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IMU (Inertial Measurement Unit)

M-G350-PD
Data Sheet

SEIKO EPSON CORPORATION

Rev. 20151218

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1. Overview

The M-G350PD is a small form factor inertial measurement unit (IMU) with 6 degrees of freedom: triaxial angular rates and linear accelerations, and provides high-stability and high-precision measurement capabilities with the use of high-precision compensation technology. A variety of calibration parameters are stored in a memory of the IMU, and are automatically reflected in the measurement data being sent to the application after the power of the IMU is turned on. With general-purpose SPI/UART support for host communication, the M-G350PD reduces technical barriers for users to introduce inertial measurement and minimizes design resources to implement inertial movement analysis and control applications.

The features of the IMU such as high stability, high precision, and small size make it easy to create and differentiate applications in various fields of industrial systems.

1.1 Features

- Small Size, Lightweight : 24x24x10mm, 7grams
- Low-Noise, High-stability
    - Gyro Bias Instability : 6 deg/hr
    - Angular Random Walk : 0.2 deg/$\sqrt{\mathrm{hr}}$
- Initial Bias Error : to 0.5 deg/s (1σ)
- 6 Degrees Of Freedom
  Triple Gyroscopes : ±300 deg/s
  Tri-Axis Accelerometer : ±3 G
- 16bit data resolution
- Digital Serial Interface : SPI / UART
- Calibrated Stability (Bias, Scale Factor, Axial alignment)
- Data output rate : to 1k Sps
- Calibration temperature range : −20°C to +70°C
- Operating temperature range : −40°C to +85°C
- Single Voltage Supply : 3.3 V
- Low Power Consumption : 30mA (Typ.)

1.2 Applications

- Motion analysis and control
- Unmanned systems
- Navigation systems
- Vibration control and stabilization
- Pointing and tracking systems

1.3 Functional Block Diagram

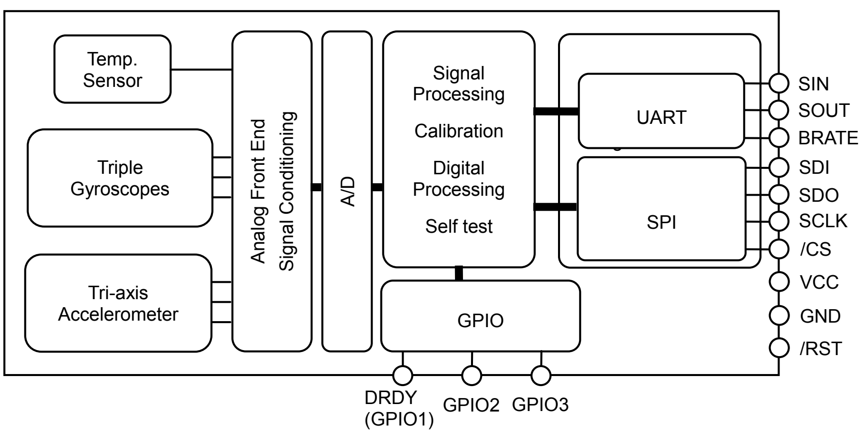


Figure 1.1 Functional Block Diagram

2. Product Specifications

2.1 Absolute Maximum Ratings

Table 2.1 Absolute Maximum Ratings

Parameter	Min.	Typ.	Max.	Unit
VCC to GND	−0.3	—	6.0	V
Digital Input Voltage to GND	−0.3	—	5.3	V
Digital Output Voltage to GND	−0.3	—	VCC +0.3	V
Storage Temperature Range	−40	—	85	°C
Acceleration / Shock (Half-sine 0.5msec)	—	—	500	G

Precautions about ESD

Electrostatic discharge (ESD) may damage the product.

When you store or handle the product, take appropriate preventive measures against electrostatic discharge (ESD).

Damages caused by electrostatic discharge (ESD) range from tiny performance degradation or partial malfunction to complete breakdown.

This is a high-precision product. Even tiny performance degradation may cause the product not to conform to the specifications.

2.2 Recommended Operating Condition

Table 2.2 Recommended Operating Conditions

Parameter	Condition	Min.	Typ.	Max.	Unit
VCC to GND		3.15	3.3	3.45	V
Digital Input Voltage to GND		GND	—	VCC	V
Digital Output Voltage to GND		−0.3	—	VCC +0.3	V
Calibration Temperature Range	Performance parameters are applicable	−20	—	70	°C
Operating Temperature Range		−40	—	85	°C

2.3 Characteristics and Electrical Specifications

Table 2.3 Sensor Section Specifications

T_A=25°C, VCC=3.3V, angular rate=0 deg/s, ≤±1G, unless otherwise noted.

Parameter	Test Conditions / Comments	Min.	Typ.	Max.	Unit
GYRO SENSOR					
Sensitivity					
Dynamic Range	—	±300	—	—	deg/s
Scale Factor	—	Typ-0.5%	0.0125	Typ+0.5%	(deg/s)/LSB
Temperature Coefficient	1 σ, −20°C ≤ T_A ≤ +70°C	—	10	—	ppm/°C
Nonlinearity	Best fit straight line	—	0.1	—	% of FS
Misalignment	1 σ,Axis-to-axis, Δ = 90° ideal	—	±0.1	—	deg
Bias					
Initial Error	1 σ	—	0.5	—	deg/s
Temperature Coefficient	1 σ, −20°C ≤ T_A ≤ +70°C		0.03		(deg/s)/°C
(Linear approximation)			0.001		
Bias Instability		—	6	—	deg/hr
Angular Random Walk		—	0.2	—	deg/ $\sqrt{hr}$
Linear Acceleration Effect			<0.01		(deg/s)/G
Noise					
Noise Density	f = 10 to 20 Hz	—	0.004	—	(deg/s)/ $\sqrt{Hz}$, rms
Frequency Property					
3 dB Bandwidth	—	—	133	—	Hz
ACCELEROMETERS					
Sensitivity					
Dynamic Range	—	±3	—	—	G
Scale Factor	—	Typ-0.5%	0.125	Typ+0.5%	mG/LSB
Temperature Coefficient	1σ, −20°C ≤ T_A ≤ +70°C	—	20	—	ppm/°C
Nonlinearity	≤ 1G , Best fit straight line	—	0.1	—	% of FS
Misalignment	1 σ,Axis-to-axis, Δ = 90° ideal	—	0.03	—	deg
Bias					
Initial Error	1 σ	—	8	—	mG
Temperature Coefficient	1 σ, −20°C ≤ T_A ≤ +70°C		0.4		mG/°C
(Linear approximation)			0.02		
Bias Instability		—	0.1	—	mG
Velocity Random Walk		—	0.04	—	(m/sec)/ $\sqrt{hr}$
Noise					
Noise Density	f = 10 to 20 Hz	—	0.1	—	mG/ $\sqrt{Hz}$, rms
Frequency Property					
3 dB Bandwidth	—	—	148	—	Hz
TEMPERATURE SENSOR					
Scale Factor *1	Output = -15214(0xC492) @ +25°C	—	0.0042725	—	°C/LSB

*1) This is a reference value used for internal temperature compensation. There is no guarantee that the value gives an absolute value of the internal temperature.

Note) The values in the specifications are based on the data calibrated at the factory. The values may change according to the way the product is used.

Note) The Typ values in the specifications are average values or 1σ values.

Note) Unless otherwise noted, the Max / Min values in the specifications are design values or Max / Min values at the factory tests.

