

# **Ten Degrees of Freedom Inertial Sensor**

# ADIS16407

## **FEATURES**

Triaxial digital gyroscope with digital range scaling ±75°/sec, ±150°/sec, ±300°/sec settings Axis-to-axis alignment, <0.05° Triaxial digital accelerometer, ±18 g minimum Triaxial digital magnetometer, ±2.5 gauss minimum Digital barometer, 10 mbar to 1200 mbar Calibrated pressure range: 300 mbar to 1100 mbar Autonomous operation and data collection No external configuration commands required 210 ms start-up time, 4 ms sleep mode recovery time Factory calibrated sensitivity, bias, and axial alignment Calibration temperature range: -40°C to +85°C SPI-compatible serial interface **Embedded temperature sensor Programmable operation and control** Automatic and manual bias correction controls Bartlett window FIR length, number of taps Digital I/O: data ready, alarm indicator, general-purpose Alarms for condition monitoring Sleep mode for power management **DAC output voltage** Enable external sample clock input up to 1.1 kHz Single command self test Single-supply operation: 4.75 V to 5.25 V 2000 g shock survivability Operating temperature range: -40°C to +105°C

## **GENERAL DESCRIPTION**

The ADIS16407 iSensor® device is a complete inertial system that includes a triaxial gyroscope, a triaxial accelerometer, a triaxial magnetometer, and pressure sensors. Each sensor in the ADIS16407 combines industry-leading *i*MEMS<sup>®</sup> technology with signal conditioning that optimizes dynamic performance. The factory calibration characterizes each sensor for sensitivity, bias, alignment, and linear acceleration (gyro bias). As a result, each sensor has its own dynamic compensation formulas that provide accurate sensor measurements.

The ADIS16407 provides a simple, cost-effective method for integrating accurate, multiaxis inertial sensing into industrial systems, especially when compared with the complexity and investment associated with discrete designs. All necessary motion testing and calibration are part of the production process at the factory, greatly reducing system integration time. Tight orthogonal alignment simplifies inertial frame alignment in navigation systems. The SPI and register structure provide a simple interface for data collection and configuration control.

The ADIS16407 has a compatible pinout for systems that currently use ADIS1635x, ADIS1636x, and ADIS1640x IMU products. The ADIS16407 is packaged in a module that is approximately 23 mm  $\times$  23 mm  $\times$  23 mm and has a standard connector interface.

## **APPLICATIONS**

**Platform stabilization and control** Navigation Robotics



## FUNCTIONAL BLOCK DIAGRAM

#### Figure 1.

#### Rev. 0

Information furnished by Analog Devices is believed to be accurate and reliable. However, no responsibility is assumed by Analog Devices for its use, nor for any infringements of patents or other rights of third parties that may result from its use. Specifications subject to change without notice. No license is granted by implication or otherwise under any patent or patent rights of Analog Devices. Trademarks and registered trademarks are the property of their respective owners.

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A. www.analog.com Tel: 781.329.4700 Fax: 781.461.3113 ©2011 Analog Devices, Inc. All rights reserved.

# **TABLE OF CONTENTS**

Features
Applications
General Description
Functional Block Diagram 1
Revision History 2
Specifications
Timing Specifications 6
Absolute Maximum Ratings7
ESD Caution7
Pin Configuration and Function Descriptions
Typical Performance Characteristics
Basic Operation10
Reading Sensor Data10
Reading Sensor Data10 Output Data Registers11
Reading Sensor Data    10      Output Data Registers    11      Input ADC Channel    13
Reading Sensor Data    10      Output Data Registers    11      Input ADC Channel    13      Device Configuration    13
Reading Sensor Data    10      Output Data Registers    11      Input ADC Channel    13      Device Configuration    13      User Registers    14
Reading Sensor Data    10      Output Data Registers    11      Input ADC Channel    13      Device Configuration    13      User Registers    14      System Functions    15
Reading Sensor Data10Output Data Registers11Input ADC Channel13Device Configuration13User Registers14System Functions15Global Commands15
Reading Sensor Data10Output Data Registers11Input ADC Channel13Device Configuration13User Registers14System Functions15Global Commands15Power Management15
Reading Sensor Data10Output Data Registers11Input ADC Channel13Device Configuration13User Registers14System Functions15Global Commands15Power Management15Product Identification15
Reading Sensor Data10Output Data Registers11Input ADC Channel13Device Configuration13User Registers14System Functions15Global Commands15Power Management15Product Identification15Memory Management15
Reading Sensor Data10Output Data Registers11Input ADC Channel13Device Configuration13User Registers14System Functions15Global Commands15Power Management15Product Identification15Memory Management15Self Test Function16
Reading Sensor Data10Output Data Registers11Input ADC Channel13Device Configuration13User Registers14System Functions15Global Commands15Power Management15Product Identification15Memory Management15Self Test Function16Status/Error Flags16

Data Ready Input/Output Indicator	
General-Purpose Input/Output	
Auxiliary DAC	
Digital Processing Configuration	
Sample Rate	
Input Clock Configuration	
Digital Filtering	
Dynamic Range	
Calibration	19
Gyroscopes	
Accelerometers	
Magnetometer Calibration	
Flash Updates	
Restoring Factory Calibration	
Alarms	
Static Alarm Use	22
Dynamic Alarm Use	22
Alarm Reporting	
Applications Information	
Installation/Handling	
Gyroscope Bias Optimization	
Interface Printed Circuit Board (PCB)	
Outline Dimensions	
Ordering Guide	

## **REVISION HISTORY**

4/11—Revision 0: Initial Version

# **SPECIFICATIONS**

 $T_A = 25^{\circ}$ C, VDD = 5 V, angular rate = 0°/sec, dynamic range = ±300°/sec ± 1 g, unless otherwise noted.

## Table 1.

Parameter	Test Conditions/Comments Min Typ Max			Max	Unit
GYROSCOPES					
Dynamic Range		±300	±350		°/sec
Initial Sensitivity	Dynamic range = $\pm 300^{\circ}$ /sec	0.0495	0.05	0.0505	°/sec/LSB
	Dynamic range = $\pm 150^{\circ}$ /sec		0.025		°/sec/LSB
	Dynamic range = $\pm 75^{\circ}$ /sec		0.0125		°/sec/LSB
Sensitivity Temperature Coefficient	$-40^{\circ}C \le T_{A} \le +85^{\circ}C$		±40		ppm/°C
Misalignment	Axis to axis		±0.05		Degrees
5	Axis to frame (package)		±0.5		Degrees
Nonlinearity	Best fit straight line		±0.1		% of FS
Initial Bias Error	±1 σ		±3		°/sec
In-Run Bias Stability	1 σ, SMPL PRD = 0x0001		0.007		°/sec
Angular Random Walk	$1 \sigma$ , SMPL PRD = 0x0001		1.9		°/√hr
Bias Temperature Coefficient	$-40^{\circ}C \le T_{A} \le +85^{\circ}C$		±0.01		°/sec/°C
Linear Acceleration Effect on Bias	Any axis, 1 $\sigma$ (MSC_CTRL[7] = 1)		0.05		°/sec/g
Bias Voltage Sensitivity	VDD = 4.75 V to 5.25 V		±0.3		°/sec/V
Output Noise	±300°/sec range, no filtering		0.8		°/sec rms
Rate Noise Density	$f = 25 Hz, \pm 300^{\circ}/sec$ range, no filtering		0.044		°/sec/√Hz rms
3 dB Bandwidth			330		Hz
Sensor Resonant Frequency			14.5		kHz
ACCELEROMETERS	Each axis				
Dynamic Range		±18			q
Initial Sensitivity		3.285	3.33	3.38	mg/LSB
Sensitivity Temperature Coefficient	–40°C ≤ T <sub>A</sub> ≤ +85°C		±50		ע ס°/mag
Misalignment	Axis to axis		0.2		Degrees
5	Axis to frame (package)		±0.5		Degrees
Nonlinearity	Best fit straight line		0.1		% of FS
Initial Bias Error	±1 σ		±50		m <i>q</i>
In-Run Bias Stability	1 σ, SMPL_PRD = 0x0001		0.2		m <i>q</i>
Velocity Random Walk	$1 \sigma$ , SMPL PRD = 0x0001		0.2		m/sec/√hr
Bias Temperature Coefficient	$-40^{\circ}C \le T_{A} \le +85^{\circ}C$		±0.3		mg/°C
Bias Voltage Sensitivity	VDD = 4.75 V to 5.25 V		2.5		mg/V
Output Noise	No filtering		9		m <i>q</i> rms
Noise Density	No filtering		0.5		mg/√Hz rms
3 dB Bandwidth	5		330		Hz
Sensor Resonant Frequency			5.5		kHz
MAGNETOMETER					
Dynamic Range		±2.5	±3.5		gauss
Initial Sensitivity	25℃	0.49	0.5	0.51	mgauss/LSB
Sensitivity Temperature Coefficient	25°C, 1 σ		600		ppm/°C
Misalignment	Axis to axis		0.25		Degrees
	Axis to frame (package)		0.5		Degrees
Nonlinearity	Best fit straight line		0.5		% of FS
Initial Bias Error	25°C, 0 gauss stimulus		±4		mgauss
Bias Temperature Coefficient	$-40^{\circ}C \le T_A \le +85^{\circ}C$		0.5		mgauss/°C
Output Noise	25°C, no filtering, rms		1.15		mgauss
Noise Density	25°C, no filtering, rms		0.06		mgauss/√Hz
Bandwidth	-3 dB		1540		Hz

