Ten Degrees of Freedom Inertial Sensor

Data Sheet **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**

APPLICATIONS

- **Platform stabilization and control**
- **Navigation**
- **Robotics**

GENERAL DESCRIPTION

The ADIS16407 *i*Sensor® 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® 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 × 23 mm × 23 mm and has a standard connector interface.

FUNCTIONAL BLOCK DIAGRAM

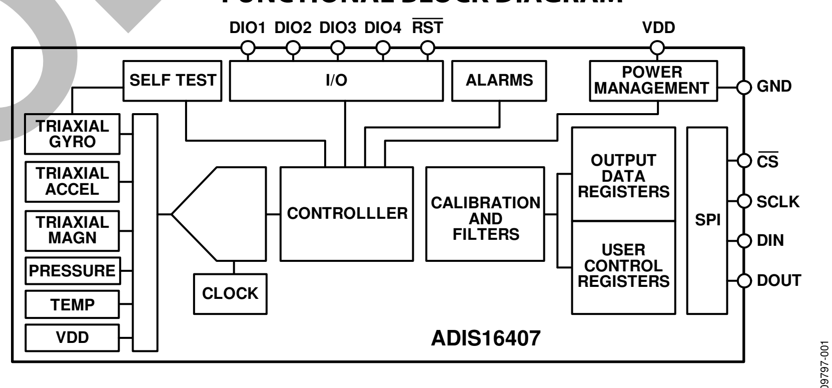


Figure 1.

Rev. C

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781.329.4700 www.analog.com
Fax: 781.461.3113

TABLE OF CONTENTS

REVISION HISTORY

10/11—Rev. B to Rev. C

Change to Burst Read Function Section and Figure 12 ... 10
Changed .25 m*g* to 3.333 m*g* ... Throughout
Changes to System Functions Section ... 15
Change to Product Identification Section ... 15
Change to Table 36 ... 15
Changes to Digital Filtering Section, Table 47, Caption for Figure 18, and Figure 19 ... 18
Change to Table 67 ... 22

7/11—Rev. A to Rev. B

Change to Table 1, Barometer, Sensitivity Parameter ... 4
Added Barometer Section; Changes to Table 40 ... 16
Changes to Table 55, Table 56, Table 57 ... 20
Changes to Table 58, Table 59, Table 60 ... 21

6/11—Rev. 0 to Rev. A

Changes to Device Configuration Section and Figure 16 ... 13
Changes to Figure 19 ... 18
Changes to Figure 25 Caption ... 24
Changes to Ordering Guide ... 24