Table 2.4 Interface Specifications

T_A=25°C, VCC=3.3V, unless otherwise noted

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
LOGIC INPUTS*1					
Positive Trigger Voltage	LVCMOS Schmitt	1.2	—	2.52	V
Negative Trigger Voltage	LVCMOS Schmitt	0.75	—	1.98	V
Hysteresis Voltage	LVCMOS Schmitt	0.3	—	—	V
Logic 1 Input Current, IINH	VIH = 3.3 V	—	0.1	—	μA
Logic 0 Input Current, IINL	VIL = 0 V	—	—	—	
All Pins Except RST	—	—	0.1	—	μA
Pin RST	—	—	0.04	—	mA
Input Capacitance, CIN	—	—	8	—	pF
RST Voltage range		0		Vcc+0.3	V
RST High-level input voltage, V_{IH}	—	0.7xVCC	—	—	V
RST Low-level input voltage, V_{IL}	—	—	—	0.3xVCC	V
RST Low pulse width	—	10	—	—	ms
Pull-up resistor	—	32	80	224	kΩ
DIGITAL OUTPUTS*1					
Output High Voltage, VOH	ISOURCE=1.4mA LVCMOS	2.9	—	—	V
Output Low Voltage, VOL	ISINK=1.4mA LVCMOS	—	—	0.4	V
Backup MEMORY	Endurance*2, @25 degree C	10^6	—	—	Cycles
FUNCTIONAL TIMES*3	Time until data is available				
Power-On Start-Up Time	—	—		800	ms
Reset Recovery Time	—	—		800	ms
User Calibration Time	—	—		1200	ms
Calibration Reset Time	—	—		100	ms
Flash Test Time	—	—		5	ms
Flash backup Time	—	—		100	ms
Self Test Time	—	—		80	ms
DATA OUTPUT RATE	DOUT_RATE = 0x01	—	—	1000	Sps
Clock Accuracy	—	—	—	±0.01	%
POWER SUPPLY	Operating voltage range, VCC	3.15	3.3	3.45	V
Power Supply Current	—	—	30	—	mA

*1) Digital I/O signal pins operate at 3.3V inside the chip. All digital I/O signal pins (except RST) can tolerate 5V input.

*2) This item is not included in the factory test items but its characteristic is confirmed.

*3) These specifications do not include the effect of temperature fluctuation and response time of the internal filter.

2.4 Timing Specifications

Table 2.5 Timing Specification

T_A=25°C, VCC=3.3V, unless otherwise noted

Parameter	Description	Min.	Typ.	Max.	Unit
f_{SCLK}		0.01	—	2.0	MHz
t_{STALL}	Stall period between data	20	—	—	μs
$t_{WRITERATE}$	Write Rate	40	—	—	μs
$t_{READRATE}$	Read rate	40	—	—	μs
t_{CS}	Chip select to clock edge	10	—	—	ns
t_{DAV}	SO valid after SCLK edge	—	—	80	ns
t_{DSU}	SI setup time before SCLK rising edge	10	—	—	ns
t_{DHD}	SI hold time after SCLK rising edge	10	—	—	ns
t_{SCLKR}, t_{SCLKF}	SCLK rise/fall times	—	—	20	ns
t_{DF}, t_{DR}	SO rise/fall times	—	—	20	ns
t_{SFS}	high after SCLK edge CS	80	—	—	ns

Note) The specifications above are not included in the factory test items but their characteristic is confirmed.

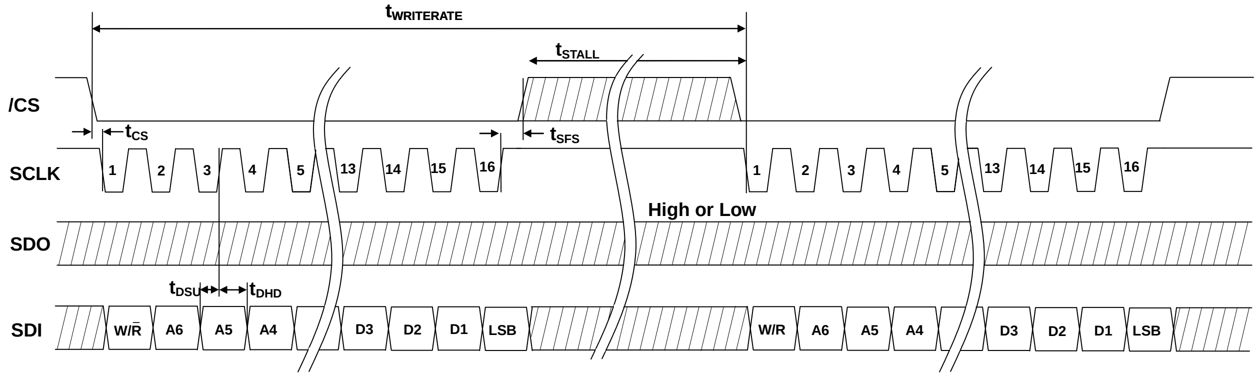


Figure 2.1 SPI Timing and Sequence 1/2

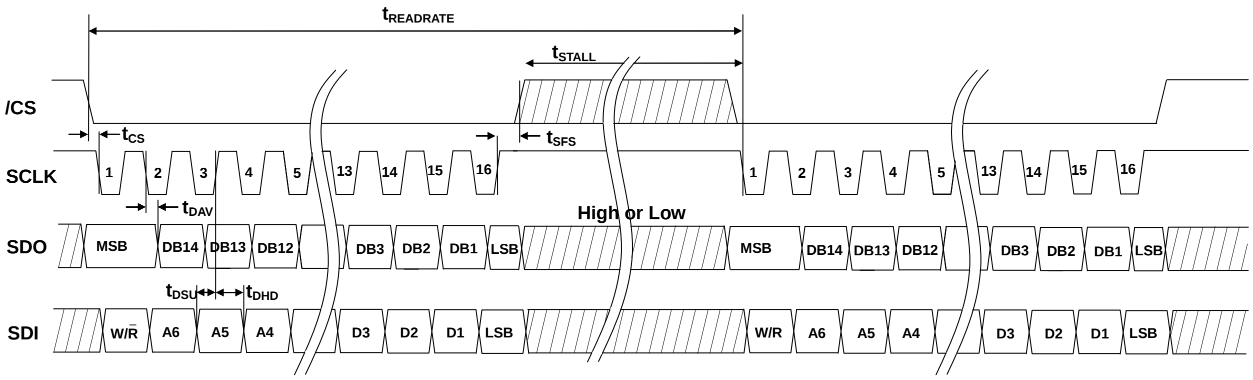


Figure 2.2 SPI Timing and Sequence 2/2

2.5 Socket Pin Layout and Functions

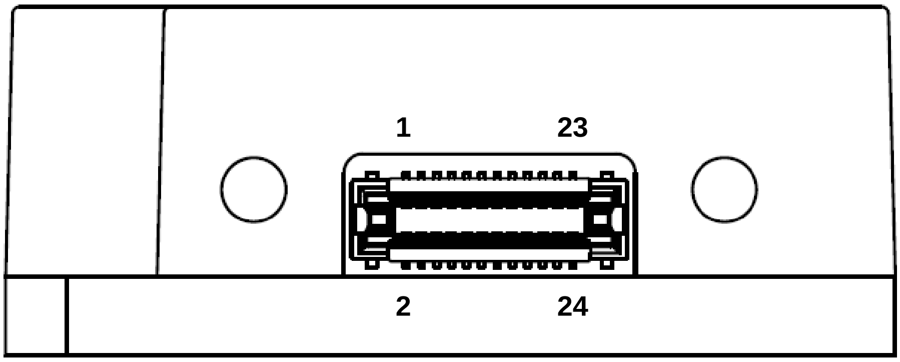


Figure 2.3 Socket Pin Assignment

Table 2.6 Pin Function Descriptions

Pin No.	Mnemonic	Type*1	Description
1,2,3,4,22,23,24	NC	N/A	Do Not Connect
5	SCLK	I	SPI Serial Clock *2 *5
6	SDI	I	SPI Data Input *2 *5
7	/CS	I	SPI Chip Select *2 *5
8	SDO	O	SPI Data Output *2 *5
9	SOUT	O	UART Data Output *2
10	SIN	I	UART Data Input *2
11,12	VCC	S	Power Supply 3.3V
13,14,15,16	GND	S	Ground
17	DRDY (GPIO1)	I/O	Data Ready (General Purpose I/O1)
18	GPIO2	I/O	General Purpose I/O2
19	GPIO3	I/O	General Purpose I/O3
20	BRATE	I	UART Baud Rate *3 High(VCC) : 460.8kBaud Low(GND) : 230.4kBaud
21	/RST	I	Reset *4

*1) Pin Type I: Input, O: Output, I/O: Input/Output, S: Supply, N/A: Not Applicable

*2) Connect either SPI or UART but not both. Connecting both SPI and UART at the same time may result in malfunction of the device. Regarding unused pin, please connect unused input pins to VCC through resistor.

*3) Change the baud rate setting when the power for the IMU is OFF, or perform a hardware reset or a software rest (write “1” to SOFT_RST at GLOB_CMD[3Eh], bit[7]) after the baud rate setting is changed.

*4) If the /RST pin is not used, keep the pin at High (VCC) voltage level through resistor.

*5) SPI multiple slave configuration is not supported.

Note) All input pins have weak pull up resistors inside the IMU.