Parameter	Test Conditions/Comments	Min	Тур	Max	Unit
BAROMETER					
Pressure Range					
Operating		300		1100	mbar
Extended <sup>1</sup>		10		1200	mbar
Sensitivity	BARO OUT only <sup>2</sup>		0.08		mbar/LSB
Total Error	$25^{\circ}$ C. 300 mbar to 1100 mbar		1.5		mbar
Relative Error <sup>3</sup>	$-40^{\circ}$ C to $+85^{\circ}$ C 300 mbar to 1100 mbar		2.5		mbar
Linearity <sup>4</sup>	$25^{\circ}$ C 300 mbar to 1100 mbar		0.1		% of FS
Linconty	$-40^{\circ}$ C to $+85^{\circ}$ C 300 mbar to 1100 mbar		0.1		% of FS
Noise			0.027		mbar rms
TEMPERATURE SENSOR			0.027		
Scale Factor	25°C, output = 0x0000		0.14		°C/LSB
ADC INPUT					
Resolution			12		Bits
Integral Nonlinearity			+2		LSB
Differential Nonlinearity			+1		LSB
Offset Error			+4		L SB
Gain Error			_ · +2		I SR
Input Bange		0	±Ζ	3 3	V
Input Capacitance	During acquisition	Ū	20	5.5	nF
	5  kO/100  pE to GND		20		pi
Besolution			12		Rits
Relative Accuracy	101 LSB < input code < 4095 LSB		+4		I SR
Differential Nonlinearity			⊥- <del>-</del> +1		L SB
			±1 +5		mV
Gain Error			±0 5		0%
Quiteut Banga		0	±0.5	2.2	%0 V
Output kange		0	2	5.5	0
Output Impedance			2		12
			10		μs
		2.0			M
Input High Voltage, VIII		2.0		0.0	V
Input Low voltage, Vil	$\overline{CC}$ since $  t_{2} \rangle$ and $  t_{2} \rangle$			0.8	V
	CS signal to wake up from sleep mode			0.55	v
CS Wake-Up Pulse Width		20			μs
Logic 1 Input Current, I <sub>H</sub>	$V_{H} = 3.3 V$		±0.2	±10	μΑ
Logic 0 Input Current, IL	$V_{IL} = 0 V$				-
All Pins Except RST			40	60	μΑ
RST Pin			1		mA
Input Capacitance, C <sub>IN</sub>			10		pF
DIGITAL OUTPUTS <sup>5</sup>					
Output High Voltage, V <sub>он</sub>	I <sub>SOURCE</sub> = 1.6 mA	2.4			V
Output Low Voltage, V <sub>OL</sub>	$I_{SINK} = 1.6 \text{ mA}$			0.4	V
FLASH MEMORY	Endurance <sup>6</sup>	10,000			Cycles
Data Retention <sup>7</sup>	T <sub>J</sub> = 85°C	20			Years
FUNCTIONAL TIMES <sup>8</sup>	Time until new data is available				
Power-On Start-Up Time			210		ms
Reset Recovery Time			90		ms
Sleep Mode Recovery Time			7		ms
Flash Memory Update Time			75		ms
Flash Memory Test Time			30		ms
Automatic Self Test Time	SMPL_PRD = 0x0001		52		ms

Parameter	Test Conditions/Comments	Min	Тур	Max	Unit
CONVERSION RATE					SPS
xGYRO_OUT, xACCL_OUT, xMAGN_OUT	SMPL_PRD = 0x0001		819.2		SPS
BAR_OUT, BARO_OUTL <sup>9</sup>	$SMPL_PRD = 0x0001$		51.2		SPS
Clock Accuracy				±3	%
Sync Input Clock <sup>10</sup>		0.8		1.1	kHz
POWER SUPPLY	Operating voltage range, VDD	4.75	5.0	5.25	V
Power Supply Current			70		mA
	Sleep mode		1.4		mA

<sup>5</sup> The digital I/O signals are driven by an internal 3.3 V supply, and the inputs are 5 V tolerant. <sup>6</sup> Endurance is qualified as per JEDEC Standard 22, Method A117, and measured at -40°C, +25°C, +85°C, and +125°C.

<sup>7</sup> The data retention lifetime equivalent is at a junction temperature (T<sub>J</sub>) of 85°C as per JEDEC Standard 22, Method A117. Data retention lifetime decreases with junction temperature.

<sup>9</sup> Thes Etimes do not include thermal settling and internal filter response times (330 Hz bandwidth), which may affect overall accuracy. <sup>9</sup> The BARO\_OUT and BARO\_OUTL registers sample at a rate that is 1/16<sup>th</sup> that of the other output registers.

<sup>10</sup> The sync input clock functions below the specified minimum value, but at reduced performance levels.

 <sup>&</sup>lt;sup>1</sup> The extended pressure range is guaranteed by design.
 <sup>2</sup> See Table 22 for the BAR\_OUTL register details, which offer additional digital resolution improvements.
 <sup>3</sup> The relative error assumes that the initial error, at +25°C, is corrected in the end application.

<sup>&</sup>lt;sup>4</sup> Linearity errors assume a full scale (FS) of 1000 mbar.

## TIMING SPECIFICATIONS

 $T_A = 25^{\circ}C$ , VDD = 5 V, unless otherwise noted.

### Table 2.

		No	ormal Me	ode	B	Burst Rea	d	
Parameter	Description	Min <sup>1</sup>	Тур	Max	Min <sup>1</sup>	Тур	Max	Unit
<b>f</b> sclk	Serial clock	0.01		2.0	0.01		1.0	MHz
t <sub>stall</sub>	Stall period between data	9			1/f <sub>SCLK</sub>			μs
<b>t</b> readrate	Read rate	40						μs
t <sub>cs</sub>	Chip select to SCLK edge	48.8			48.8			ns
t <sub>DAV</sub>	DOUT valid after SCLK edge			100			100	ns
t <sub>DSU</sub>	DIN setup time before SCLK rising edge	24.4			24.4			ns
<b>t</b> DHD	DIN hold time after SCLK rising edge	48.8			48.8			ns
tsclkr, tsclkf	SCLK rise/fall times, not shown in Timing Diagrams		5	12.5		5	12.5	ns
tdr, tdf	DOUT rise/fall times, not shown in Timing Diagrams		5	12.5		5	12.5	ns
t <sub>SFS</sub>	CS high after SCLK edge	5			5			ns
t1	Input sync positive pulse width	5			5			μs
t <sub>x</sub>	Input sync low time	100			100			μs
t <sub>2</sub>	Input sync to data ready output		600			600		μs
t <sub>3</sub>	Input sync period	910			910			μs

<sup>1</sup> Guaranteed by design and characterization, but not tested in production.



Figure 4. Input Clock Timing Diagram

Rev. 0 | Page 6 of 24

## **ABSOLUTE MAXIMUM RATINGS**

#### Table 3.

Parameter	Rating
Acceleration	
Any Axis, Unpowered	2000 g
Any Axis, Powered	2000 g
VDD to GND	–0.3 V to +6.0 V
Digital Input Voltage to GND	–0.3 V to +5.3 V
Digital Output Voltage to GND	–0.3 V to +3.6 V
Analog Input to GND	–0.3 V to +3.6 V
Temperature	
Operating Range	–40°C to +105°C
Storage Range	-65°C to +125°C <sup>1, 2</sup>
Pressure	6 bar

<sup>1</sup> Extended exposure to temperatures outside the specified temperature range of  $-40^{\circ}$ C to  $+105^{\circ}$ C can adversely affect the accuracy of the factory calibration. For best accuracy, store the parts within the specified operating range of  $-40^{\circ}$ C to  $+105^{\circ}$ C.

<sup>2</sup> Although the device is capable of withstanding short-term exposure to 150°C, long-term exposure threatens internal mechanical integrity.

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

## Table 4. Package Characteristics

Package Type	θ」Α	θις	Device Weight
24-Lead Module (ML-24-2)	39.8°C/W	14.2°C/W	16 grams

## **ESD CAUTION**



**ESD** (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

## **PIN CONFIGURATION AND FUNCTION DESCRIPTIONS**



NOTES 1. THIS VIEW REPRESENTS THE TOP VIEW OF THE MATING CONNECTOR. 2. WHEN CONNECTED, THE PINS ARE NOT VISIBLE. 3. MATING CONNECTOR: SAMTEC CLM-112-02 OR EQUIVALENT. 4. DNC = DO NOT CONNECT.

Figure 5. Pin Configuration

#### **Table 5. Pin Function Descriptions**



Figure 6. Axial Orientation

Pin No.	Mnemonic	Type <sup>1</sup>	Description
1	DIO3	I/O	Configurable Digital Input/Output.
2	DIO4/CLKIN	I/O	Configurable Digital Input/Output or Sync Clock Input.
3	SCLK	1	SPI Serial Clock.
4	DOUT	0	SPI Data Output. Clocks the output on the SCLK falling edge.
5	DIN	1	SPI Data Input. Clocks the input on the SCLK rising edge.
6	CS	1	SPI Chip Select.
7	DIO1	I/O	Configurable Digital Input/Output.
8	RST	1	Reset.
9	DIO2	I/O	Configurable Digital Input/Output.
10, 11, 12	VDD	S	Power Supply.
13, 14, 15	GND	S	Power Ground.
16, 17, 18, 19, 22, 23, 24	DNC	N/A	Do Not Connect. Do not connect to these pins.
20	AUX_DAC	0	Auxiliary, 12-Bit DAC Output.
21	AUX_ADC	1	Auxiliary, 12-Bit ADC Input.