4/11—Revision 0: Initial Version

SPECIFICATIONS

T_A = 25°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	Unit
GYROSCOPES					
Dynamic Range		±300	±350		°/sec
Initial Sensitivity	Dynamic range = ±300°/sec	0.0495	0.05	0.0505	°/sec/LSB
	Dynamic range = ±150°/sec		0.025		°/sec/LSB
	Dynamic range = ±75°/sec		0.0125		°/sec/LSB
Sensitivity Temperature Coefficient	−40°C ≤ T_A ≤ +85°C		±40		ppm/°C
Misalignment	Axis to axis		±0.05		Degrees
	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 σ, SMPL_PRD = 0x0001		1.9		°/√hr
Bias Temperature Coefficient	−40°C ≤ T_A ≤ +85°C		±0.01		°/sec/°C
Linear Acceleration Effect on Bias	Any axis, 1 σ (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, ±300°/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			*g*
Initial Sensitivity		3.285	3.33	3.38	m*g*/LSB
Sensitivity Temperature Coefficient	−40°C ≤ T_A ≤ +85°C		±50		ppm/°C
Misalignment	Axis to axis		0.2		Degrees
	Axis to frame (package)		±0.5		Degrees
Nonlinearity	Best fit straight line		0.1		% of FS
Initial Bias Error	±1 σ		±50		m*g*
In-Run Bias Stability	1 σ, SMPL_PRD = 0x0001		0.2		m*g*
Velocity Random Walk	1 σ, SMPL_PRD = 0x0001		0.2		m/sec/√hr
Bias Temperature Coefficient	−40°C ≤ T_A ≤ +85°C		±0.3		m*g*/°C
Bias Voltage Sensitivity	VDD = 4.75 V to 5.25 V		2.5		m*g*/V
Output Noise	No filtering		9		m*g* rms
Noise Density	No filtering		0.5		m*g*/√Hz rms
3 dB Bandwidth			330		Hz
Sensor Resonant Frequency			5.5		kHz
MAGNETOMETER					
Dynamic Range		±2.5	±3.5		gauss
Initial Sensitivity	25°C	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°C ≤ T_A ≤ +85°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	Typ	Max	Unit
BAROMETER					
Pressure Range					
Operating		300		1100	mbar
Extended[1]		10		1200	mbar
Sensitivity			0.3125		µbar/LSB
Total Error	25°C, 300 mbar to 1100 mbar		1.5		mbar
Relative Error[2]	−40°C to +85°C, 300 mbar to 1100 mbar		2.5		mbar
Linearity[3]	25°C, 300 mbar to 1100 mbar		0.1		% of FS
	−40°C to +85°C, 300 mbar to 1100 mbar		0.15		% of FS
Noise			0.027		mbar rms
TEMPERATURE SENSOR					
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		LSB
Gain Error			±2		LSB
Input Range		0		3.3	V
Input Capacitance	During acquisition		20		pF
DAC OUTPUT	5 kΩ/100 pF to GND				
Resolution			12		Bits
Relative Accuracy	101 LSB ≤ input code ≤ 4095 LSB		±4		LSB
Differential Nonlinearity			±1		LSB
Offset Error			±5		mV
Gain Error			±0.5		%
Output Range		0		3.3	V
Output Impedance			2		Ω
Output Settling Time			10		µs
LOGIC INPUTS[4]					
Input High Voltage, V_{IH}		2.0			V
Input Low Voltage, V_{IL}				0.8	V
	$\overline{CS}$ signal to wake up from sleep mode			0.55	V
$\overline{CS}$ Wake-Up Pulse Width		20			µs
Logic 1 Input Current, I_{IH}	V_{IH} = 3.3 V		±0.2	±10	µA
Logic 0 Input Current, I_{IL}	V_{IL} = 0 V				
All Pins Except $\overline{RST}$			40	60	µA
$\overline{RST}$ Pin			1		mA
Input Capacitance, C_{IN}			10		pF
DIGITAL OUTPUTS[4]					
Output High Voltage, V_{OH}	I_{SOURCE} = 1.6 mA	2.4			V
Output Low Voltage, V_{OL}	I_{SINK} = 1.6 mA			0.4	V
FLASH MEMORY	Endurance[5]	10,000			Cycles
Data Retention[6]	T_J = 85°C	20			Years
FUNCTIONAL TIMES[7]	Time until new data is available				
Power-On Start-Up Time			220		ms
Reset Recovery Time			105		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	Typ	Max	Unit
CONVERSION RATE					SPS
xGYRO_OUT, xACCL_OUT, xMAGN_OUT	SMPL_PRD = 0x0001		819.2		SPS
BAR_OUT, BARO_OUTL[8]	SMPL_PRD = 0x0001		51.2		SPS
Clock Accuracy				±3	%
Sync Input Clock[9]		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

[1] The extended pressure range is guaranteed by design.
[2] The relative error assumes that the initial error, at +25°C, is corrected in the end application.
[3] Linearity errors assume a full scale (FS) of 1000 mbar.
[4] The digital I/O signals are driven by an internal 3.3 V supply, and the inputs are 5 V tolerant.
[5] Endurance is qualified as per JEDEC Standard 22, Method A117, and measured at −40°C, +25°C, +85°C, and +125°C.
[6] The data retention lifetime equivalent is at a junction temperature (T_J) of 85°C as per JEDEC Standard 22, Method A117. Data retention lifetime decreases with junction temperature.
[7] These times do not include thermal settling and internal filter response times (330 Hz bandwidth), which may affect overall accuracy.
[8] The BARO_OUT and BARO_OUTL registers sample at a rate that is 1/16th that of the other output registers.
[9] The sync input clock functions below the specified minimum value, but at reduced performance levels.

TIMING SPECIFICATIONS

T_A = 25°C, VDD = 5 V, unless otherwise noted.

Table 2.

Parameter	Description	Normal Mode			Burst Read			Unit
		Min[1]	Typ	Max	Min[1]	Typ	Max	
f_{SCLK}	Serial clock	0.01		2.0	0.01		1.0	MHz
t_{STALL}	Stall period between data	9			$1/f_{SCLK}$			µs
$t_{READRATE}$	Read rate	40						µs
$t_{\overline{CS}}$	Chip select to SCLK edge	48.8			48.8			ns
t_{DAV}	DOUT valid after SCLK edge			100			100	ns
t_{DSU}	DIN setup time before SCLK rising edge	24.4			24.4			ns
t_{DHD}	DIN hold time after SCLK rising edge	48.8			48.8			ns
t_{SCLKR}, t_{SCLKF}	SCLK rise/fall times, not shown in Timing Diagrams		5	12.5		5	12.5	ns
t_{DR}, t_{DF}	DOUT rise/fall times, not shown in Timing Diagrams		5	12.5		5	12.5	ns
t_{SFS}	$\overline{CS}$ high after SCLK edge	5			5			ns
t_1	Input sync positive pulse width	5			5			µs
t_x	Input sync low time	100			100			µs
t_2	Input sync to data ready output		600			600		µs
t_3	Input sync period	910			910			µs

[1] Guaranteed by design and characterization, but not tested in production.