3. Mechanical Dimensions

3.1 Outline Dimensions

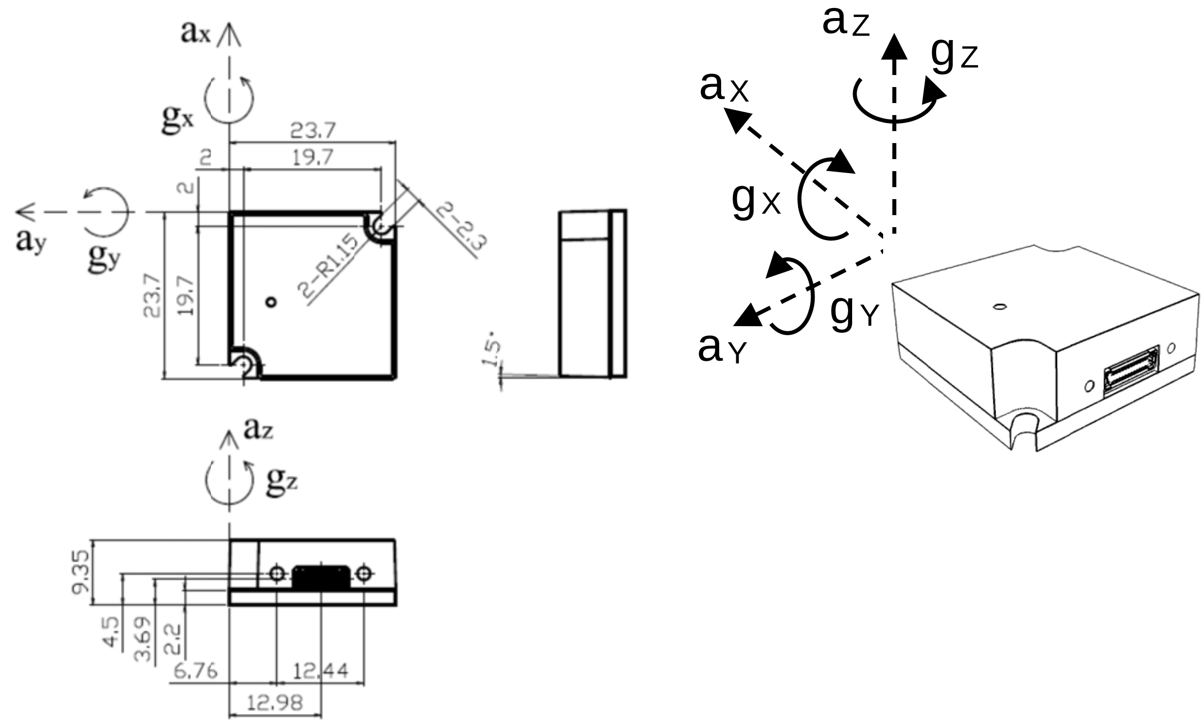


Figure 3.1 Outline Dimensions (millimeters)

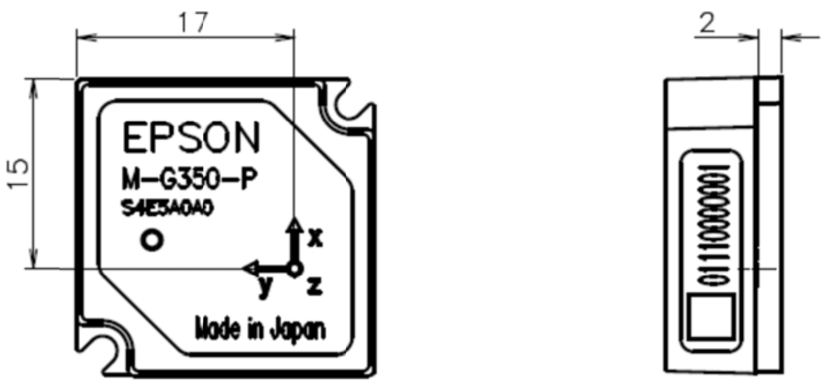


Figure 3.2 Acceleration Sensor Origin (millimeters)

*1) The arrow marking on the top label shows the origin of Acceleration.

*2) The label on the side of IMU describes the unit identification (ID) code.

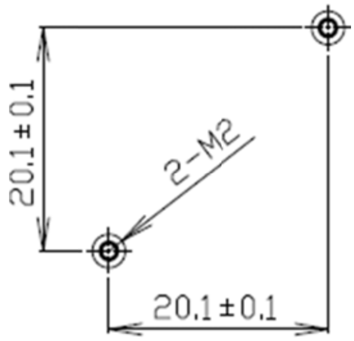


Figure 3.3 Suggested Guide Pin & Mounting Screw Hole Location (millimeters)

Use M2 pan head screws to mount the IMU in order to avoid deformation of the flange.

For information about the location of the screw holes, see Figure 3.3.

3.2 Socket Dimensions

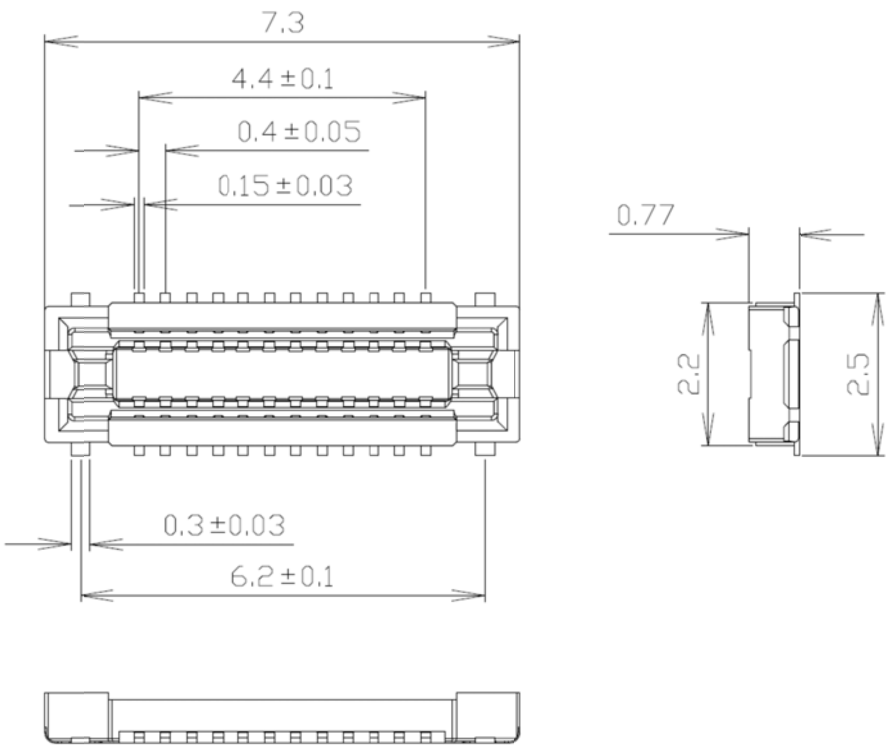


Figure 3.4 Socket Pin Assignment

Table 3.1 Socket Part Number

Maker	Parts Number	RoHS Compliant
Panasonic	AXE524124	Yes

Table 3.2 shows the connector manufacturer and the model number of the recommended header used at the host side.

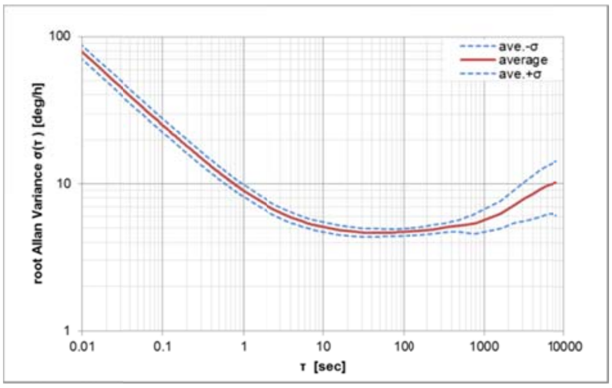
Table 3.2 Header Part Number

Maker	Parts Number	RoHS Compliant
Panasonic	AXE624224	Yes

Use M1.6 (P 0.35mm) pan head screws to fix the header part of the connector harness to the socket of the IMU. Select the length of the screws so that the length of engagement under the surface of the IMU is 3±0.5mm.

Note: The IMU connector rating for insertion and removal is a maximum of 20 times.

