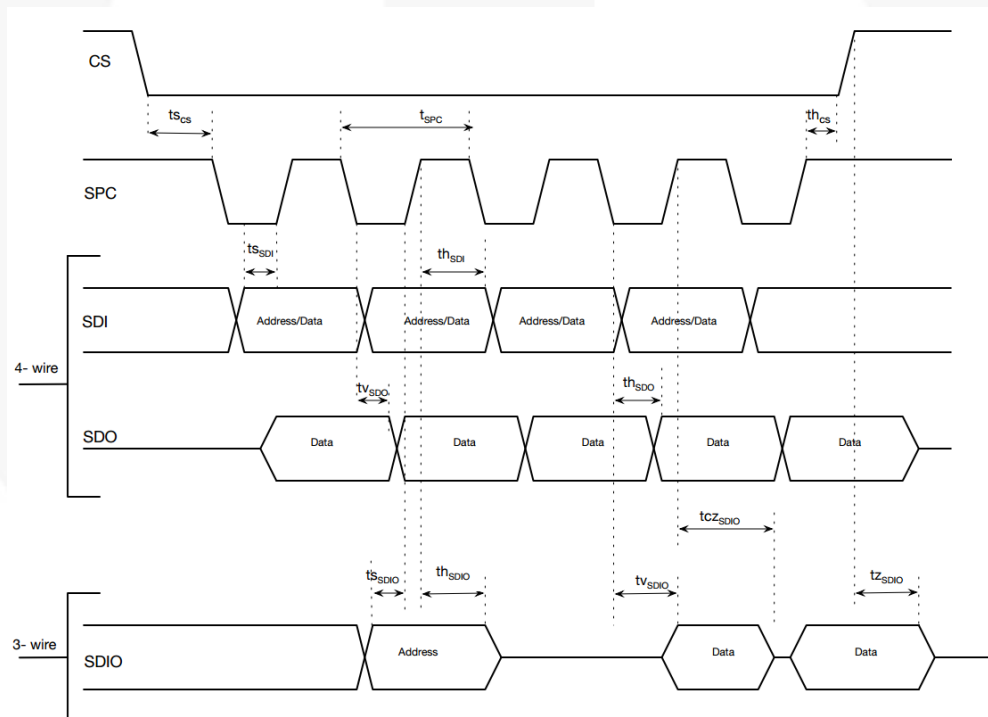
### 11.1.1 SPI Timing Characteristics

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

$V_{DDd} = 1.8\text{ V}$ ,  $T = 25^\circ\text{C}$  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  |
| $t_{SCS}$    | CS Setup Time                | 6    |      | ns   |
| $t_{HCS}$    | CS Hold Time                 | 8    |      | ns   |
| $t_{SDI}$    | SDI Input Setup Time         | 5    |      | ns   |
| $t_{HSDI}$   | SDI Input Hold Time          | 15   |      | ns   |
| $t_{VSDO}$   | SDO Time for Valid Output    |      | 50   | ns   |
| $t_{HSDO}$   | SDO Hold Time for Output     | 9    |      | ns   |
| $t_{DSDO}$   | SDO Disable Time for Output  |      | 50   | ns   |
| $t_{SSDIO}$  | SDIO Address Setup Time      | 5    |      | ns   |
| $t_{HSDIO}$  | SDIO Address Hold Time       | 15   |      | ns   |
| $t_{VSDIO}$  | SDIO Time for Valid Data     |      | 50   | ns   |
| $t_{CZSDIO}$ | SDIO Time from SPC to High Z |      | 50   | ns   |
| $t_{ZSDIO}$  | SDIO Time from CS to High Z  |      | 50   | ns   |



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

## 11.2 I<sup>2</sup>C Interface

Table 38 provides the I<sup>2</sup>C interface timing characteristics while Figure 20 and Figure 21 illustrate the I<sup>2</sup>C timing for both fast and standard modes, respectively.

During the slave device selection phase, the I<sup>2</sup>C master supplies the 7-bit I<sup>2</sup>C 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 k $\Omega$  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.