Timing Diagrams

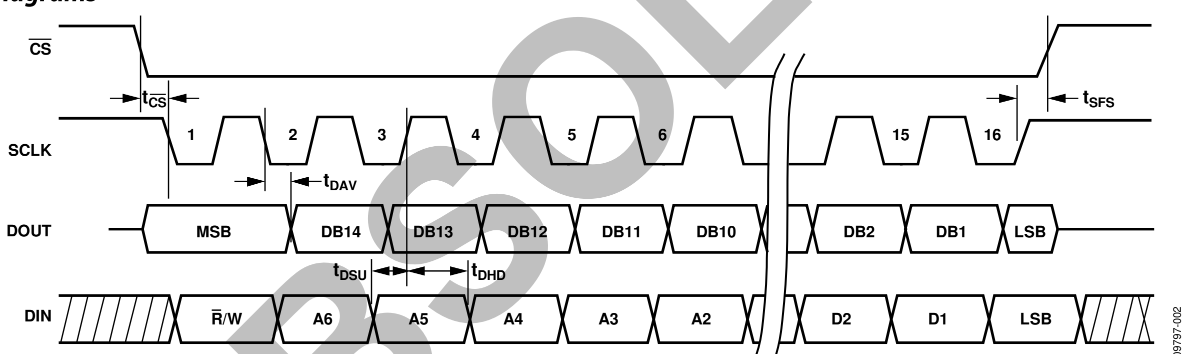


Figure 2. SPI Timing and Sequence

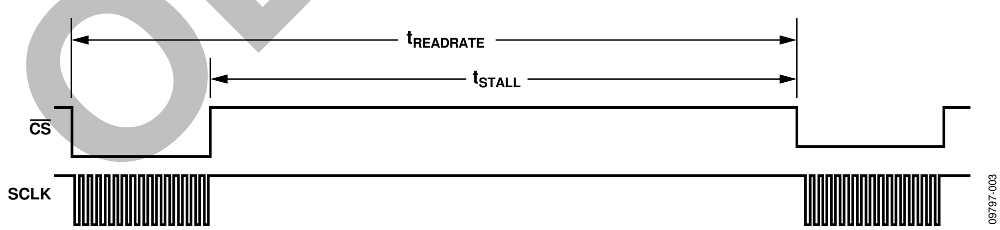


Figure 3. Stall Time and Data Rate

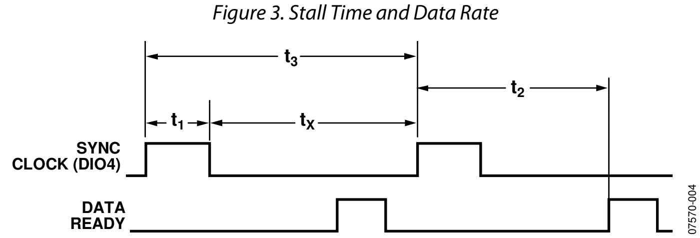


Figure 4. Input Clock Timing Diagram

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[1, 2]
Pressure	6 bar

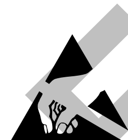
[1] Extended exposure to temperatures outside the specified temperature range of −40°C to +105°C can adversely affect the accuracy of the factory calibration. For best accuracy, store the parts within the specified operating range of −40°C to +105°C.
[2] Although the device is capable of withstanding 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_{JA}	θ_{JC}	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

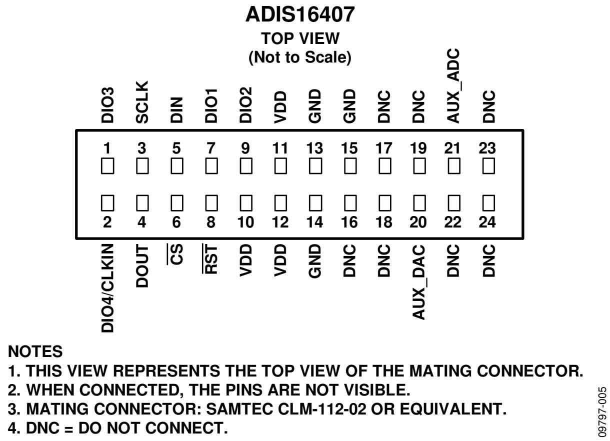


Figure 5. Pin Configuration

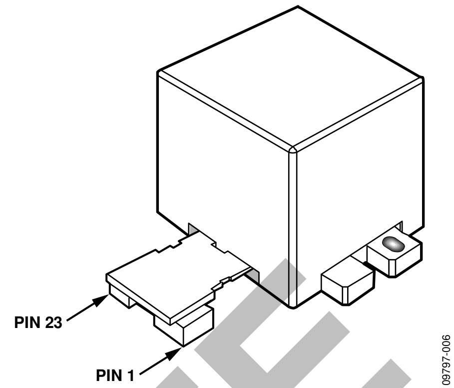


Figure 6. Axial Orientation

Table 5. Pin Function Descriptions

Pin No.	Mnemonic	Type[1]	Description
1	DIO3	I/O	Configurable Digital Input/Output.
2	DIO4/CLKIN	I/O	Configurable Digital Input/Output or Sync Clock Input.
3	SCLK	I	SPI Serial Clock.
4	DOUT	O	SPI Data Output. Clocks the output on the SCLK falling edge.
5	DIN	I	SPI Data Input. Clocks the input on the SCLK rising edge.
6	$\overline{\text{CS}}$	I	SPI Chip Select.
7	DIO1	I/O	Configurable Digital Input/Output.
8	$\overline{\text{RST}}$	I	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	O	Auxiliary, 12-Bit DAC Output.
21	AUX_ADC	I	Auxiliary, 12-Bit ADC Input.