4. Typical Performance Characteristics



Data Output Rate: 125Sps
Average Filter TAP: N=16

Figure 4.1 Gyro Allan Variance Characteristic (N=9)

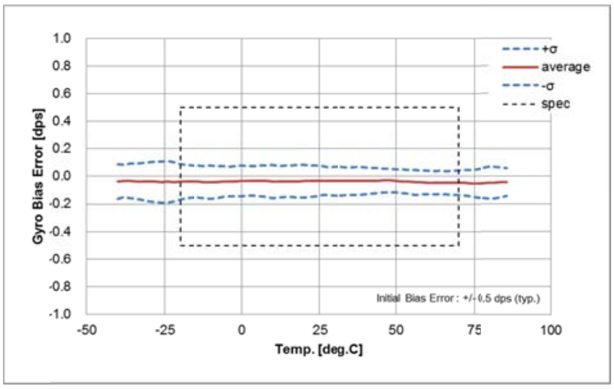
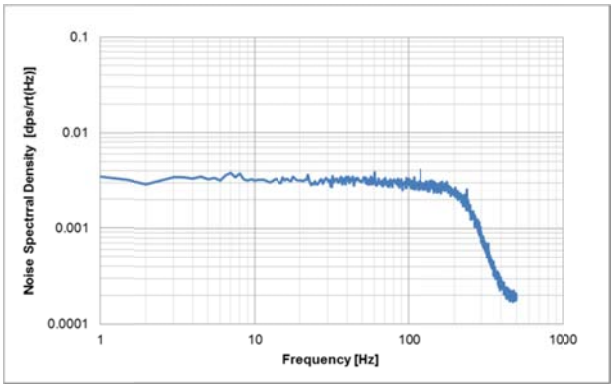
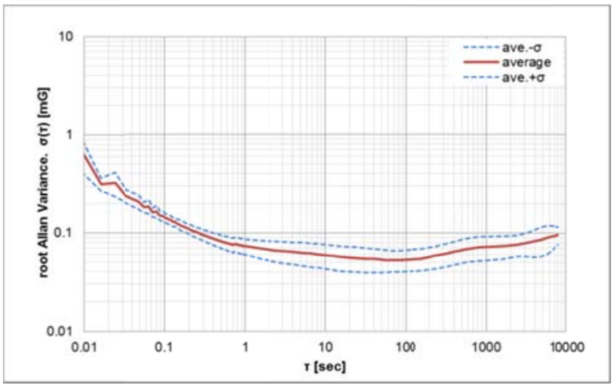


Figure 4.2 Gyro Bias vs. Temperature Characteristic (N=40)



Data Output Rate: 1kSps
Average Filter TAP: N=4

Figure 4.3 Gyro Noise Frequency Characteristic



Data Output Rate: 125Sps
Average Filter TAP: N=16

Figure 4.4 Accelerometer Allan Variance Characteristic (N=9)

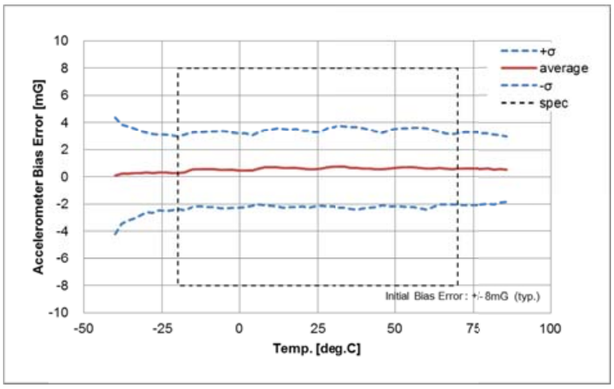
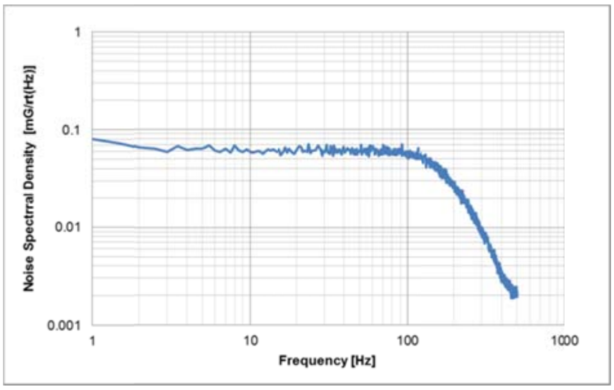


Figure 4.5 Accelerometer Bias vs. Temperature Characteristic (N=40)



Data Output Rate: 1kSps
Average Filter TAP: N=**4**

Figure 4.6 Accelerometer Noise Frequency Characteristic

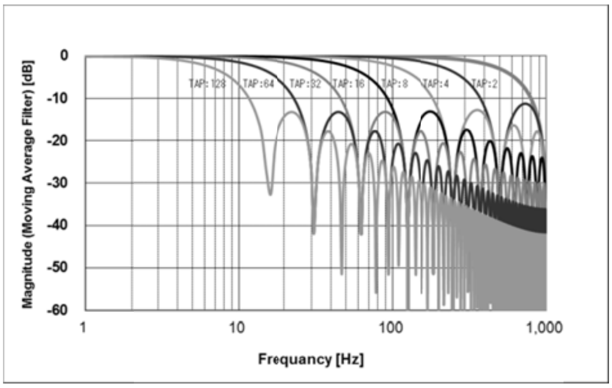


Figure 4.7 Internal Moving Average Filter Characteristic

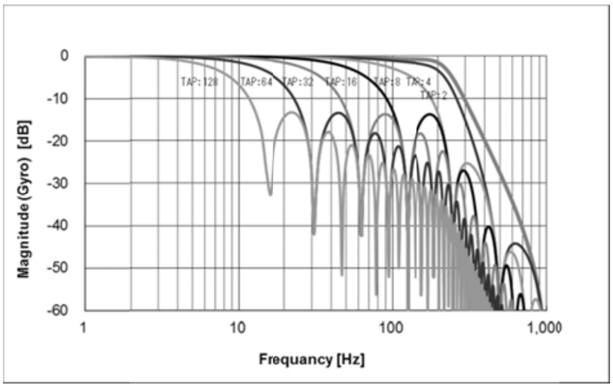


Figure 4.8 Gyro Filter Bandwidth Characteristic

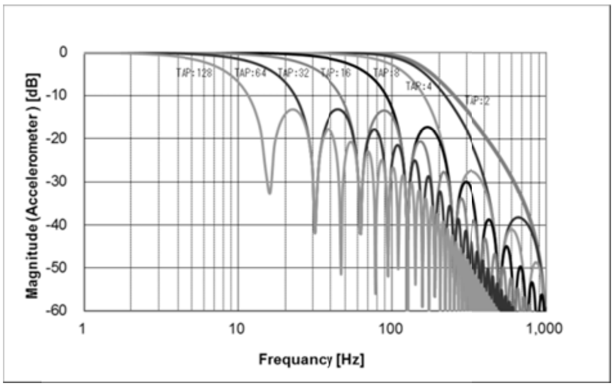


Figure 4.9 Accelerometer Filter Bandwidth Characteristic

The product characteristics shown above are just examples and are not guaranteed as specifications.

5. Basic Operation

5.1 Connection to Host

The device is connected to the host via SPI or UART. The following is an example of the connection.

NOTE: SPI multiple slave configuration is not supported.

NOTE: Connect either SPI or UART but not both. Connecting both SPI and UART at the same time may result in malfunction of the device.

NOTE: Refer to Table 2.6 Pin Function Description for the connection of unused pins.