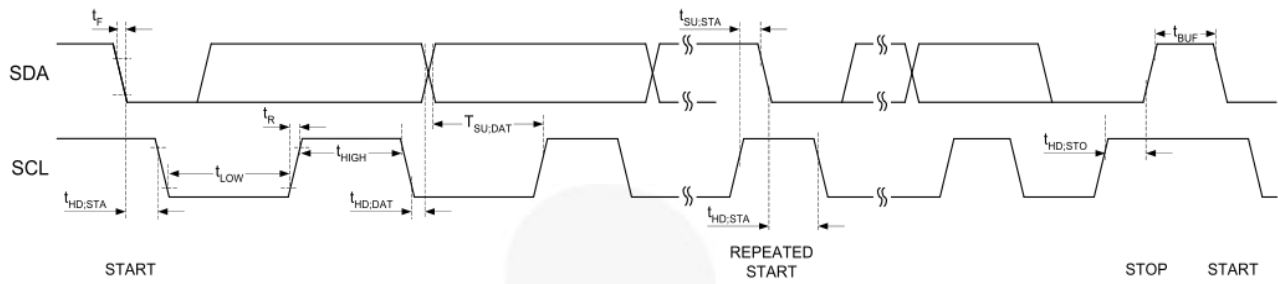
For additional technical details about the I<sup>2</sup>C standard, such as pull-up resistor sizing the user is referred to “UM10204 I<sup>2</sup>C-bus specification and user manual” published by NXP B.V.

**Table 38. I2C Timing Characteristics**

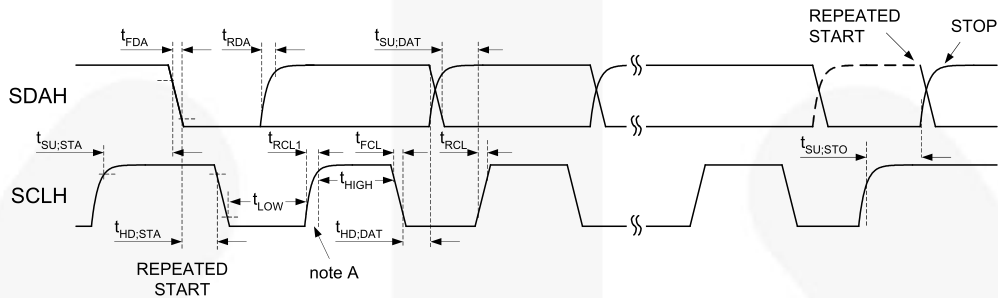
| Symbol                             | Parameter   | Conditions    | Min. | Typ.                    | Max. | Unit |
|------------------------------------|---|---------------|------|-------------------------|------|------|
| f <sub>SCL</sub>                   | SCL Clock Frequency   | Standard Mode |      |                         | 100  | kHz  |
|                                    |   | Fast Mode     |      |                         | 400  |      |
| t <sub>BUF</sub>                   | Bus-Free Time between STOP and START Conditions                                       | Standard Mode |      | 4700                    |      | ns   |
|                                    |   | Fast Mode     |      | 1300                    |      |      |
| t <sub>HD;STA</sub>                | START or Repeated START Hold Time   | Standard Mode |      | 4000                    |      | ns   |
|                                    |   | Fast Mode     |      | 600                     |      |      |
| t <sub>LOW</sub>                   | SCL LOW Period  | Standard Mode |      | 4700                    |      | ns   |
|                                    |   | Fast Mode     |      | 1300                    |      |      |
| t <sub>HIGH</sub>                  | SCL HIGH Period   | Standard Mode |      | 4000                    |      | ns   |
|                                    |   | Fast Mode     |      | 600                     |      |      |
| t <sub>SU;STA</sub>                | Repeated START Setup Time   | Standard Mode |      | 4700                    |      | ns   |
|                                    |   | Fast Mode     |      | 600                     |      |      |
| t <sub>SU;DAT</sub>                | Data Setup Time   | Standard Mode |      | 250                     |      | ns   |
|                                    |   | Fast Mode     |      | 100                     |      |      |
| t <sub>HD;DAT</sub>                | Data Hold Time  | Standard Mode | 0    |                         | 3450 | ns   |
|                                    |   | Fast Mode     | 0    |                         | 900  |      |
| t <sub>RCL, t<sub>R</sub></sub>    | SCL Rise Time   | Standard Mode |      |                         | 1000 | ns   |
|                                    |   | Fast Mode     |      | $20 + 0.1 * C_B^{(16)}$ | 300  |      |
| t <sub>FCL</sub>                   | SCL Fall Time   | Standard Mode |      |                         | 300  | ns   |
|                                    |   | Fast Mode     |      | $20 + 0.1 * C_B^{(16)}$ | 300  |      |
| t <sub>RDA, t<sub>RCL1</sub></sub> | SDA Rise Time.<br>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 <sub>FDA</sub>                   | SDA Fall Time   | Standard Mode |      |                         | 300  | ns   |
|                                    |   | Fast Mode     |      | $20 + 0.1 * C_B^{(16)}$ | 300  |      |
| t <sub>SU;STO</sub>                | Stop Condition Setup Time   | Standard Mode |      | 4000                    |      | ns   |
|                                    |   | Fast Mode     |      | 600                     |      |      |