00-797-005

<sup>1</sup> S is supply, O is output, I is input, N/A is not applicable.

# **TYPICAL PERFORMANCE CHARACTERISTICS**







## **BASIC OPERATION**

The ADIS16407 is an autonomous system that requires no user initialization. When it has a valid power supply, it initializes itself and starts sampling, processing, and loading sensor data into the output registers at a sample rate of 819.2 SPS. DIO1 pulses high after each sample cycle concludes. The SPI interface enables simple integration with many embedded processor platforms, as shown in Figure 9 (electrical connection) and Table 6 (pin functions).



Figure 9. Electrical Connection Diagram

Table 6. Generic Master	r Processor Pin	Names and	Functions
-------------------------	-----------------	-----------	-----------

Pin Name	Function
SS	Slave select
SCLK	Serial clock
MOSI	Master output, slave input
MISO	Master input, slave output
IRQ	Interrupt request

The ADIS16407 SPI interface supports full duplex serial communication (simultaneous transmit and receive) and uses the bit sequence shown in Figure 13. Table 7 provides a list of the most common settings that require attention to initialize the serial port of a processor for the ADIS16407 SPI interface.

#### Table 7. Generic Master Processor SPI Settings

Processor Setting	Description
Master	The ADIS16407 operates as a slave
SCLK Rate $\leq 2 \text{ MHz}^1$	Maximum serial clock rate
SPI Mode 3	CPOL = 1 (polarity), CPHA = 1 (phase)
MSB-First Mode	Bit sequence
16-Bit Mode	Shift register/data length



cs SCLK DIN

DOUT

## **READING SENSOR DATA**

The ADIS16407 provides two different options for acquiring sensor data: single register and burst register. A single register read requires two 16-bit SPI cycles. The first cycle requests the contents of a register using the bit assignments in Figure 13. Bit DC7 to Bit DC0 are don't care for a read, and then the output register contents follow on DOUT during the second sequence. Figure 10 includes three single register reads in succession. In this example, the process starts with DIN = 0x0400 to request the contents of XGYRO OUT, then follows with 0x0600 to request YGYRO\_OUT and 0x0800 to request ZGYRO\_OUT. Full duplex operation enables processors to use the same 16-bit SPI cycle to read data from DOUT while requesting the next set of data on DIN. Figure 11 provides an example of the four SPI signals when reading XGYRO\_OUT in a repeating pattern.



#### **Burst Read Function**

The burst read function enables the user to read all output registers using one command on the DIN line and shortens the stall time between each 16-bit segment to one SCLK cycle (see Table 2). Figure 12 provides the burst read sequence of data on each SPI signal. The sequence starts with writing 0x3E00 to DIN, followed by each output register clocking out on DOUT, in the order in which they appear in Table 8.



## **OUTPUT DATA REGISTERS**

The output registers in Table 8 provide the most recent sensor data produced by the ADIS16407. Each output register has flags for new data indication and error/alarm conditions, which reduces the need to monitor DIAG\_STAT.

#### **Table 8. Output Data Register Formats**

Register	Address	Measurement	
SUPPLY_OUT	0x02	Power supply	
XGYRO_OUT	0x04	Gyroscope, x-axis	
YGYRO_OUT	0x06	Gyroscope, y-axis	
ZGYRO_OUT	0x08	Gyroscope, z-axis	
XACCL_OUT	0x0A	Accelerometer, x-axis	
YACCL_OUT	0x0C	Accelerometer, y-axis	
ZACCL_OUT	0x0E	Accelerometer, z-axis	
XMAGN_OUT	0x10	Magnetometer, x-axis	
YMAGN_OUT	0x12	Magnetometer, y-axis	
ZMAGN_OUT	0x14	Magnetometer, z-axis	
BARO_OUT	0x16	Barometer/pressure, higher	
BARO_OUTL	0x18	Barometer/pressure, lower	
TEMP_OUT <sup>1</sup>	0x1A	Internal temperature	
AUX_ADC	0x1C	Auxiliary ADC	

<sup>1</sup> This is most useful for monitoring relative changes in the temperature.



Figure 14. Inertial Sensor Direction Reference

## Gyroscopes

Figure 14 provides arrows (g<sub>x</sub>, g<sub>y</sub>, g<sub>z</sub>) that indicate the direction of rotation, which produces a positive response in the gyroscope output registers: XGYRO\_OUT (x-axis, Table 9), YGYRO\_OUT (y-axis, Table 10), and ZGYRO\_OUT (z-axis, Table 11). Table 12 illustrates the gyroscope data format.

Table 9. XGYRO	_OUT (Base	Address = $0x04$ ),	, Read Only
----------------	------------	---------------------	-------------

Bits	Description
[15]	New data indicator (ND), 1 = new data in register
[14]	Error/alarm, 1 = active, see DIAG_STAT for error flags
[13:0]	X-axis gyroscope data, twos complement format, 0.05°/sec per LSB, when SENS_AVG[15:8] = 0x04

Table 10. YGYRO	OUT (Base	e Address = 0x0	6), Read Only
-----------------	-----------	-----------------	---------------

Bits	Description
[15]	New data indicator (ND), 1 = new data in register
[14]	Error/alarm, 1 = active, see DIAG_STAT for error flags
[13:0]	Y-axis gyroscope data, twos complement format, 0.05°/sec per LSB, when SENS_AVG[15:8] = 0x04

#### Table 11. ZGYRO\_OUT (Base Address = 0x08), Read Only

Bits	Description
[15]	New data indicator (ND), 1 = new data in register
[14]	Error/alarm, 1 = active, see DIAG_STAT for error flags
[13:0]	Z-axis gyroscope data, twos complement format, 0.05°/sec per LSB, when SENS_AVG[15:8] = 0x04

#### Table 12. Rotation Rate, Twos Complement Format

<b>Rotation Rate</b>	Decimal	Hex	Binary
+300°/sec	+6000	0x1770	xx01 0111 0111 0000
+0.1°/sec	+2	0x0002	xx00 0000 0000 0010
+0.05°/sec	+1	0x0001	xx00 0000 0000 0001
0°/sec	0	0x0000	xx00 0000 0000 0000
–0.05°/sec	-1	0x3FFF	xx11 1111 1111 1111
–0.1°/sec	-2	0x3FFE	xx11 1111 1111 1110
-300°/sec	-6000	0x2890	xx10 1000 1001 0000

### Accelerometers

Figure 14 provides arrows (a<sub>x</sub>, a<sub>y</sub>, a<sub>z</sub>) that indicate the direction of acceleration, which produces a positive response in the gyroscope output registers: XACCL\_OUT (x-axis, Table 13), YACCL\_OUT (y-axis, Table 14), and ZACCL\_OUT (z-axis, Table 15). Table 16 illustrates the accelerometer data format.

#### Table 13. XACCL\_OUT (Base Address = 0x0A), Read Only

Bits	Description
[15]	New data indicator (ND), 1 = new data in register
[14]	Error/alarm, 1 = active, see DIAG_STAT for error flags
[13:0]	X-axis acceleration data, twos complement format, 0.25 mg per LSB

## Table 14. YACCL\_OUT (Base Address = 0x0C), Read Only

Bits	Description
[15]	New data indicator (ND), 1 = new data in register
[14]	Error/alarm, 1 = active, see DIAG_STAT for error flags
[13:0]	Y-axis acceleration data, twos complement format, 0.25 mg per LSB

### Table 15. ZACCL\_OUT (Base Address = 0x0E), Read Only

Bits	Description
[15]	New data indicator (ND), 1 = new data in register
[14]	Error/alarm, 1 = active, see DIAG_STAT for error flags
[13:0]	Z-axis acceleration data, twos complement format, 0.25 mg per LSB

Acceleration	Decimal	Hex	Binary
+18 <i>g</i>	+5401	0x1519	xx01 0101 0001 1001
+6.667 m <i>g</i>	+2	0x0002	xx00 0000 0000 0010
+3.333 mg	+1	0x0001	xx00 0000 0000 0001
0 <i>g</i>	0	0x0000	xx00 0000 0000 0000
–3.333 m <i>g</i>	-1	0x3FFF	xx11 1111 1111 1111
–6.667 m <i>g</i>	-2	0x3FFE	xx11 1111 1111 1110
–18 <i>g</i>	-5401	0x2AE7	xx10 1010 1110 0111
			·

## Table 16. Acceleration, Twos Complement Format

### Magnetometers

Figure 14 provides arrows (m<sub>x</sub>, m<sub>y</sub>, m<sub>z</sub>) that indicate the direction of the magnetic field, which produces a positive response in the gyroscope output registers: XMAGN\_OUT (x-axis, Table 17), YMAGN\_OUT (y-axis, Table 18), and ZAMAGN\_OUT (z-axis, Table 19). Table 20 illustrates the magnetic field intensity data format.