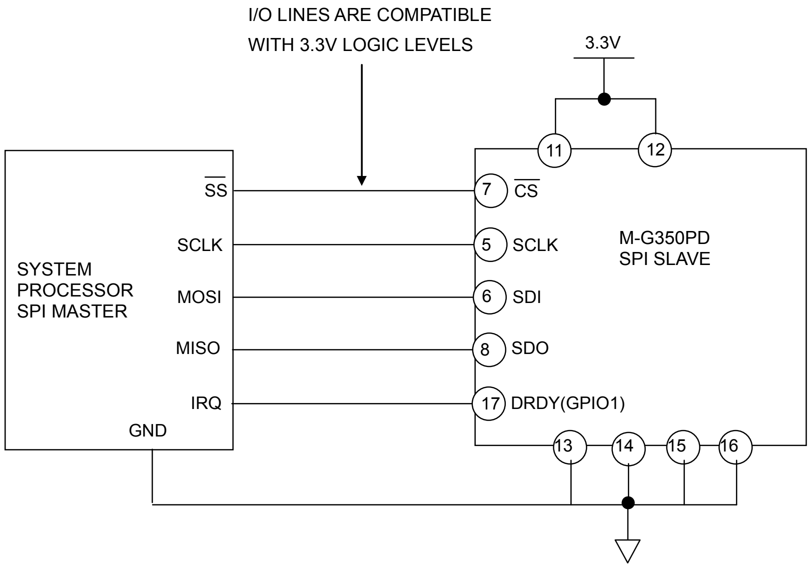


Figure 5.1 SPI Connection

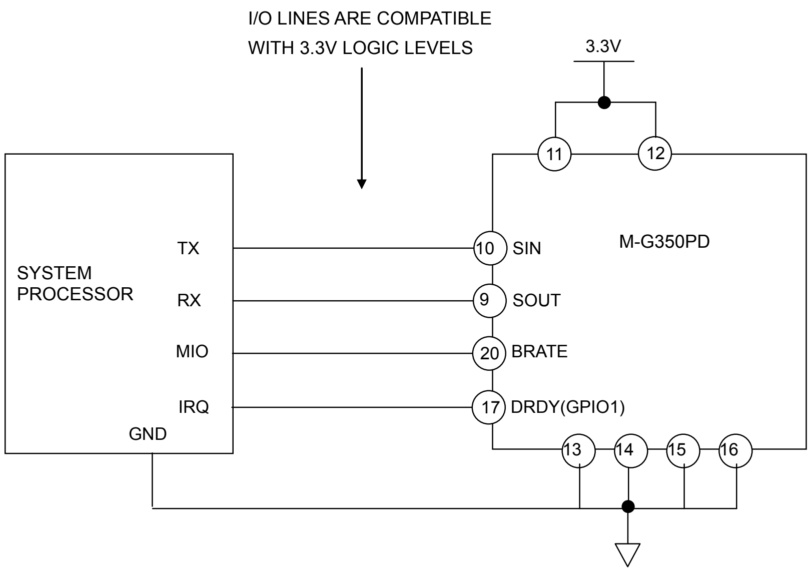


Figure 5.2 UART Connection

5.2 Operation Mode

The device has the following two operation modes. Only when UART is used, the sampling mode has two submodes: Manual mode and Auto mode.

(1) Configuration mode
(2) Sampling mode
- Manual mode
- Auto mode (for UART only)

Immediately after a hardware reset or power on, internal initialization starts. During the internal initialization, all the register values and states of external pins are undefined. After the internal initialization is completed, the device goes into the Configuration mode. Configure various operational settings in the Configuration mode(*1). After configuration is completed, go to the Sampling mode to read out the temperature, angular rate, and acceleration data. To change the operation mode, write to the **MODE_CMD** (bit[9:8] of the MODE_CTRL[38h] register). When software reset is execute (by writing 1 to the **SOFT_RST** (bit[7] of the GLOB_CMD[3Eh] register)), internal initialization is executed and then the device goes into the Configuration mode regardless of the current operation mode.

When the UART interface is used, writing to the **UART_AUTO** (bit[0] of the UART_CTRL[3Ah] register) can switch between the Manual mode and the Auto mode(*2).

NOTE: When SPI interface is used, Manual mode must be selected. Otherwise, the device does not work properly.

*1) Make sure that the device is in the Configuration mode when you write to the registers to configure operational settings. In Sampling mode, writing to registers is ignored except the following cases.

- Writing to the **MODE_CMD** (bit[9:8] of the MODE_CTRL[38h])
- Writing to the **GPIO_DATA** (bit[10:8] of the GPIO[10h])
- Writing to the **SOFT_RST** (bit[7] of the GLOB_CMD[3Eh])

*2) While in the UART Auto mode and sensor sampling is active, register read access is not supported. Otherwise, the sampling data transmitted in the UART Auto mode, will be corrupted by the response data from the register read.