**Note:**

16. C<sub>B</sub> is the bus capacitance.



**Figure 20. I<sup>2</sup>C Standard Mode Interface Timing**



- = MCS Current Source Pull-up
- = R<sub>p</sub> Resistor Pull-up

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

**Figure 21. I<sup>2</sup>C Fast Mode Interface Timing**

# 12 Package and Handling

## 12.1 Package Drawing

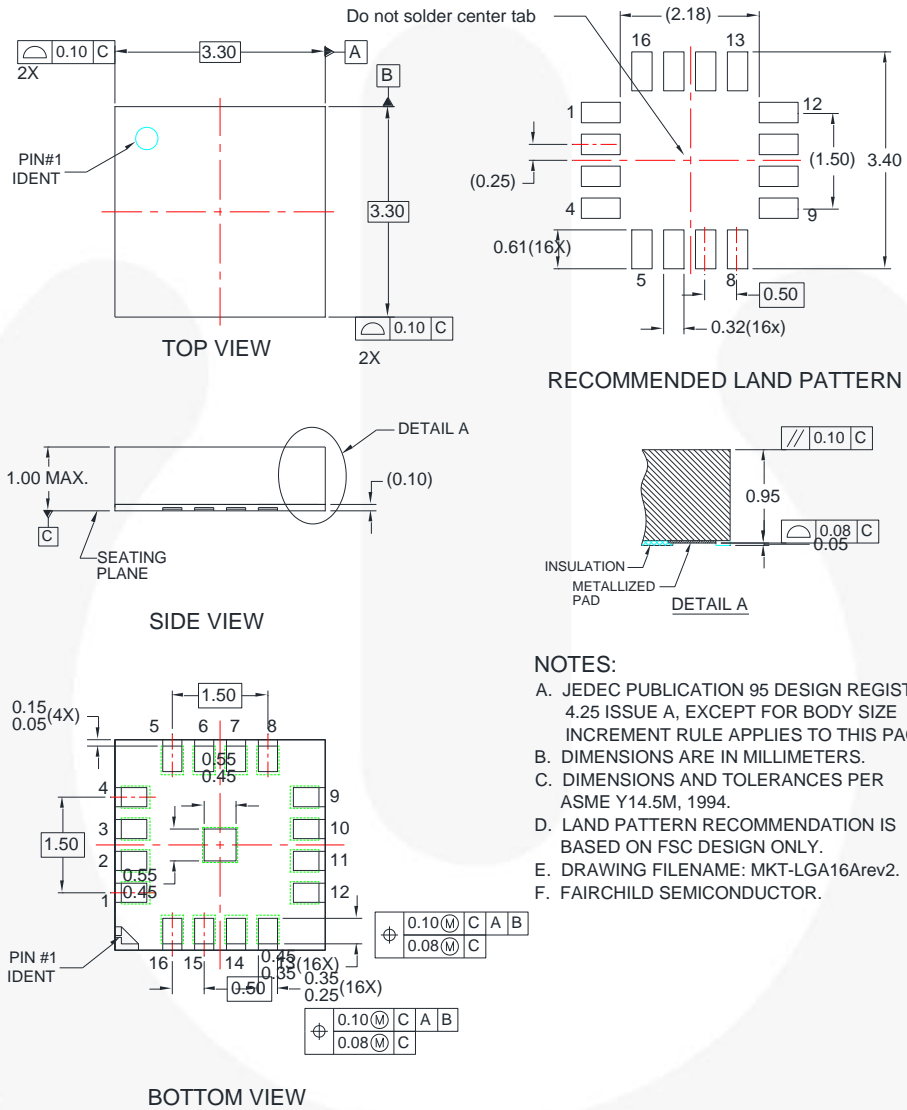
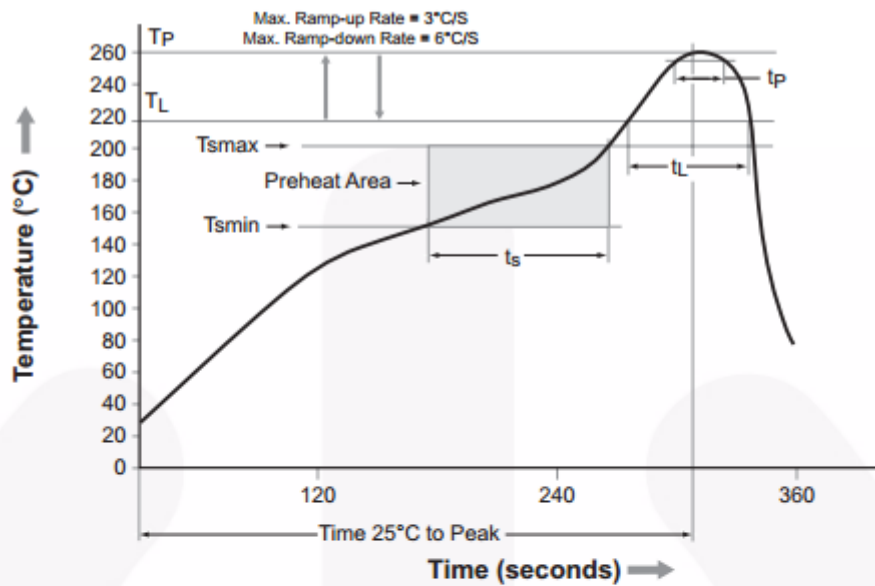