Table 17. XMAGN\_OUT (Base Address = 0x10), Read Only

Bits	Description
[15]	New data indicator (ND), 1 = new data in register
[14]	Error/alarm, 1 = active, see DIAG_STAT for error flags
[13:0]	X-axis magnetic field intensity data, twos complement format, 0.5 mgauss per LSB

### Table 18. YMAGN\_OUT (Base Address = 0x12), Read Only

Bits	Description
[15]	New data indicator (ND), 1 = new data in register
[14]	Error/alarm, 1 = active, see DIAG_STAT for error flags
[13:0]	Y-axis magnetic field intensity data, twos complement
	format, 0.5 mgauss per LSB

#### Table 19. ZMAGN\_OUT (Base Address = 0x14), Read Only

Bits	Description
[15]	New data indicator (ND), 1 = new data in register
[14]	Error/alarm, 1 = active, see DIAG_STAT for error flags
[13:0]	Z-axis magnetic field intensity data, twos complement format, 0.5 mgauss per LSB

## Table 20. Magnetometer, Twos Complement Format

Magnetic Field	Decimal	Hex	Binary
+2.5 gauss	+5000	0x1388	xx01 0011 1000 1000
+0.001 gauss	+2	0x0002	xx00 0000 0000 0010
+0.0005 gauss	+1	0x0001	xx00 0000 0000 0001
0 gauss	0	0x0000	xx00 0000 0000 0000
–0.0005 gauss	-1	0x3FFF	xx11 1111 1111 1111
–0.0005 gauss	-2	0x3FFE	xx11 1111 1111 1110
–2.5 gauss	-5000	0x2C78	xx10 1100 0111 1000

#### **Barometric Pressure**

The barometric pressure measurements are contained in two registers, BARO\_OUT (Table 21) and BARO\_OUTL (Table 22) registers. Table 23 provides several numerical format examples for BARO\_OUT, which is sufficient for most applications.

Use BAR\_OUTL and the following steps to increase the numerical resolution by 8-bits for best performance:

- 1. Read BAR\_OUT and multiply by 256 (shift 8 bits)
- 2. Read BAR\_OUTL and max off upper 8 bits
- 3. Add results together for a 24-bit result, where 1 LSB = 0.0003125 and 0x00000 = 0 mbar

Bits	Description
[15]	New data indicator (ND), 1 = new data in register
[14]	Error/alarm, 1 = active, see DIAG_STAT for error flags
[13:0]	Barometric pressure data, binary data format, 0.08 mbar per LSB, 0x0000 = 0 mbar

#### Table 22. BARO\_OUTL (Base Address = 0x18), Read Only

Bits	Description
[15:8]	Not used
[7:0]	Barometric pressure data, binary data format, 0.0003125 mbar per LSB, 0x0000 = 0 mbar

#### Table 23. Pressure, Binary, BARO\_OUT Only

Pressure			
(mbar)	Decimal	Hex	Binary
1200	15,000	0x3A98	xx11 1010 1001 1000
1100	13,750	0x35B6	xx11 0101 1011 0110
1000	12,500	0x30D4	xx11 0000 1101 0100
0.16	2	0x0002	xx00 0000 0000 0010
0.08	1	0x0001	xx00 0000 0000 0001
0	0	0x0000	xx00 0000 0000 0000

#### Internal Temperature

The internal temperature measurement data loads into the TEMP\_OUT (Table 24) register. Table 25 illustrates the temperature data format.

#### Table 24. TEMP\_OUT (Base Address = 0x1A), Read Only

	•
Bits	Description
[15]	New data indicator (ND), 1 = new data in register
[14]	Error/alarm, 1 = active, see DIAG_STAT for error flags
[13:12]	Not used
[11:0]	Internal temperature data, twos complement, $0.136^{\circ}C/ISB.25^{\circ}C = 0x000$

#### Table 25. Temperature, Twos Complement Format

Temperature	Decimal	Hex	Binary	
+105°C	+588 LSB	0x24C	xxxx 0010 0100 1100	
+85°C	+441 LSB	0x1B9	xxxx 0001 1011 1001	
+25.272°C	+2 LSB	0x002	xxxx 0000 0000 0010	
+25.136°C	+1 LSB	0x001	xxxx 0000 0000 0001	
+25°C	0 LSB	0x000	xxxx 0000 0000 0000	
+24.864°C	–1 LSB	0xFFF	xxxx 1111 1111 1111	
+24.728°C	–2 LSB	0xFFE	xxxx 1111 1111 1110	
-40°C	–478 LSB	0xE22	xxxx 1110 0010 0010	

## **Power Supply**

The SUPPLY\_OUT register (Table 26) provides a measurement of the voltage that is on the VDD pins of the device. Table 27 illustrates the power supply data format.

Table 26. SUPPLY\_OUT (Base Address = 0x02), Read Only

Bits	Description
[15]	New data indicator (ND), 1 = new data in register
[14]	Error/alarm, 1 = active, see DIAG_STAT for error flags
[13:12]	Not used
[11:0]	Power supply measurement data, binary format, 2.418 mV/LSB, $0 V = 0x000$

Table 27. Power Supply Data, Binary Format

Voltage	Decimal	Hex	Binary
+5.25 V	2171	0x87B	xxxx 1000 0111 1011
+5.0 V	2068	0x814	xxxx 1000 0001 0100
+4.75 V	1964	0x7AC	xxxx 0111 1010 1100
1 V	414	0x19E	xxxx 0001 1001 1110
4.836 mV	2	0x002	xxxx 0000 0000 0010
2.418 mV	1	0x001	xxxx 0000 0000 0001
0 V	0	0x000	xxxx 0000 0000 0000

## **INPUT ADC CHANNEL**

The AUX\_ADC register provides access to the auxiliary ADC input channel. The ADC is a 12-bit successive approximation converter that has an input circuit equivalent to the one shown in Figure 15. The maximum input is 3.3 V. The ESD protection diodes can handle 10 mA without causing irreversible damage. The on resistance (R1) of the switch has a typical value of 100  $\Omega$ . The sampling capacitor, C2, has a typical value of 16 pF.



Figure 15. Equivalent Analog Input Circuit (Conversion Phase: Switch Open, Track Phase: Switch Closed)

Table 28. AUX	_ADC (Base A	Address = 0x1C),	Read Only
---------------	--------------	------------------	-----------

Bits	Description
[15]	New data indicator (ND), 1 = new data in register
[14]	Error/alarm, 1 = active, see DIAG_STAT for error flags
[13:12]	Not used
[11:0]	Analog input channel data, binary format, 0.8059 mV/LSB, 0 V = 0x000

Table 29. Analog In	put, Offset Binary	Format
---------------------	--------------------	--------

Input Voltage	Decimal	Hex	Binary
3.3 V	4095	0xFFF	xxxx 1111 1111 1111
1 V	1241	0x4D9	xxxx 0100 1101 1001
1.6118 mV	2	0x002	xxxx 0000 0000 0010
805.9 μV	1	0x001	xxxx 0000 0000 0001
0 V	0	0x000	xxxx 0000 0000 0000

### **DEVICE CONFIGURATION**

The control registers in Table 30 provide users with a variety of configuration options. The SPI provides access to these registers, one byte at a time, using the bit assignments in Figure 13. Each register has 16 bits, where Bits[7:0] represent the lower address, and Bits[15:8] represent the upper address. Figure 16 provides an example of writing 0x03 to Address 0x3A (SMPL\_PRD[15:8]), using DIN = 0xB703. This example reduces the sample rate by a factor of eight (see Table 46).



### **Dual Memory Structure**

Writing configuration data to a control register updates its SRAM contents, which are volatile. After optimizing each relevant control register setting in a system, set GLOB\_CMD[3] = 1 (DIN = 0xBE08) to backup these settings in nonvolatile flash memory. The flash backup process requires a valid power supply level for the entire 75 ms process time. Table 30 provides a user register memory map that includes a flash backup column. A "yes" in this column indicates that a register has a mirror location in flash and, when backed up properly, it automatically restores itself during startup or after a reset. Figure 17 provides a diagram of the dual memory structure used to manage operation and store critical user settings.