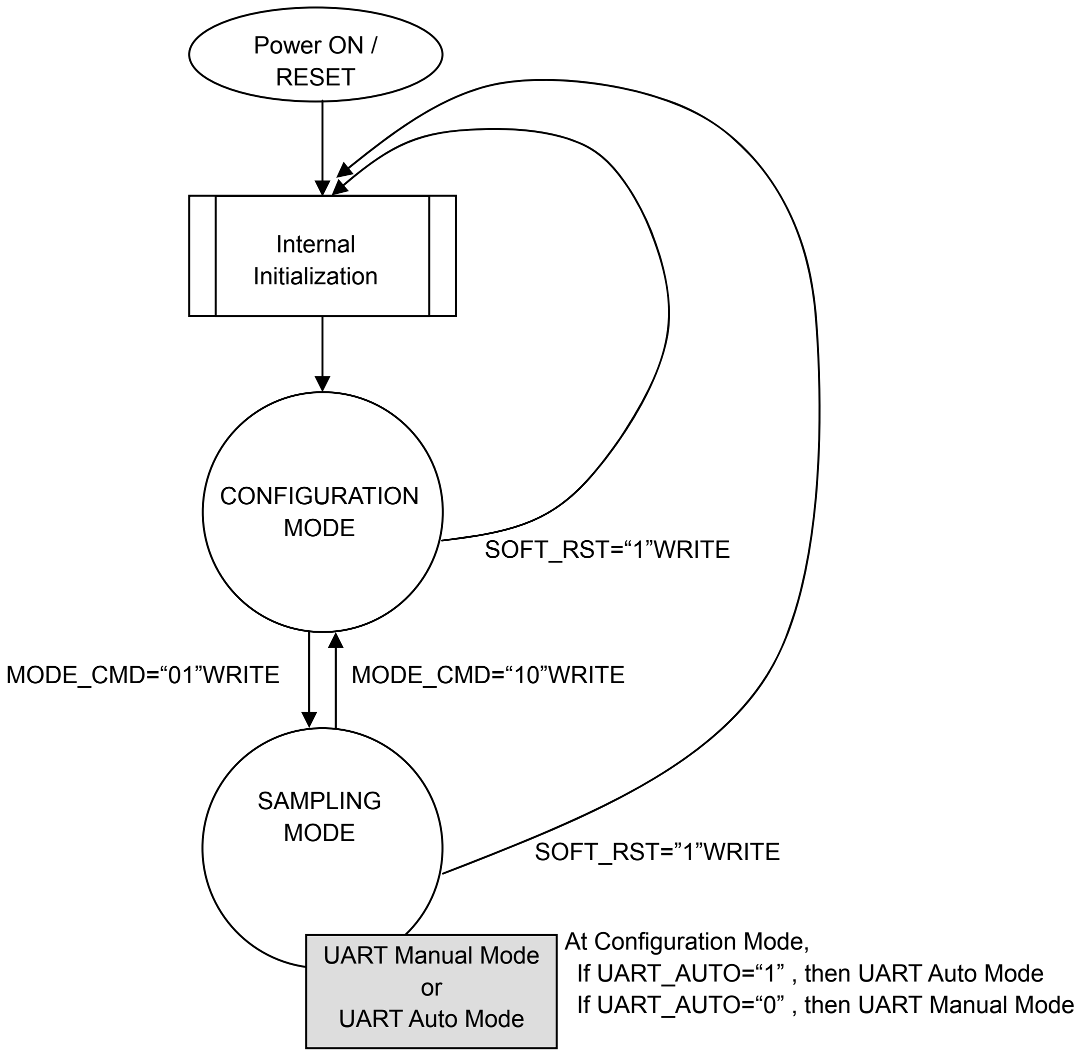


Figure 5.3 Operational State Diagram

5.3 Functional Block

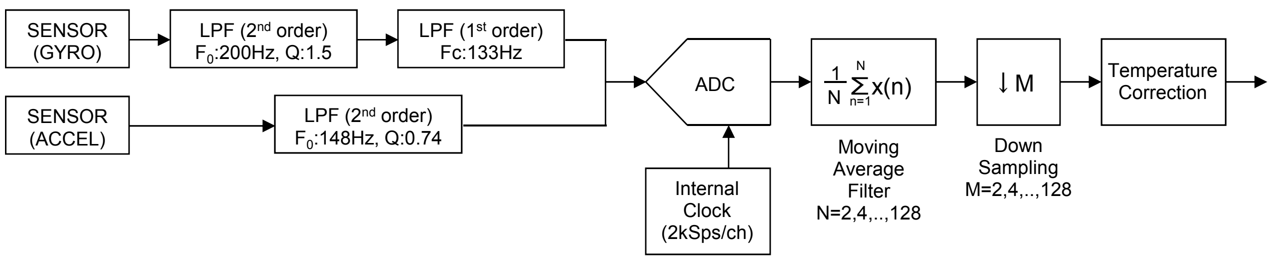


Figure 5.4 Functional Block Diagram

5.4 Data Output Timing

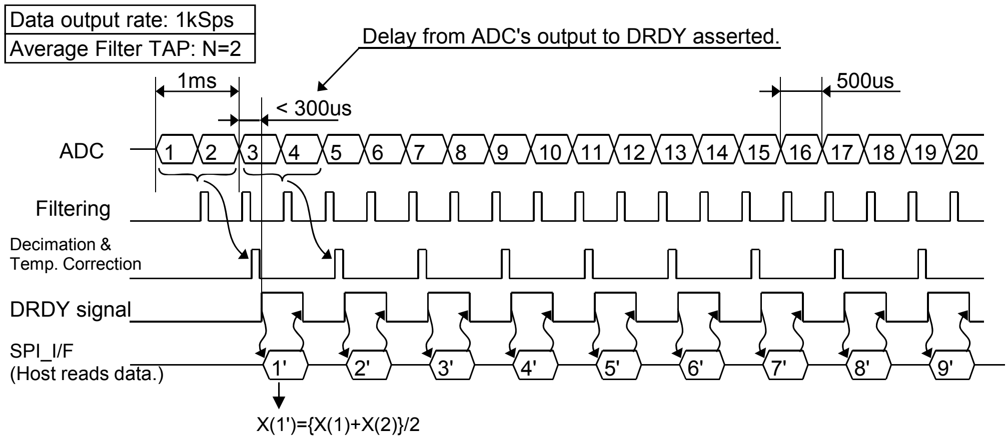


Figure 5.5 Data Output Timing – Output Rate 1kSps, Average Filter TAP N=2

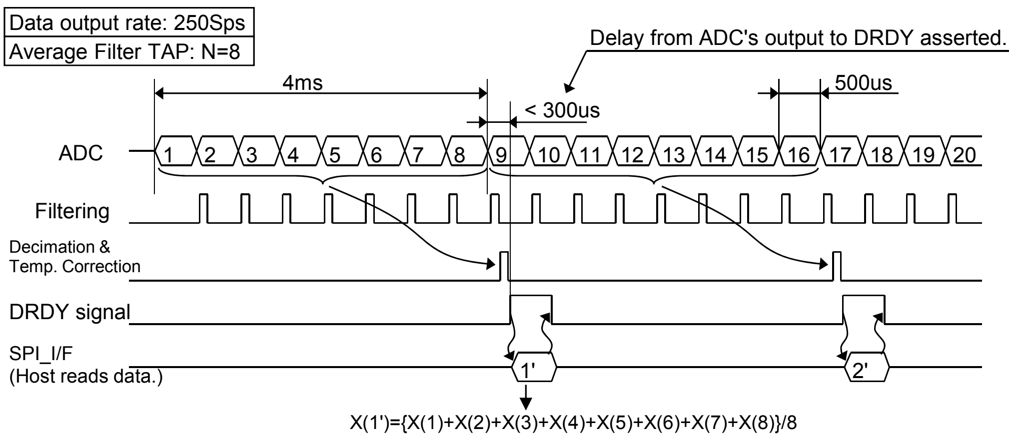


Figure 5.6 Data Output Timing – Output Rate 250Sps, Average Filter TAP N=8

5.5 Data Ready Signal

The Data Ready signal is asserted when one sampling cycle completes and registers are updated with new sensor values. When the sensor values are read out, the Data Ready signal becomes negated.

The Data Ready signal is output to the pin when the **DRDY_ON** bit[2] of the MSC_CTRL[34h] register is set to “1”. The polarity of the signal can be changed by writing to the **DRDY_POL** bit[1] of the MSC_CTRL[34h] register.

The Data Ready signal is the logical sum of all the ND flags corresponding to each sensor value. If all the ND flags are disabled in the **ND_EN** setting (bit[15:9] of the SIG_CTRL[32h] register), the Data Ready will not be asserted. On the other hand, if all the sensor values enabled in the **ND_EN** setting (bit[15:9] of the SIG_CTRL[32h] register) are not read out, the Data Ready signal is kept asserted and never becomes negated.

NOTE: In UART auto mode, the Data Ready signal is fixed to the “inactive” level.

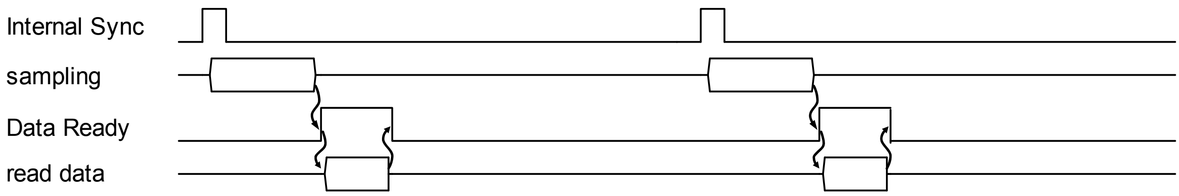


Figure 5.7 Data Ready Signal Timing

5.6 Sampling Counter

The sampling counter is a 16-bit rolling counter with a value that is incremented at every sampling timing of the internal A/D converter. The sampling counter value can be read by the COUNT[12h] register. The count interval is 500usec/count and is based on the precision of the internal reference oscillator (crystal).

Additionally, during UART burst mode and in UART Auto mode, the counter value can be included in the normal response by setting the **COUNT_CTRL** (bit[0] of the COUNT_CTRL [50h] register). For information about the response format, see 6.3 DATA PACKET FORMAT.

5.7 GPIO

The device has three general purpose I/O ports (GPIO). By accessing the GPIO[10h] register, the direction (in/out) of each port can configured and data can be read/written to. The GPIO port can be read in the normal mode, and also in the UART burst mode or UART Auto mode.

GPIO1 is shared with the Data Ready signal. The switch between GPIO1 and Data Ready signal can be controlled by **DRDY_ON** of MSC_CTRL[0x34] bit[2] register. When **DRDY_ON** is written as “0”, GPIO1 pin acts as general purpose I/O port..

5.8 Self Test

The self test function can be used to check whether the outputs of the gyroscope and the accelerometer are within the pre-determined range and operating properly based on these results. For the gyroscope, the test result is OK if the bias of the output for each X-, Y-, or Z-axis is close to zero when the device is not moving. For the accelerometer, the test result is OK if the absolute value of the output as a three dimensional vector is equal to the gravitational acceleration. When you perform the self test, make sure the device does not move during the test and the test is conducted in a place without vibration.

For information about the execution time of the self test, see “Self Test Time” in Table 2.4 Interface Specifications.

To use the self test function, see the description of the **SELF_TEST** (bit[10] of the MSC_CTRL[34h] register) and the **ST_ERR_ALL** (bit[1] of the DIAG_STAT[3Ch] register).

5.9 User Calibration

The user calibration function is used to cancel the quiescent bias offset value of the gyroscope at the time of execution. The steps of the user calibration executed inside the IMU are as follows.

(1) Record the output of the gyroscope for a certain period of time, and record the average value of those outputs as the quiescent bias offset value.

(2) After this point, when the output of the gyroscope is read from the host, the quiescent bias offset value is always subtracted from the output of the gyroscope and the device sends the subtracted value to the host.

When performing the user calibration, make sure the device does not move during the calibration and the calibration is conducted in a place without vibration.

After performing the user calibration, the recorded quiescent bias offset value can be reset to the factory default.

For information about the execution time of the user calibration, see "User Calibration Time" in Table 2.4 Interface Specifications.

To use the user calibration function, see the description of the **CAL_GYRO** (bit[13:12] of the MSC_CTRL[34h] register) and the **CAL_ERR** (bit[7] of the DIAG_STAT[3Ch] register).

NOTE: The device does not have a user calibration function for the accelerometers.

6. Digital Interface

The device has the following two external interfaces.

(1) SPI interface

(2) UART interface

The SPI interface and the UART interface have almost the same functions, except additionally the UART interface supports Auto mode and burst mode functions. Because both interfaces are always enabled, the user needs only to connect the desired interface pins SPI or UART, without needing any hardware pin configuration or selection.

NOTE: Connecting both SPI and UART at the same time is not supported and may result in malfunction of the device.

The registers inside the device are accessed via the SPI or UART interfaces.

In this document, data sent to the device is called “command” and data sent back in response to the command is called “response”. There are two types of commands: write command and read command. The write command has no response. The write command always writes to the internal register in 8-bit words. The response to the read command, i.e. the data from the internal register, is always read in 16-bit words.