[1] S is supply, O is output, I is input, N/A is not applicable.

TYPICAL PERFORMANCE CHARACTERISTICS

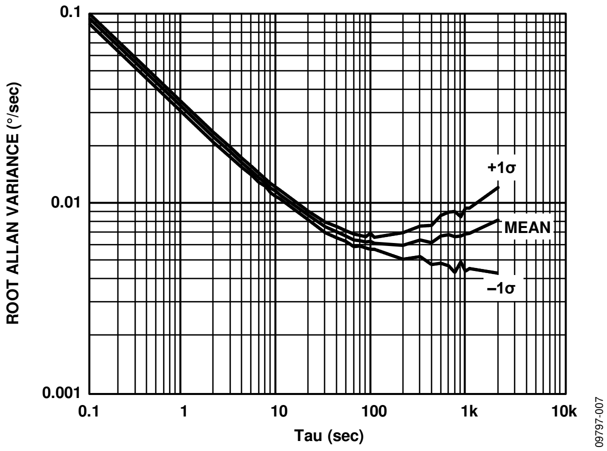


Figure 7. Gyroscope Root Allan Variance

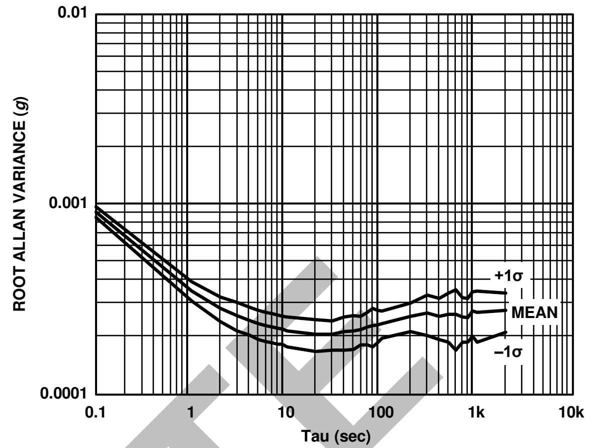


Figure 8. Accelerometer Root Allan Variance

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).

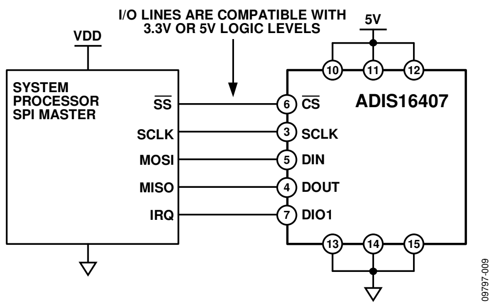


Figure 9. Electrical Connection Diagram

Table 6. Generic Master 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 ≤ 2 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

[1] For burst read, SCLK rate ≤ 1 MHz.

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.

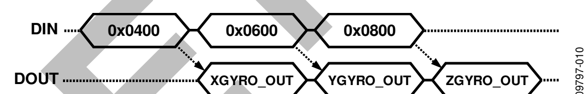


Figure 10. SPI Read Example

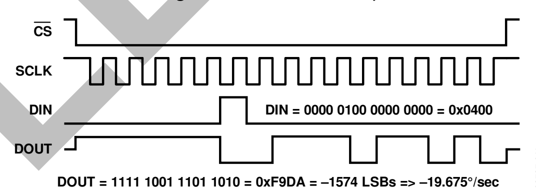


Figure 11. Example SPI Read, Second 16-Bit Sequence

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 0x4200 to DIN, followed by each output register clocking out on DOUT, in the order in which they appear in Table 8.