Figure 17. SRAM and Flash Memory Diagram

# **USER REGISTERS**

Table 30. User Register Memory Map<sup>1</sup>

FLASH_CNT   R   Yes   0x00   N/A   Flash memory write count	See Table 38
SUPPLY_OUT         R         No         0x02         N/A         Power supply measurement	See Table 26
XGYRO_OUT R No 0x04 N/A X-axis gyroscope output	See Table 9
YGYRO_OUT R No 0x06 N/A Y-axis gyroscope output	See Table 10
ZGYRO_OUT R No 0x08 N/A Z-axis gyroscope output	See Table 11
XACCL_OUT R No 0x0A N/A X-axis accelerometer output	See Table 13
YACCL_OUT R No 0x0C N/A Y-axis accelerometer output	See Table 14
ZACCL_OUT R No 0x0E N/A Z-axis accelerometer output	See Table 15
XMAGN_OUT         R         No         0x10         N/A         X-axis magnetometer measurement	See Table 17
YMAGN_OUT R No 0x12 N/A Y-axis magnetometer measurement	See Table 18
ZMAGN_OUT R No 0x14 N/A Z-axis magnetometer measurement	See Table 19
BARO_OUT R No 0x16 N/A Barometer pressure measurement, high word	See Table 21
BARO_OUTL R No 0x18 N/A Barometer pressure measurement, low word	See Table 22
TEMP_OUT R No 0x1A N/A Temperature output	See Table 24
AUX_ADC R No 0x1C N/A Auxiliary ADC measurement	See Table 28
XGYRO_OFF R/W Yes 0x1E 0x0000 X-axis gyroscope bias offset factor	See Table 49
YGYRO_OFF R/W Yes 0x20 0x0000 Y-axis gyroscope bias offset factor	See Table 50
ZGYRO_OFF R/W Yes 0x22 0x0000 Z-axis gyroscope bias offset factor	See Table 51
XACCL_OFF R/W Yes 0x24 0x0000 X-axis acceleration bias offset factor	See Table 52
YACCL OFF R/W Yes 0x26 0x0000 Y-axis acceleration bias offset factor	See Table 53
ZACCL OFF R/W Yes 0x28 0x0000 Z-axis acceleration bias offset factor	See Table 54
XMAGN HIC R/W Yes 0x2A 0x0000 X-axis magnetometer, hard iron factor	See Table 55
YMAGN_HIC R/W Yes 0x2C 0x0000 Y-axis magnetometer, hard iron factor	See Table 56
ZMAGN_HIC R/W Yes 0x2E 0x0000 Z-axis magnetometer, hard iron factor	See Table 57
XMAGN_SIC R/W Yes 0x30 0x0800 X-axis magnetometer, soft iron factor	See Table 58
YMAGN_SIC R/W Yes 0x32 0x0800 Y-axis magnetometer, soft iron factor	See Table 59
ZMAGN_SIC R/W Yes 0x34 0x0800 Z-axis magnetometer, soft iron factor	See Table 60
GPIO_CTRL R/W No 0x36 0x0000 Auxiliary digital input/output control	See Table 42
MSC_CTRL R/W Yes 0x38 0x0006 Miscellaneous control	See Table 39
SMPL PRD R/W Yes 0x3A 0x0001 Internal sample period (rate) control	See Table 46
SENS AVG R/W Yes 0x3C 0x0402 Dynamic range and digital filter control	See Table 47
SLP_CTRL W No 0x3E N/A Sleep mode control	See Table 33
DIAG STAT R No 0x40 0x0000 System status	See Table 40
GLOB CMD W N/A 0x42 0x0000 System command	See Table 32
ALM MAG1 R/W Yes 0x44 0x0000 Alarm 1 amplitude threshold	See Table 62
ALM MAG2 R/W Yes 0x46 0x0000 Alarm 2 amplitude threshold	See Table 63
ALM_SMPL1 R/W Yes 0x48 0x0000 Alarm 1 sample size	See Table 64
ALM_SMPL2 R/W Yes 0x4A 0x0000 Alarm 2 sample size	See Table 65
ALM_CTRL R/W Yes 0x4C 0x0000 Alarm control	See Table 66
AUX_DAC	See Table 43
Reserved N/A N/A 0x50 N/A Reserved	
LOT ID1 R Yes 0x52 N/A Lot identification number	See Table 34
I OT ID2 R Yes 0x54 N/A Lot identification number	See Table 35
PROD ID R Yes 0x56 0x4107 Product identifier	See Table 36
SERIAL NUM R Yes 0x58 N/A	See Table 37

<sup>1</sup> N/A means not applicable. <sup>2</sup> Each register contains two bytes. The address of the lower byte is displayed. The address of the upper byte is equal to the address of the lower byte plus 1.

## SYSTEM FUNCTIONS

The ADIS16407 provides a number of system level controls for managing its operation, using the registers in Table 31.

## Table 31. System Tool Registers

<b>Register Name</b>	Address	Description
MSC_CTRL	0x38	Self test, calibration, data ready
SLP_CTRL	0x3E	Sleep mode control
DIAG_STAT	0x40	Error flags
GLOB_CMD	0x42	Single command functions
LOT_ID1	0x52	Lot Identification Code 1
LOT_ID2	0x54	Lot Identification Code 2
PROD_ID	0x56	Product identifier
SERIAL_NUM	0x58	Serial number

## **GLOBAL COMMANDS**

The GLOB\_CMD register in Table 32 provides trigger bits for software reset, flash memory management, DAC control, and calibration control. Start each of these functions by writing a 1 to the assigned bit in GLOB\_CMD. After completing the task, the bit automatically returns to 0. For example, set GLOB\_CMD[7] = 1 (DIN = 0xC280) to initiate a software reset, which stops the sensor operation and runs the device through its start-up sequence. Set GLOB\_CMD[3] = 1 (DIN = 0xC208) to back up the user register contents in nonvolatile flash. This sequence includes loading the control registers with the data in their respective flash memory locations prior to producing new data.

## Table 32. GLOB\_CMD (Base Address = 0x42), Write Only

Bits	Description (Default = 0x0000)
[15:8]	Not used
[7]	Software reset
[6:4]	Not used
[3]	Flash update
[2]	Auxiliary DAC data latch
[1]	Factory calibration restore
[0]	Gyroscope bias correction

## **POWER MANAGEMENT**

The SLP\_CTRL register (see Table 33) provides two sleep modes for system level management: normal and timed. Set SLP\_CTRL[8] = 1 (DIN = 0xBF01) to start normal sleep mode. When the device is in sleep mode, the following events can cause it to wake up: asserting  $\overline{CS}$  from high to low, asserting  $\overline{RST}$  from high to low, or cycling the power. Use SLP\_CTRL[7:0] to put the device into sleep mode for a specified period. For example, SLP\_CNT[7:0] = 0x64 (DIN = 0xBE64) puts the ADIS16407 to sleep for 50 seconds.

Table 33. SLP\_CTRL (Base Address = 0x3E), Write Only

Bits	Description	
[15:9]	Not used	
[8]	Normal sleep mode (1 = start sleep mode)	
[7:0]	Timed sleep mode (write 0x01 to 0xFF to start) Sleep mode duration, binary, 0.5 sec/LSB	

## **PRODUCT IDENTIFICATION**

The PROD\_ID register in Table 36 contains the binary equivalent of 16,407. It provides a product specific variable for systems that need to track this in their system software. The LOT\_ID1 and LOT\_ID2 registers in Table 34 and Table 35 combine to provide a unique, 32-bit lot identification code. The SERIAL\_NUM register in Table 37 contains a binary number that represents the serial number on the device label. The assigned serial numbers in SERIAL\_NUM are lot specific.

#### Table 34. LOT\_ID1 (Base Address = 0x52), Read Only

	_ (	
Bits	Description	
[15:0]	Lot identification, binary code	
Table 35	5. LOT_ID2 (Base Address = 0x54), Read Only	
Bits	Description	
[15:0]	Lot identification, binary code	
Table 36	5. PROD_ID Bit (Base Address = 0x56), Read Only	
BITS	Description (Default = 0x4017)	
[15:0]	Product identification = 0x4017	
Table 37. SERIAL_NUM (Base Address = 0x58), Read Only		
Bits	Description	
[15:12]	Reserved	
[11:0]	Serial number, 1 to 4094 (0xFFE)	

## MEMORY MANAGEMENT

The FLASH\_CNT register in Table 38 provides a 16-bit counter that helps track the number of write cycles to the nonvolatile flash memory. The flash updates every time a manual flash update occurs. A manual flash update is initiated by the GLOB\_CMD[3] bit and is also performed at the completion of the GLOB\_CMD[1:0] functions (see Table 32).

Table 38	. FLASH_	_CNT (Bas	e Address	= 0x00),	Read Only

Bits	Description
[15:0]	Binary counter

## **Checksum Test**

Set MSC\_CTRL[11] = 1 (DIN = 0xB908) to perform a checksum test of the internal program memory. This function takes a summation of the internal program memory and compares it with the original summation value for the same locations (from factory configuration). Check the results in the DIAG\_STAT register, which is in Table 40. DIAG\_STAT[6] equals 0 if the sum matches the correct value, and 1 if it does not. Make sure that the power supply is within specification for the entire 20 ms that this function takes to complete.

Rev. 0 | Page 15 of 24

## **SELF TEST FUNCTION**

The MSC\_CTRL register in Table 39 provides a self test function for the gyroscopes and accelerometers. This function allows the user to verify the mechanical integrity of each MEMS sensor. When enabled, the self test applies an electrostatic force to each internal sensor element, which causes them to move. The movement in each element simulates its response to actual rotation/ acceleration and generates a predictable electrical response in the sensor outputs. The ADIS16407 exercises this function and compares the response to an expected range of responses and reports a pass/fail response to DIAG\_STAT[5]. If this is high, the DIAG\_STAT[15:10] provide pass/fail flags for each inertial sensor.

Table 39. MSC	_CTRL (Base Address =	0x38), Read/Write
---------------	-----------------------	-------------------

Bits	Description (Default = 0x0006)
[15:12]	Not used
[11]	Checksum memory test (cleared upon completion) <sup>1</sup>
	1 = enabled, 0 = disabled
[10]	Internal self test (cleared upon completion) <sup>1</sup>
	1 = enabled, 0 = disabled
[9:8]	Do not use, always set to 00
[7]	Linear acceleration bias compensation for gyroscopes
	1 = enabled, 0 = disabled
[6]	Point of percussion, see Figure 6
	1 = enabled, 0 = disabled
[5:3]	Not used
[2]	Data ready enable
	1 = enabled, 0 = disabled
[1]	Data ready polarity
	1 = active high, 0 = active low
[0]	Data ready line select
	1 = DIO2, 0 = DIO1

<sup>1</sup> The bit is automatically reset to 0 after finishing the test.