Only the UART interface has a special mode called the burst mode in addition to the normal mode to read the internal registers (refer to Section 6.2.2 UART Read Timing (Burst Mode)).

6.1 SPI Interface

Table 6.1 shows the communication settings of SPI interface and Table 6.2 shows the SPI timing.

Table 6.1 SPI Communication Conditions

Item	Setting
Mode	Slave
Word length	16 bits
Phase	Rising edge
Polarity	Negative logic

Table 6.2 SPI Timing

Parameter	Min.	Max.	Unit
f_{SCLK}	0.01	2.0	MHz
t_{STALL}	20	—	μs
$t_{WRITERATE}$	40	—	μs
$t_{READRATE}$	40	—	μs

6.1.1 SPI Read Timing

The response to the read command, i.e. the data from the internal register, is always returned in 16-bit words. The SPI interface supports sending the next command during the same bus cycle as receiving a response to the read command (full-duplex).

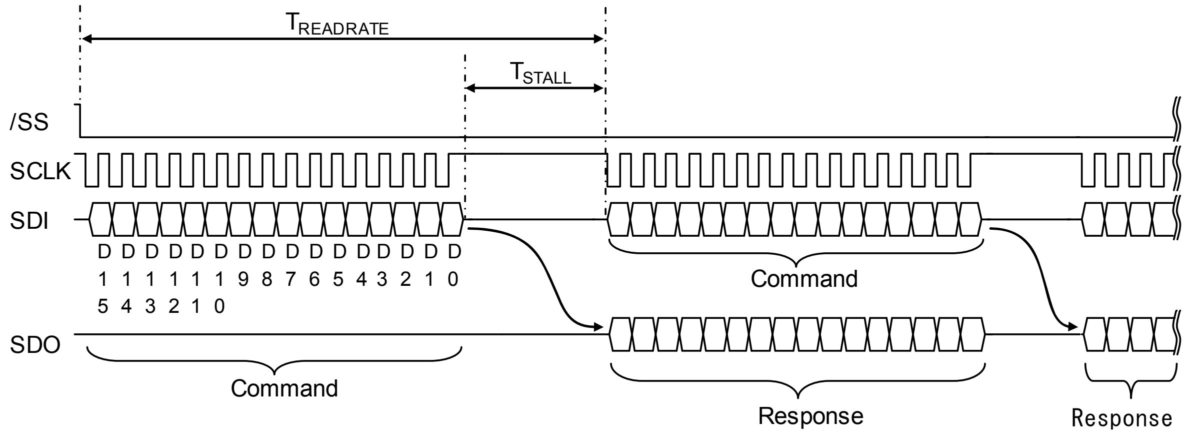


Figure 6.1 SPI Read Timing

Table 6.3 Command Format (Read)

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	A[6:0]							XX							

A[6:0] ・・・ Register address (even address)

XX ・・・ Don't Care

Table 6.4 Response Format (Read)

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
D[15:8]								D[7:0]							

D[15:8] ・・・ Register read data (upper byte)

D[7:0] ・・・ Register read data (lower byte)

6.1.2 SPI Write Timing

A write command to a register has no response. Unlike register reading, registers are written in 8-bit words.

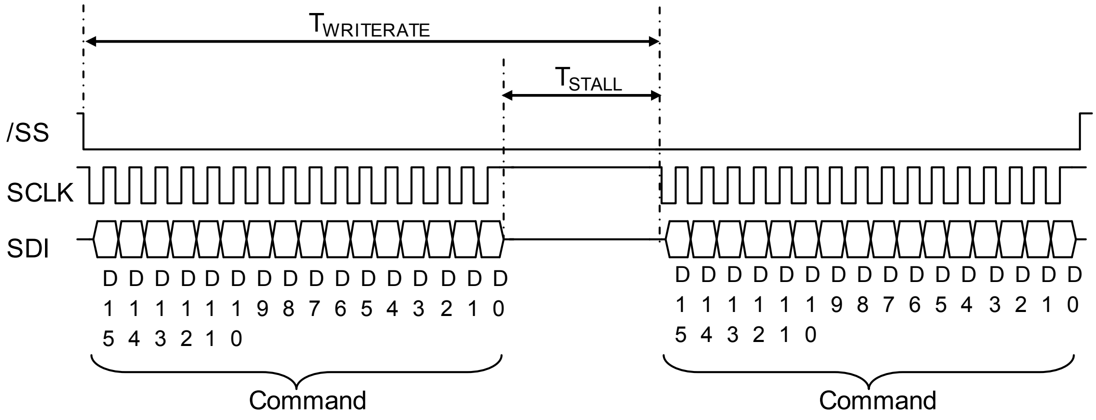


Figure 6.2 SPI Write Timing

Table 6.5 Command Format (Write)

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	A[6:0]							D[7:0]							

A[6:0] ･･･ Register address (even or odd)

D[7:0] ･･･ Register write data

6.2 UART Interface

Table 6.6 shows the supported UART communication settings and Figure 6.3 shows the UART bit format.

NOTE: The baud rate setting should be changed when the power for the IMU is OFF, or requires asserting a hardware reset after the baud rate setting is changed.

Table 6.6 UART Communication Conditions

Item	Setting
Transfer speed	230.4kbps/460.8kbps (Selected by the BRATE Pin)
Start	1 bit
Data	8 bits
Stop	1 bit
Parity	None
Delimiter	CR(0x0D)

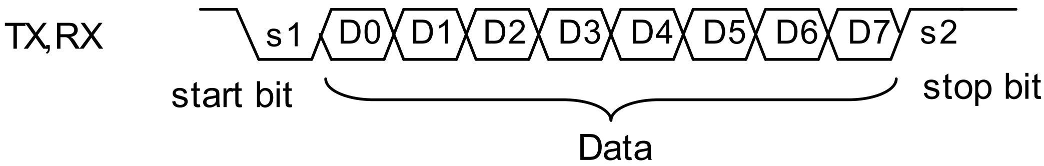


Figure 6.3 UART Bit Format

For the UART interface, a delimiter (1 byte) is placed at the end of each command (by the host) and response (by the IMU). In addition for responses, the address (1 byte) specified by the command is added (by the IMU) to the beginning of the response.

Table 6.7 and Table 6.8 show the UART timing.

Table 6.7 UART Timing (If the sampling counter value is not attached)

Parameter	Normal mode				Burst mode		Unit
	Manual mode		Auto mode				
	Min.	Max.	Min.	Max.	Min.	Max.	
t_{STALL}(230.4kbps)	—	20	—	1060	—	40	μs
t_{STALL}(460.8kbps)	—	20	—	590	—	40	μs
$t_{WRITERATE}$(230.4kbps)	350	—	1410	—	—	—	μs
$t_{WRITERATE}$(460.8kbps)	200	—	790	—	—	—	μs
$t_{READRATE}$(230.4kbps)	350	—	1410	—	1060	—	μs
$t_{READRATE}$(460.8kbps)	200	—	790	—	590	—	μs

Table 6.8 UART Timing (If the sampling counter value is attached)

Parameter	Normal mode				Burst mode		Unit
	Manual mode		Auto mode				
	Min.	Max.	Min.	Max.	Min.	Max.	
t_{STALL}(230.4kbps)	—	20	—	1150	—	40	μs
t_{STALL}(460.8kbps)	—	20	—	630	—	40	μs
$t_{WRITERATE}$(230.4kbps)	350	—	1500	—	—	—	μs
$t_{WRITERATE}$(460.8kbps)	200	—	830	—	—	—	μs
$t_{READRATE}$(230.4kbps)	350	—	1500	—	1150	—	μs
$t_{READRATE}$(460.8kbps)	200	—	830	—	630	—	μs

6.2.1 UART Read Timing (Normal Mode)

The response to the read command, i.e. the data from the internal register, is always one 16-bit data at a time. The register address (AD) comes at the beginning of the response, for example, 0x38 for the MODE_CTRL register.