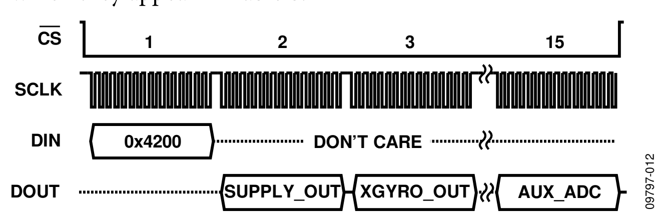


Figure 12. Burst Read Sequence

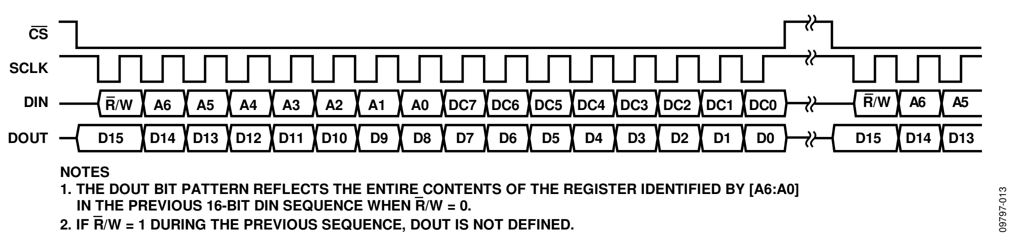


Figure 13. SPI Communication Bit Sequence

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[1]	0x1A	Internal temperature
AUX_ADC	0x1C	Auxiliary ADC

[1] This is most useful for monitoring relative changes in the temperature.

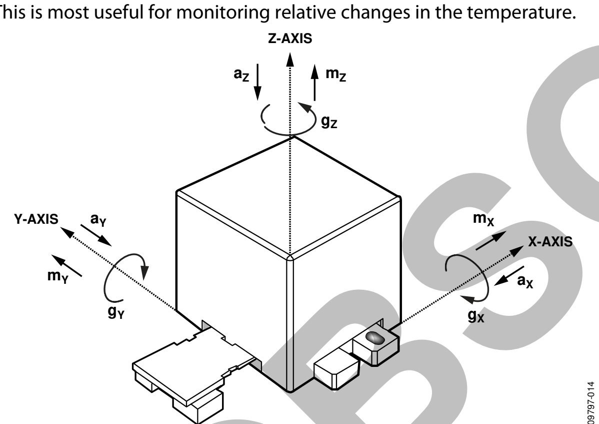


Figure 14. Inertial Sensor Direction Reference

Gyroscopes

Figure 14 provides arrows (g_X, g_Y, g_Z) 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 Address = 0x06), 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

Rotation Rate	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_X, a_Y, a_Z) 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, 3.333 m*g* 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, 3.333 m*g* 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, 3.333 m*g* per LSB

Table 16. Acceleration, Twos Complement Format

Acceleration	Decimal	Hex	Binary
+18 *g*	+5401	0x1519	xx01 0101 0001 1001
+6.667 m*g*	+2	0x0002	xx00 0000 0000 0010
+3.333 m*g*	+1	0x0001	xx00 0000 0000 0001
0 *g*	0	0x0000	xx00 0000 0000 0000
−3.333 m*g*	−1	0x3FFF	xx11 1111 1111 1111
−6.667 m*g*	−2	0x3FFE	xx11 1111 1111 1110
−18 *g*	−5401	0x2AE7	xx10 1010 1110 0111

Magnetometers

Figure 14 provides arrows (m_X, m_Y, m_Z) 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

Table 21. BARO_OUT (Base Address = 0x16), 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]	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°C/LSB, 25°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 Ω. The sampling capacitor, C2, has a typical value of 16 pF.

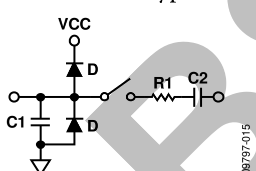


Figure 15. Equivalent Analog Input Circuit (Conversion Phase: Switch Open, Track Phase: Switch Closed)

Table 28. AUX_ADC (Base 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 Input, 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 0x3B (SMPL_PRD[15:8]), using DIN = 0xBB03. This example reduces the sample rate by a factor of eight (see Table 46).

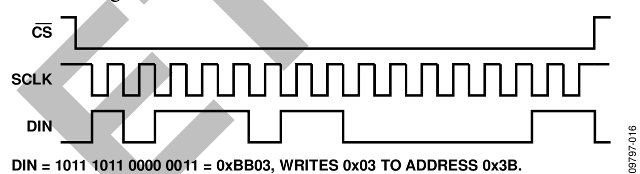


Figure 16. Example SPI Write Sequence

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.

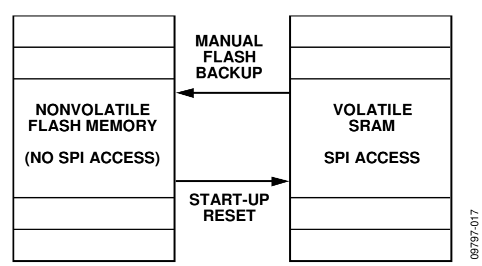


Figure 17. SRAM and Flash Memory Diagram

USER REGISTERS

Table 30. User Register Memory Map[1]

Name	R/W	Flash Backup	Address[2]	Default	Function	Bit Assignments
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	R/W	No	0x4E	0x0000	Auxiliary DAC data	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
LOT_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	Serial number	See Table 37

[1] N/A means not applicable.
[2] 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 controls for managing operation, using the registers in Table 31.