## STATUS/ERROR FLAGS

The DIAG\_STAT register in Table 40 provides error flags for a number of functions. Each flag uses 1 to indicate an error condition and 0 to indicate a normal condition. Reading this register provides access to the status of each flag and resets all of the bits to 0 for monitoring future operation. If the error condition remains, the error flag returns to 1 at the conclusion of the next sample cycle. DIAG\_STAT[0] does not require a read of this register to return to 0. If the power supply voltage goes back into range, this flag clears automatically. The SPI communication error flag in DIAG\_STAT[3] indicates that the number of SCLKs in a SPI sequence did not equal a multiple of 16 SCLKs.

Table 40. DIAG	_STAT (Base	Address = 0x40)	, Read Only
----------------	-------------	-----------------	-------------

Bits	Description (Default = 0x0000)
[15]	Z-axis accelerometer self test failure
	1 = fail, 0 = pass
[14]	Y-axis accelerometer self test failure
	1 = fail, 0 = pass
[13]	X-axis accelerometer self test failure
	1 = fail, 0 = pass
[12]	Z-axis gyroscope self test failure
	0 = pass
[11]	Y-axis gyroscope self test failure
	1 = fail, 0 = pass
[10]	X-axis gyroscope self test failure
	1 = fail, 0 = pass
[9]	Alarm 2 status
	1 = active, 0 = inactive
[8]	Alarm 1 status
	1 = active, 0 = inactive
[7]	Not used
[6]	Flash test, checksum flag
	1 = fail, 0 = pass
[5]	Self test diagnostic error flag
	1 = fail, 0 = pass
[4]	Sensor overrange
	1 = overrange, 0 = normal
[3]	SPI communication failure
	1 = fail, 0 = pass
[2]	Flash update failure
	1 = fail, 0 = pass
[1]	Power supply high
	1 = VDD > 5.25 V
	$0 = VDD \le 5.25 V$
[0]	Power supply low
	1 = VDD < 4.75 V
	$0 = VDD \ge 4.75 V$

# **INPUT/OUTPUT CONFIGURATION**

Table 41 provides a summary of registers that provide input/output configuration and control.

## Table 41. Input/Output Registers

Register Name	Address	Description
GPIO_CTRL	0x36	General-purpose I/O control
MSC_CTRL	0x38	Self test, calibration, data ready
AUX_DAC	0x4E	Output voltage control, AUX_DAC

## DATA READY INPUT/OUTPUT INDICATOR

The factory default setting of MSC\_CTRL[2:0] = 110 establishes DIO1 as a positive polarity data ready signal. See Table 39 for additional data ready configuration options. For example, set MSC\_CTRL[2:0] = 100 (DIN = 0xB804) to change the polarity of the data ready signal on DIO1 for interrupt inputs that require negative logic inputs for activation. The pulse width is typically between 60  $\mu$ s and 150  $\mu$ s, including jitter (±30  $\mu$ s).

## **GENERAL-PURPOSE INPUT/OUTPUT**

DIO1, DIO2, DIO3, and DIO4 are configurable, general-purpose input/output lines that serve multiple purposes. The data ready controls in MSC\_CTRL[2:0] have the highest priority for configuring DIO1 and DIO2. The alarm indicator controls in ALM\_CTRL[2:0] have the second highest priority for configuring DIO1 and DIO2. The external clock control associated with SMPL\_PRD[0] has the highest priority for DIO4 configuration (see Table 46). GPIO\_CTRL in Table 42 has the lowest priority for configuring DIO1, DIO2, and DIO4, and has absolute control over DIO3.

#### Table 42. GPIO\_CTRL (Base Address = 0x36), Read/Write

Bits	Description (Default = 0x0000)
[15:12]	Not used
[11]	General-Purpose I/O Line 4 (DIO4) data level
[10]	General-Purpose I/O Line 3 (DIO3) data level
[9]	General-Purpose I/O Line 2 (DIO2) data level
[8]	General-Purpose I/O Line 1 (DIO1) data level
[7:4]	Not used
[3]	General-Purpose I/O Line 4 (DIO4) direction control
	1 = output, 0 = input
[2]	General-Purpose I/O Line 3 (DIO3) direction control
	1 = output, 0 = input
[1]	General-Purpose I/O Line 2 (DIO2) direction control
	1 = output, 0 = input
[0]	General-Purpose I/O Line 1 (DIO1) direction control
	1 = output, 0 = input

## Example Input/Output Configuration

For example, set GPIO\_CTRL[3:0] = 0100 (DIN = 0xB604) to set DIO3 as an output signal pin and DIO1, DIO2, and DIO4 as input signal pins. Set the output on DIO3 to 1 by setting GPIO\_CTRL[10] = 1 (DIN = 0xB704). Then, read GPIO\_CTRL[7:0] (DIN = 0x3600) and mask off GPIO\_CTRL[9:8] and GPIO\_CTRL[11] to monitor the digital signal levels on DIO4, DIO2, and DIO1.

## **AUXILIARY DAC**

The AUX\_DAC register in Table 43 provides user controls for setting the output voltage on the AUX\_DAC pin. The 12-bit AUX\_DAC line can drive its output to within 5 mV of the ground reference when it is not sinking current. As the output approaches 0 V, the linearity begins to degrade (~100 LSB starting point). As the sink current increases, the nonlinear range increases. The DAC latch command in GLOB\_CMD[2] (see Table 32) moves the values of the AUX\_DAC register into the DAC input register, enabling both bytes to take effect at the same time. This prevents undesirable output levels, which reflect single byte changes of the AUX\_DAC register.

## Table 43. AUX\_DAC (Base Address = 0x4E), Read/Write

Bits	Description (Default = 0x0000)
[15:12]	Not used
[11:0]	Data bits, scale factor = $0.8059 \text{ mV/LSB}$ , offset binary format, $0 \text{ V} = 0 \text{ LSB}$

## Table 44. Setting AUX\_DAC = 1 V

DIN	Description	
0xCED9	AUX_DAC[7:0] = 0xD9 (217 LSB)	
0xCF04	AUX_DAC[15:8] = 0x04 (1024 LSB)	
0xC204	GLOB_CMD[2] = 1; move values into the DAC input register, resulting in a 1 V output level	

# **DIGITAL PROCESSING CONFIGURATION**

<b>Register Name</b>	Address	Description
SMPL_PRD	0x3A	Sample rate control
SENS_AVG	0x3C	Digital filtering and range control

## SAMPLE RATE

The internal sampling system produces new data in the output data registers at a rate of 819.2 SPS. The SMPL\_PRD register in Table 46 provides two functional controls that affect sampling and register update rates. SMPL\_PRD[12:8] provides a control for reducing the update rate, using an averaging filter with a decimated output. These bits provide a binomial control that divides the data rate by a factor of 2 every time this number increases by 1. For example, set SMPL\_PRD[15:8] = 0x04 (DIN = 0xBB04) to set the decimation factor to 16. This reduces the update rate to 51 SPS and the bandwidth to 25 Hz.

Bits	Description (Default = 0x0001)
[15:13]	Not used
[12:8]	D, decimation rate setting, binomial, see Figure 19
[7:1]	Not used
[0]	Clock
	1 = internal 819.2 SPS
	0 = external

## INPUT CLOCK CONFIGURATION

 $SMPL_PRD[0]$  provides a control for synchronizing the internal sampling to an external clock source. Set  $SMPL_PRD[0] = 0$  (DIN = 0xBA00) and GPIO\_CTRL[3] = 0 (DIN = 0xB600) to enable the external clock. See Table 2 and Figure 4 for timing information.

## **DIGITAL FILTERING**

The SENS\_AVG register in Table 47 provides user controls for the low-pass filter. This filter contains two cascaded averaging filters that provide a Bartlett window, FIR filter response (see Figure 19). For example, set SENS\_AVG[2:0] = 100 (DIN = 0xBC04) to set each stage to 16 taps. When used with the default sample rate of 819.2 SPS and zero decimation (SMPL\_PRD[15:8] = 0x00), this value reduces the sensor bandwidth to approximately 16 Hz.



## **DYNAMIC RANGE**

The SENS\_AVG[10:8] bits provide three dynamic range settings for this gyroscope. The lower dynamic range settings ( $\pm 75^{\circ}$ /sec and  $\pm 150^{\circ}$ /sec) limit the minimum filter tap sizes to maintain resolution. For example, set SENS\_AVG[10:8] = 010 (DIN = 0xBD02) for a measurement range of  $\pm 150^{\circ}$ /sec. Because this setting can influence the filter settings, program SENS\_AVG[10:8] before programming SENS\_AVG[2:0] if more filtering is required.

Table 47. SENS\_AVG (Base Address = 0x3C), Read/Write

Bits	Description (Default = 0x0402)
[15:11]	Not used
[10:8]	Measurement range (sensitivity) selection
	$100 = \pm 300^{\circ}$ /sec (default condition)
	$010 = \pm 150^{\circ}$ /sec, filter taps $\geq 4$ (Bits[2:0] $\geq 0x02$ )
	$001 = \pm 75^{\circ}$ /sec, filter taps $\geq 16$ (Bits[2:0] $\geq 0x04$ )
[7:3]	Not used
[2:0]	Filter Size Variable B
	Number of taps in each stage; $N_B = 2^B$
	See Figure 18 for filter response



## CALIBRATION

The mechanical structure and assembly process of the ADIS16407 provide excellent position and alignment stability for each sensor, even after subjected to temperature cycles, shock, vibration, and other environmental conditions. The factory calibration includes a dynamic characterization of each gyroscope and accelerometer over temperature and generates sensor specific correction formulas. Table 48 provides a list of registers that can help optimize system performance after installation. Figure 20 illustrates the summing function for the offset correction register of each sensor.