Figure 22. 16 Pin LGA 3.3 x 3.3 x 1 mm Package

## 12.2 Reflow Specification



| Profile Feature                  | Pb-Free Assembly Profile |
|----------------------------------|--------------------------|
| Temperature Min. (T Amin)        | 150°C                    |
| Temperature Max. (Tsmax)         | 200°C                    |
| Time (ts) from (T Amin to Tsmax) | 60–120 seconds           |
| Ramp-up Rate (tL to tp)          | 3°C/second max.          |
| Liquidous Temperature (TL)       | 217°C                    |
| Time (tL) Maintained Above (TL)  | 60–150 seconds           |
| Peak Body Package Temperature    | 260°C +0°C / -5°C        |
| Time (tp) within 5°C of 260°C    | 30 seconds               |
| Ramp-down Rate (TP to TL)        | 6°C/second max.          |
| Time 25°C to Peak Temperature    | 8 minutes max.           |

Figure 23. Reflow Profile

## 12.3 Storage Specifications

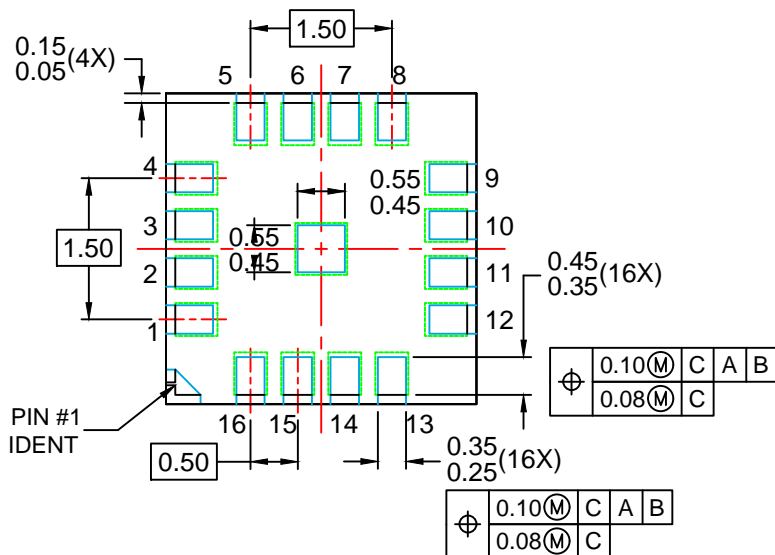
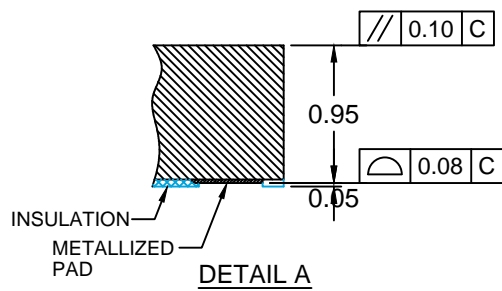
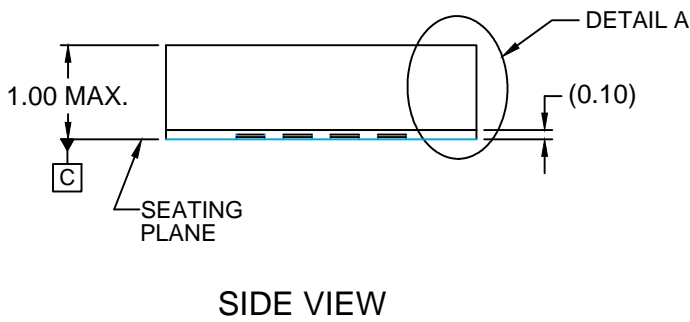
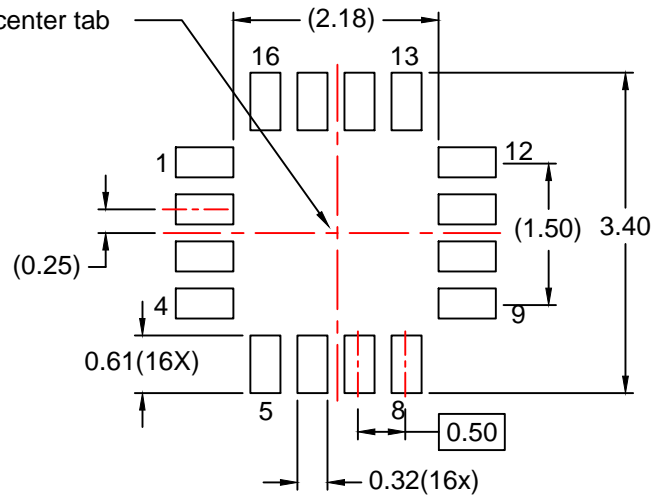
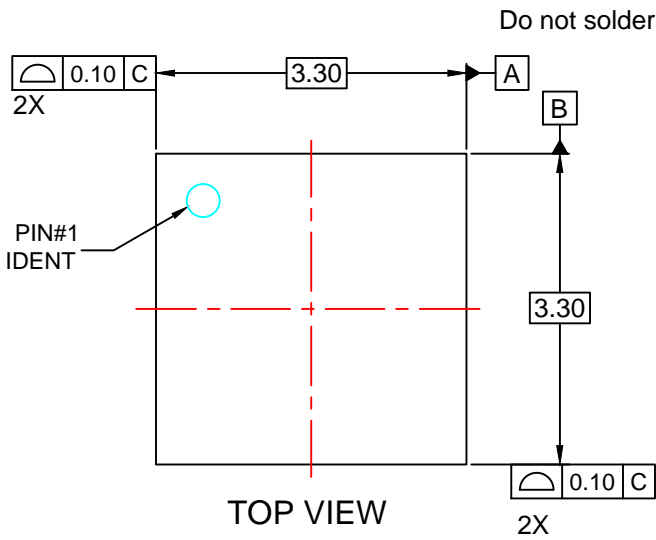
FIS1100 storage specification conforms to IPC/JEDEC J-STD-020D.01 Moisture Sensitivity Level (MSL) 3. Floor life after opening the moisture-sealed bag is 168 hours with storage conditions: Temperature: ambient to  $\leq 30^{\circ}\text{C}$  and Relative Humidity: 60%RH.

## 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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