Table 31. System Tool Registers

Register Name	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 $\overline{\text{CS}}$ from high to low, asserting $\overline{\text{RST}}$ 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 the part number. 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. LOT_ID2 (Base Address = 0x54), Read Only

Bits	Description
[15:0]	Lot identification, binary code

Table 36. PROD_ID Bit (Base Address = 0x56), Read Only

Bits	Description (Default = 0x4017)
[15:0]	Binary number, equivalent to part number Contents = 16,407 = 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 (Base 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.

SELF TEST FUNCTION

Gyroscopes/Accelerometers

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)[1] 1 = enabled, 0 = disabled
[10]	Internal self test (cleared upon completion)[1] 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

[1] The bit is automatically reset to 0 after finishing the test.

Barometer

The barometer self test function is part of the power-on and reset initialization processes. DIAG_STAT[7] (see Table 40) contains the result of this test after the device completes normal operation. If DIAG_STAT[7] = 1, initiate a software reset by setting GLOB_CMD[7] = 1 (DIN = 0xC280). If DIAG_STAT[7] = 0 after the reset process completes, then the barometer is functional. A persistent fail result in DIAG_STAT[7] indicates a potential problem with the barometer.

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 result 1 = fail, 0 = pass
[14]	Y-axis accelerometer self test result 1 = fail, 0 = pass
[13]	X-axis accelerometer self test result 1 = fail, 0 = pass
[12]	Z-axis gyroscope self test result 0 = pass
[11]	Y-axis gyroscope self test result 1 = fail, 0 = pass
[10]	X-axis gyroscope self test result 1 = fail, 0 = pass
[9]	Alarm 2 status 1 = active, 0 = inactive
[8]	Alarm 1 status 1 = active, 0 = inactive
[7]	Barometer self test 1 = fail (issue with sensor function), 0 = pass (no issue)
[6]	Flash test (checksum) result 1 = fail, 0 = pass
[5]	Self test diagnostic result 1 = fail, 0 = pass
[4]	Sensor overrange condition 1 = overrange, 0 = normal
[3]	SPI communication 1 = fail (number of SCLKs not equal to a multiple of 16) 0 = pass (number of SCLKs is equal to a multiple of 16)
[2]	Flash update verification 1 = fail (flash update was not successful) 0 = pass (flash update was successful)
[1]	Power supply high 1 = VDD > 5.25 V 0 = VDD ≤ 5.25 V
[0]	Power supply low 1 = VDD < 4.75 V 0 = VDD ≥ 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 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 μs and 150 μs, including jitter (±30 μs).

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 mV/LSB, offset binary format, 0 V = 0 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

Table 45. Digital Processing Registers

Register Name	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.

Table 46. SMPL_PRD (Base Address = 0x3A), Read/Write

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 select 33 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.

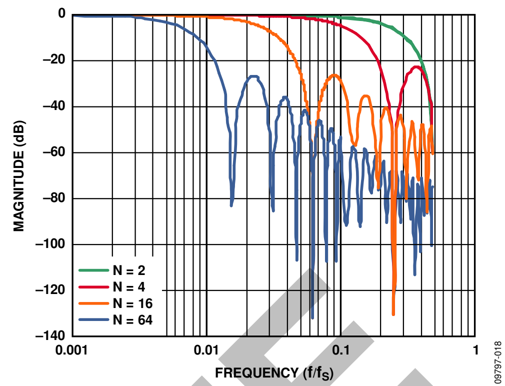


Figure 18. Bartlett Window, FIR Filter Frequency Response (Phase Delay = (2N_B – 1)/2 Samples)

DYNAMIC RANGE

The SENS_AVG[10:8] bits provide three dynamic range settings for this gyroscope. The lower dynamic range settings (±75°/sec and ±150°/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 ±150°/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 = ±300°/sec (default condition) 010 = ±150°/sec, filter taps ≥ 9 (Bits[2:0] ≥ 0x02) 001 = ±75°/sec, filter taps ≥ 33 (Bits[2:0] ≥ 0x04)
[7:3]	Not used
[2:0]	Filter Size Variable B Total number of taps; $N_T = 2^{B+1} – 1$ See Figure 18 for filter response

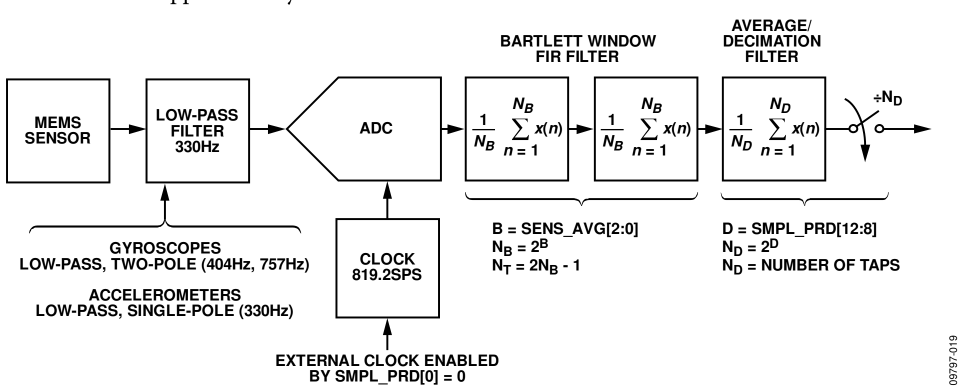


Figure 19. Sampling and Frequency Response Block Diagram

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.