Register	Address	Description
XGYRO_OFF	0x1E	Gyroscope bias, x-axis
YGYRO_OFF	0x20	Gyroscope bias, y-axis
ZGYRO_OFF	0x22	Gyroscope bias, z-axis
XACCL_OFF	0x24	Accelerometer bias, x-axis
YACCL_OFF	0x26	Accelerometer bias, y-axis
ZACCL_OFF	0x28	Accelerometer bias, z-axis
XMAGN_HIC	0x2A	Hard iron correction, x-axis
YMAGN_HIC	0x2C	Hard iron correction, y-axis
ZMAGN_HIC	0x2E	Hard iron correction, z-axis
XMAGN_SIC	0x30	Soft iron correction, x-axis
YMAGN_SIC	0x32	Soft iron correction, y-axis
ZMAGN_SIC	0x34	Soft iron correction, z-axis
MSC_CTRL	0x38	Miscellaneous calibration
GLOB_CMD	0x42	Automatic calibration

#### Table 48. Registers for User Calibration

## **GYROSCOPES**

The XGYRO\_OUT (Table 49), YGYRO\_OUT (Table 50), and ZGYRO\_OUT (Table 51) registers provide user-programmable bias adjustment function for the x-, y-, and z-axis gyroscopes, respectively. Figure 20 illustrates that they contain bias correction factors that adjust to the sensor data immediately before it loads into the output register.



Figure 20. User Calibration, XGYRO\_OFF Example

## **Gyroscope Bias Error Estimation**

Any system level calibration function must start with an estimate of the bias errors, which typically comes from a sample of gyroscope output data, when the device is not in motion. The sample size of data depends on the accuracy goals. Figure 7 provides a trade-off relationship between averaging time and the expected accuracy of a bias measurement. Vibration, thermal gradients, and power supply instability can influence the accuracy of this process.

Table 49. XGYRO	_OFF (Base	Address = 0	0x1E), Read/	Write
-----------------	------------	-------------	--------------	-------

Bits	Description (Default = 0x0000)
[15:14]	Not used
[13:0]	X-axis, gyroscope offset correction factor, twos complement, 0.0125°/sec per LSB

### Table 50. YGYRO\_OFF (Base Address = 0x20), Read/Write

Bits	Description (Default = 0x0000)	
[15:14]	Not used	
[13:0]	Y-axis, gyroscope offset correction factor, twos complement, 0.0125°/sec per LSB	
Table 51	. ZGYRO_OFF (Base Address = 0x22), Read/Write	
Bits	Description (Default = 0x0000)	
[15:14]	Not used	
[13.0]	7-axis avroscope offset correction factor	

## twos complement, 0.0125°/sec per LSB

## **Gyroscope Bias Correction Factors**

When the bias estimate is complete, multiply the estimate by -1 to change its polarity, convert it into digital format for the offset correction registers (Table 49), and write the correction factors to the correction registers. For example, lower the x-axis bias by 10 LSB (0.125°/sec) by setting XGYRO\_OFF = 0x1FF6 (DIN = 0x9F1F, 0x9EF6).

## **Single Command Bias Correction**

GLOB\_CMD[0] (Table 32) loads the xGYRO\_OFF registers with the values that are the opposite of the values that are in xGYRO\_OUT, at the time of initiation. Use this command, together with the decimation filter (SMPL\_PRD[12:8], Table 46), to automatically average the gyroscope data and improve the accuracy of this function, as follows:

- 1. Set SENS\_AVG[10:8] = 001 (DIN = 0xBD01) to optimize the xGYRO\_OUT sensitivity to 0.0125°/sec/LSB.
- 2. Set SMPL\_PRD[12:8] = 0x10 (DIN = 0xBB10) to set the decimation rate to 65,536 (2<sup>16</sup>), which provides an averaging time of 80 seconds (65,536 ÷ 819.2 SPS).
- 3. Wait for 80 seconds while keeping the device motionless.
- 4. Set GLOB\_CMD[0] = 1 (DIN = 0xC201) and wait for the time it takes to perform the flash memory backup (~75 ms).

## ACCELEROMETERS

The XACCL\_OUT (Table 52), YACCL\_OUT (Table 53), and ZACCL\_OUT (Table 54) registers provide user programmable bias adjustment function for the x-, y-, and z-axis accelerometers, respectively. These registers adjust the accelerometer data in the same manner as XGYRO\_OFF functions in Figure 20.

#### Table 52. XACCL\_OFF (Base Address = 0x24), Read/Write

Bits	Description (Default = 0x0000)	
[15:14]	Not used	
[13:0]	X-axis, accelerometer offset correction factor, twos complement, 0.25 mg/LSB	

### Table 53. YACCL\_OFF (Base Address = 0x26), Read/Write

Bits	Description (Default = 0x0000)
[15:14]	Not used
[13:0]	Y-axis, accelerometer offset correction factor, twos complement, 0.25 mg/LSB

#### Table 54. ZACCL\_OFF (Base Address = 0x28), Read/Write

Bits	Description (Default = 0x0000)		
[15:14]	Not used		
[13:0]	Z-axis, accelerometer offset correction factor, twos complement, 0.25 mg/LSB		

## Accelerometer Bias Error Estimation

Under static conditions, orient each accelerometer in positions where the response to gravity is predictable. A common approach to this is to measure the response of each accelerometer when they are oriented in peak response positions, that is, where  $\pm 1 g$  is the ideal measurement position. Next, average the  $\pm 1 g$  and -1 g accelerometer measurements together to estimate the residual bias error. Using more points in the rotation can improve the accuracy of the response.

## **Accelerometer Bias Correction Factors**

When the bias estimate is complete, multiply the estimate by -1 to change its polarity, convert it to the digital format for the offset correction registers (Table 52), and write the correction factors to the correction registers. For example, lower the x-axis bias by 10 LSB (33.3 mg) by setting XACCL\_OFF = 0x1FF6 (DIN = 0xA51F, 0xA4F6).

## **Point of Percussion Alignment**

Set  $MSC\_CTRL[6] = 1$  (DIN = 0xB846) to enable this feature and maintain the factory default settings for DIO1. This feature performs a point of percussion translation to the point identified in Figure 21. See Table 39 for more information on MSC\_CTRL.



## **MAGNETOMETER CALIBRATION**

The ADIS16407 provides registers that contribute to both hard iron and soft iron correction factors, as shown in Figure 22.



Figure 22. Hard Iron and Soft Iron Factor Correction

### **Hard Iron Correction**

The XMAGN\_HIC (Table 55), YMAGN\_HIC (Table 56), and ZMAGN\_HIC (Table 57) registers provide the user programmable bias adjustment function for the x-, y-, and z-axis magnetometers, respectively. Hard iron effects result in an offset of the magnetometer response.

#### Table 55. XMAGN\_HIC (Base Address = 0x2A), Read/Write

Table 55. AWAGN_IIIC (Dase Autress – 0x2A), Reau/ WIIte		
Bits	Description (Default = 0x0800)	
[15:14]	Not used	
[13:0]	X-axis hard iron correction factor, twos complement, 0.5 mgauss/LSB	
Table 56	. YMAGN_HIC (Base Address = 0x2C), Read/Write	
Bits	Description (Default = 0x0800)	
[15:14]	Not used	
[13:0]	Y-axis hard iron correction factor, twos complement, 0.5 mgauss/LSB	
Table 57	. ZMAGN HIC (Base Address = 0x2E), Read/Write	

Bits	Description (Default = 0x0800)
[15:14]	Not used
[13:0]	Z-axis hard iron correction factor, twos complement, 0.5 mgauss/LSB

## **Hard Iron Factors**

When the hard iron error estimation is complete, take the following steps:

- 1. Multiply the estimate by -1 to change its polarity.
- 2. Convert it into digital format for the hard iron correction registers (Table 55).
- 3. Write the correction factors to the correction registers. For example, lower the x-axis bias by 10 LSB (5 mgauss) by setting XMAGN\_HIC = 0x1FF6 (DIN = 0xAB1F, 0xAAF6).

## Soft Iron Effects

The XMAGN\_SIC (Table 58), YMAGN\_SIC (Table 59), and ZMAGN\_SIC (Table 60) registers provide an adjustment variable for the magnetometer sensitivity adjustment in each magnetometer response to simplify the process of performing a system level soft iron correction.