Table 48. Registers for User Calibration

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

GYROSCOPES

The XGYRO_OFF (Table 49), YGYRO_ OFF (Table 50), and ZGYRO_ OFF (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.

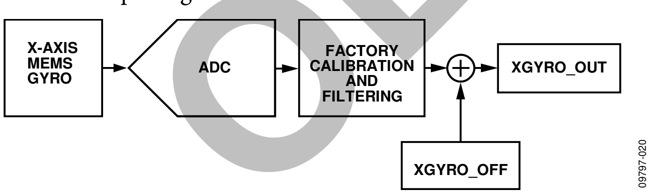


Figure 20. User Calibration, XGYRO_OFF Example

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 = 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]	Z-axis, gyroscope 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^{16}), 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_ OFF (Table 52), YACCL_ OFF (Table 53), and ZACCL_ OFF (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, 3.333 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, 3.333 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, 3.333 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 ±1 *g* is the ideal measurement position. Next, average the +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 m*g*) 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.

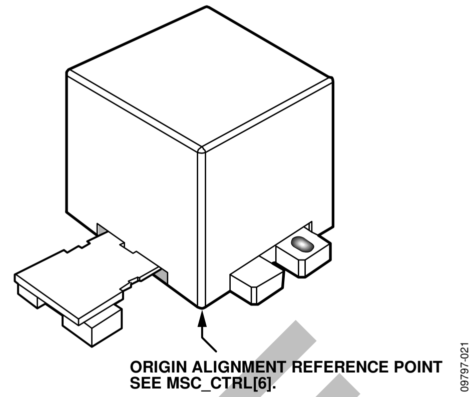


Figure 21. Point of Percussion Physical Reference

MAGNETOMETER CALIBRATION

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

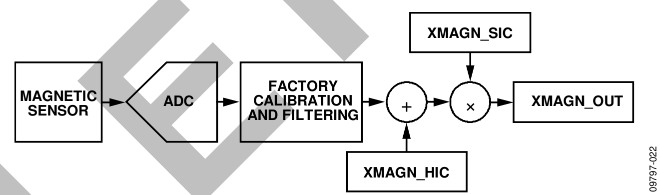


Figure 22. Hard Iron and Soft Iron Factor Correction

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

Bits	Description (Default = 0x0800)
[15:14]	Not used
[13:0]	X-axis hard iron correction factor, twos complement, 0.5 mgauss/LSB, 0x0000 = 0

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, 0x0000 = 0

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, 0x0000 = 0

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 = 0x0800)
[15:12]	Not used
[11:0]	X-axis soft iron correction factor, binary format, Scale factor = 100%/2048LSB, 0x000 = 0 Example: 0x800 = 100% (factory scale unchanged) Maximum = 0xFFF = 200% − 100%/2048

Table 59. YMAGN_SIC (Base Address = 0x32), Read/Write

Bits	Description (Default = 0x0800)
[15:12]	Not used
[11:0]	Y-axis soft iron correction factor, binary format, Scale factor = 100%/2048LSB, 0x000 = 0 Example: 0x800 = 100% (factory scale unchanged) Maximum = 0xFFF = 200% − 100%/2048

Table 60. ZMAGN_SIC (Base Address = 0x34), Read/Write

Bits	Description (Default = 0x0800)
[15:12]	Not used
[11:0]	Z-axis soft iron correction factor, binary format, Scale factor = 100%/2048LSB, 0x000 = 0 Example: 0x800 = 100% (factory scale unchanged) Maximum = 0xFFF = 200% − 100%/2048

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

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 = 1)

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.

Table 66. ALM_CTRL (Base Address = 0x4C), Read/Write

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^2. 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

DIN	Description
0xCD47, 0xCC97	ALM_CTRL = 0x4797 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*
0xCA52	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® 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).

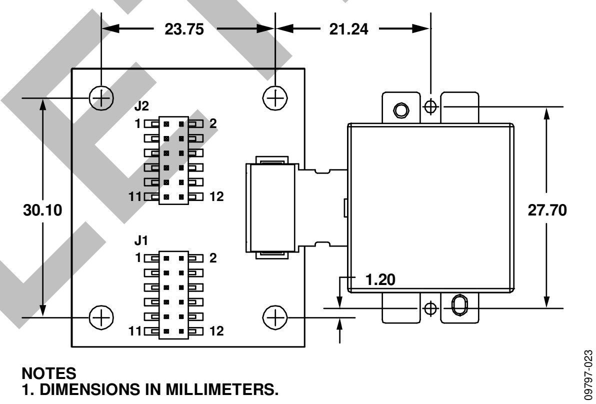


Figure 23. Physical Diagram for the ADIS16407/PCBZ

J1				J2			
RST	1	2	SCLK	AUX_ADC	1	2	GND
CS	3	4	DOUT	AUX_DAC	3	4	DIO3
DNC	5	6	DIN	GND	5	6	DIO4
GND	7	8	GND	DNC	7	8	DNC
GND	9	10	VCC	DNC	9	10	DNC
VCC	11	12	VCC	DIO2	11	12	DIO1

09797-024

Figure 24. J1/J2 Pin Assignments

OUTLINE DIMENSIONS

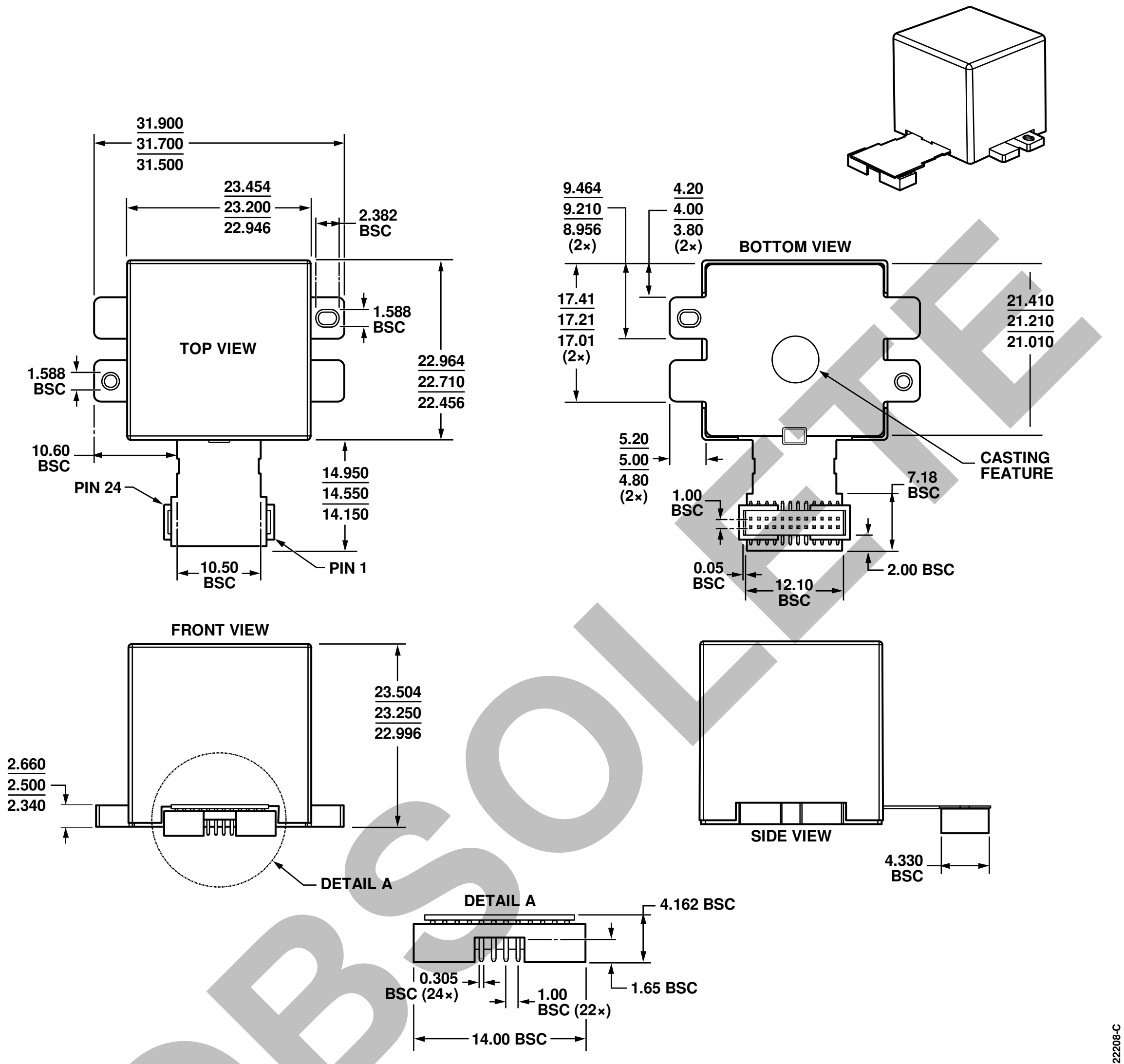


Figure 25. 24-Lead Module with Connector Interface
(ML-24-2)
Dimensions shown in millimeters

ORDERING GUIDE

Model[1]	Temperature Range	Package Description	Package Option
ADIS16407BMLZ	−40°C to +105°C	24-Lead Module with Connector Interface	ML-24-2
ADIS16407/PCBZ		Interface PCB	

[1] Z = RoHS Compliant Part.