#### Table 58. XMAGN\_SIC (Base Address = 0x30), Read/Write

Bits	Description (Default = 0x0000)
[15:12]	Not used
[11:0]	X-axis soft iron correction factor, binary format,
	2 = 0xFFF, 1 = 0x800, 0 = 0x000, ~0.0488%/LSB

#### Table 59. YMAGN\_SIC (Base Address = 0x32), Read/Write

Bits	Description (Default = 0x0000)
[15:12]	Not used
[11:0]	Y-axis soft iron correction factor, binary format,
	2 = 0xFFF, 1 = 0x800, 0 = 0x000, ~0.0488%/LSB

### Table 60. ZMAGN\_SIC (Base Address = 0x34), Read/Write

Bits	Description (Default = 0x0000)		
[15:12]	Not used		
[11:0]	Z-axis soft iron correction factor, binary format,		
	2 = 0xFFF, 1 = 0x800, 0 = 0x000, ~0.0488%/LSB		

## **Soft Iron Factors**

When the soft iron error estimation is complete, convert the sensitivity into the digital format for the soft iron correction registers (Table 58) and write the correction factors to the correction registers. A simple method for converting the correction factor is to divide it by 2 and multiply it by 4095. For example, increasing the default soft iron factor to approximately 1.15 uses a binary code for 2355, or 0x933. Increase the soft iron correction factor for the y-axis to approximately 1.15 by setting YMAGN\_SIC = 0x0933 (DIN = 0xB309, 0xB233).

## **FLASH UPDATES**

When using the user calibration registers to optimize system level accuracy, keep in mind that the register values are volatile until their contents are saved in the nonvolatile flash memory. After writing all of the correction factors into the user correction registers, set GLOB\_CMD[3] = 1 (DIN = 0xC204) to save these settings in nonvolatile flash memory. Be sure to consider the endurance rating of the flash memory when determining how often to update the user correction factors in the flash memory.

## **RESTORING FACTORY CALIBRATION**

Set GLOB\_CMD[1] = 1 (DIN = 0xC202) to execute the factory calibration restore function. This is a single command function, which resets the gyroscope and accelerometer offset registers to 0x0000 and all sensor data to 0. Then, it automatically updates the flash memory within 75 ms and restarts sampling and processing data. See Table 32 for more information on GLOB\_CMD.

## ALARMS

Alarm 1 and Alarm 2 provide two independent alarms. Table 61 lists the alarm control registers, including ALM\_CTRL (Table 66), which provides control bits for data source selection, static/ dynamic comparison, filtering, and alarm indicator.

## Table 61. Registers for Alarm Configuration

8			
Register	Address	Description	
ALM_MAG1	0x44	Alarm 1 trigger setting	
ALM_MAG2	0x46	Alarm 2 trigger setting	
ALM_SMPL1	0x48	Alarm 1 sample period	
ALM_SMPL2	0x4A	Alarm 2 sample period	
ALM_CTRL	0x4C	Alarm configuration	

## STATIC ALARM USE

The static alarms setting compares the data source selection (ALM\_CTRL[15:8]) with the values in the ALM\_MAGx registers listed in Table 62 and Table 63, using ALM\_MAGx[15] to determine the trigger polarity. The data format in these registers matches the format of the data selection in ALM\_CTRL[15:8]. See Table 67, Alarm 1, for a static alarm configuration example.

## Table 62. ALM\_MAG1 (Base Address = 0x44), Read/Write

Bits	Description (Default = 0x0000)	
[15]	Trigger polarity	
	1 = greater than, $0 =$ less than	
[14]	Not used	
[13:0] Threshold setting; matches for format of ALM_CTRL[11:8] output register selection		

## Table 63. ALM\_MAG2 (Base Address = 0x46), Read/Write

Bits	Description (Default = 0x0000)	
[15]	Trigger polarity	
	1 = greater than, $0 =$ less than	
[14]	Not used	
[13:0]	Threshold setting; matches for format of ALM_CTRL[15:12] output register selection	

## **DYNAMIC ALARM USE**

The dynamic alarm setting monitors the data selection for a rate-of-change comparison. The rate-of-change comparison is represented by the magnitude in the ALM\_MAGx registers over the time represented by the number-of-samples setting in the ALM\_SMPLx registers, located in Table 64. See Table 67, Alarm 2, for a dynamic alarm configuration example.

#### Table 64. ALM\_SMPL1 (Base Address = 0x48), Read/Write

Bits	Description (Default = 0x0000)	
[15:8]	Not used	
[7:0] Binary, number of samples (both 0x00 and 0x01		

## Table 65. ALM\_SMPL2 (Base Address = 0x4A), Read/Write

Bits	Description (Default = 0x0000)	
[15:8]	Not used	
[7:0]	Binary, number of samples (both $0x00$ and $0x01 = 1$ )	

## **ALARM REPORTING**

The DIAG\_STAT[9:8] bits provide error flags that indicate an alarm condition. The ALM\_CTRL[2:0] bits provide controls for a hardware indicator using DIO1 or DIO2.

Bits	Description (Default = 0x0000)			
[15:12]	Alarm 2 data source selection			
	0000 = disable			
	0001 = SUPPLY_OUT			
	0010 = XGYRO_OUT			
	0011 = YGYRO_OUT			
	0100 = ZGYRO_OUT			
	0101 = XACCL_OUT			
	0110 = YACCL_OUT			
	0111 = ZACCL_OUT			
	1001 =XMAGN_OUT			
	1010 = YMAGN_OUT			
	1011 = ZMAGN_OUT			
	1100 = AUX_ADC			
[11:8]	Alarm 1 data source selection (same as Alarm 2)			
[7]	Alarm 2, dynamic/static (1 = dynamic, 0 = static)			
[6]	Alarm 1, dynamic/static (1 = dynamic, 0 = static)			
[5] Not used				
[4] Data source filtering (1 = filtered, 0 = unfiltered)				
[3]	Not used			
[2]	Alarm indicator $(1 = enabled, 0 = disabled)$			
[1]	Alarm indicator active polarity (1 = high, $0 = low$ )			
[0]	Alarm output line select $(1 = DIO2, 0 = DIO1)$			

## Alarm Example

Table 67 offers an example that configures Alarm 1 to trigger when filtered ZACCL\_OUT data drops below 0.7 *g*, and Alarm 2 to trigger when filtered ZGYRO\_OUT data changes by more than 50°/sec over a 100 ms period, or 500°/sec<sup>2</sup>. The filter setting helps reduce false triggers from noise and refine the accuracy of the trigger points. The ALM\_SMPL2 setting of 82 samples provides a comparison period that is approximately equal to 100 ms for an internal sample rate of 819.2 SPS.

#### Table 67. Alarm Configuration Example 1

<u> </u>				
DIN	Description			
0xCD47,	ALM_CTRL = 0x4797			
0xCC97	Alarm 2: dynamic, Δ-ZGYRO_OUT (Δ-time, ALM_SMPL2) > ALM_MAG2			
	Alarm 1: static, ZACCL_OUT < ALM_MAG1, filtered data DIO2 output indicator, positive polarity			
0xC703, 0xC6E8	ALM_MAG2 = 0x03E8 = 1,000 LSB = 50°/sec			
0xC500, 0xC4D2	$ALM_MAG1 = 0x00D2 = 210 LSB = +0.7 g$			
0xC866	ALM_SMPL2[7:0] = 0x52 = 82 samples 82 samples ÷ 819.2 SPS = ~100 ms			

## APPLICATIONS INFORMATION INSTALLATION/HANDLING

For ADIS16407 installation, use the following two step process:

- 1. Secure the base plate using machine screws.
- 2. Press the connector into its mate.

## For removal

- 1. Gently pry the connector from its mate using a small slot screwdriver.
- 2. Remove the screws and lift up the device.

Never attempt to unplug the connector by pulling on the plastic case or base plate. Although the flexible connector is very reliable in normal operation, it can break when subjected to unreasonable handling. When broken, the flexible connector cannot be repaired. The AN-1045 Application Note, *iSensor® IMU Mounting Tips*, provides more information about developing an appropriate mechanical interface design.

## **GYROSCOPE BIAS OPTIMIZATION**

The factory calibration corrects for initial and temperature dependent bias errors in the gyroscopes. Use the autonull command (GLOB\_CMD[0]) and decimation filter (SMPL\_PRD[12:8]) to address rate random walk (RRW) behaviors. Control physical, power supply, and temperature stability during the averaging times to help ensure optimal accuracy during this process. Refer to the AN-1041 Application Note, *iSensor*<sup>\*</sup> *IMU Quick Start Guide and Bias Optimization Tips*, for more information about optimizing performance.

## **INTERFACE PRINTED CIRCUIT BOARD (PCB)**

The ADIS16407/PCBZ includes one ADIS16407BMLZ and one interface PCB. The interface PCB simplifies the process of integrating these products into an existing processor system.

J1 and J2 are dual row, 2 mm (pitch) connectors that work with a number of ribbon cable systems, including 3M Part 152212-0100-GB (ribbon crimp connector) and 3M Part 3625/12 (ribbon cable). Figure 23 provides a hole pattern design for installing the ADIS16407BMLZ and the interface PCB onto the same surface. Figure 24 provides the pin assignments for each connector, which match the pin descriptions for the ADIS16407BMLZ. The ADIS16407does not require any external capacitors for normal operation; therefore, the interface PCB does not use the C1/C2 pads (not shown in Figure 23).



# **OUTLINE DIMENSIONS**



#### **ORDERING GUIDE**

Model <sup>1</sup>	Temperature Range	Package Description	Package Option
ADIS16407BMLZ	-40°C to +105°C	24-Lead Module with Connector Interface	ML-24-5
ADIS16407/PCBZ		Interface PCB	

 $^{1}$  Z = RoHS Compliant Part.

©2011 Analog Devices, Inc. All rights reserved. Trademarks and registered trademarks are the property of their respective owners. D09797-0-4/11(0)



www.analog.com