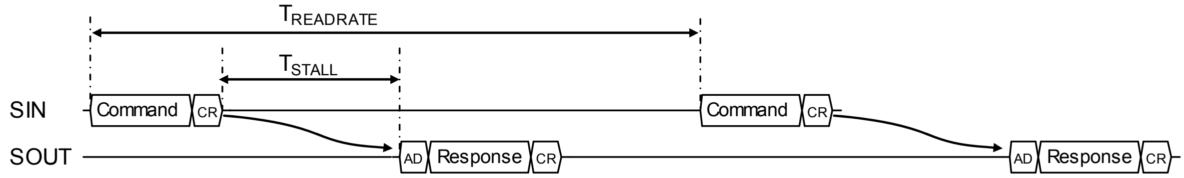


Figure 6.4

Table 6.9 Command Format (Read)

First byte								Second byte								Third byte							
7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
0	A[6:0]							XX								0x0D							

A[6:0] ・・・ Register address (even address)

XX ・・・ Don't Care

0x0D ・・・ Delimiter

Table 6.10 Response Format (Read)

First byte								Second byte								Third byte								Fourth byte							
7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
0	A[6:0]							D[15:8]								D[7:0]								0x0D							

A[6:0] ・・・ Register address (even address)

D[15:8] ・・・ Register read data (upper byte)

D[7:0] ・・・ Register read data (lower byte)

0x0D ・・・ Delimiter

6.2.2 UART Read Timing (Burst Mode)

Only when 0x20 is specified for the register address, the device operates in the burst mode. The ND flag/EA flag, temperature sensor output, tri-axis gyroscope output, tri-axis accelerometer output, and GPIO data are transmitted in succession as a response. For information about the response format, see 6.3 DATA PACKET FORMAT.

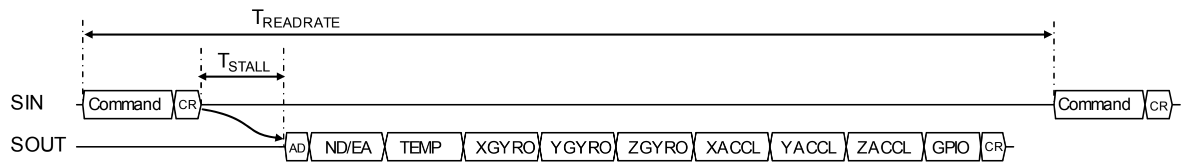


Figure 6.5 UART Read Timing (Burst Mode)

Table 6.11 Command Format (Burst mode)

First byte								Second byte								Third byte							
7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
0	0x20							XX								0x0D							

0x20 ･･･ Burst command

XX ･･･ Don't Care

0x0D ･･･ Delimiter

6.2.3 UART Write Timing

A write command to a register will have no response. Unlike register reading, registers are written in 8-bit words.

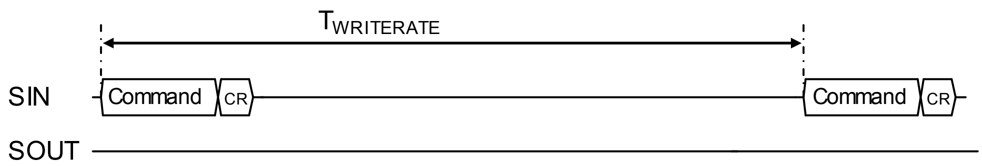


Figure 6.6

Table 6.12 Command Format (Write)

First byte								Second byte								Third byte							
7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
1	A[6:0]							D[7:0]								0x0D							

A[6:0] ･･･ Register address (even or odd)

D[7:0] ･･･ Register write data

0x0D ･･･ Delimiter

6.2.4 UART Auto Mode Operation

When UART Auto Mode is active, all sensor outputs are sent as burst transfer automatically at the programmed output data rate without the request from the Host. For example, if 1000 Sps is specified, the ND flag/EA flag, temperature sensor output, tri-axis gyroscope output, tri-axis accelerometer output, and GPIO data are transmitted in succession every 1ms as a response. For information about the response format, see 6.3 Data Packet Format.

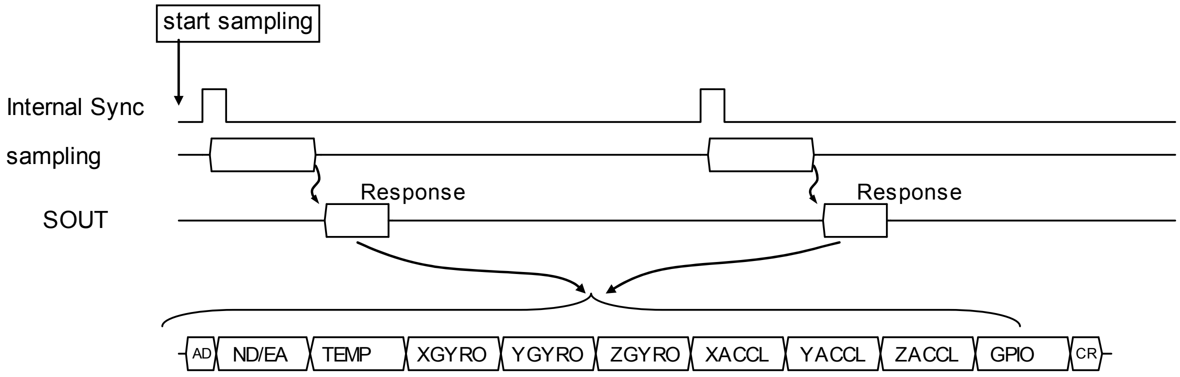


Figure 6.7 UART Auto Mode Operation

6.3 Data Packet Format

The following table shows the data packet format sent to the host in the UART burst mode and the UART auto mode.

Table 6.13 Data Packet Format (UART Burst/Auto Mode)

Byte No.	Name	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
1	ADDRESS	0x20							
2	ND	ND (Temp)	ND (XGyro)	ND (YGyro)	ND (ZGyro)	ND (XACCL)	ND (YACCL)	ND (ZACCL)	—
3	EA	—	—	—	—	—	—	—	EA
4	TEMP_ OUT_H	TEMP_OUT [15:8]							
5	TEMP_ OUT_L	TEMP_OUT [7:0]							
6	XGYRO_ OUT_H	XGYRO_OUT [15:8]							
7	XGYRO _OUT_L	XGYRO_OUT [7:0]							
8	YGYRO _OUT_H	YGYRO_OUT [15:8]							
9	YGYRO _OUT_L	YGYRO_OUT [7:0]							
10	ZGYRO _OUT_H	ZGYRO_OUT [15:8]							
11	ZGYRO _OUT_L	ZGYRO_OUT [7:0]							
12	XACCL _OUT_H	XACCL_OUT [15:8]							
13	XACCL _OUT_L	XACCL _OUT [7:0]							
14	YACCL _OUT_H	YACCL _OUT [15:8]							
15	YACCL _OUT_L	YACCL _OUT [7:0]							
16	ZACCL _OUT_H	ZACCL _OUT [15:8]							
17	ZACCL _OUT_L	ZACCL _OUT [7:0]							
18	GPIO_H	—	—	—	—	—	GPIO _DATA3	GPIO _DATA2	GPIO _DATA1
19	GPIO_L	—	—	—	—	—	GPIO _DIR3	GPIO _DIR2	GPIO _DIR1
(20 *1)	(COUNT_H)	(COUNT [15:8])							
(21 *1)	(COUNT_L)	(COUNT [7:0])							
20(22 *1)	CR	0x0D							

*1) If the sampling counter value attachment function is enabled in UART burst mode or UART Auto mode.

7. User Registers

A host device (for example, a microcontroller) can control the IMU by accessing the control registers inside the device.

During the Power-On Start-Up Time after the power on or the Reset Recovery time specified in the Table 2.4 Interface Specifications, all the register values are undefined because internal initialization is in progress. Make sure the IMU registers are only accessed after the Power-On Start-Up Time is over.

For information about the initial values of the control registers after internal initialization is finished, see the “Default” column in the Table 7.1. Control registers with ○ mark in the “Flash Backup” column can be saved to the non-volatile memory by the user, and the initial values after the power on will be the values read from the non-volatile memory. If the read out from the non-volatile memory fails, the FLASH_ERR (bit[2] of the DIAG_STAT[3Ch] register) is set to 1 (error).

Make sure that the IMU is in the Configuration Mode before writing to the registers. In the Sampling Mode, writing to registers is ignored except for the following cases.

- Writing to the **MODE_CMD** (bit[9:8] of the MODE_CTRL[38h])
- Writing to the **GPIO_DATA** (bit[10:8] of the GPIO[10h])
- Writing to the **SOFT_RST** (bit[7] of the GLOB_CMD[3Eh])

While in the UART Auto Mode and Sampling Mode is active, register read access is not supported. Otherwise, the sampling data transmitted in the UART Auto Mode, will be corrupted by the response data from the register read.

Each register is 16-bit long and one address is assigned to every 8 bits. Registers are read in 16-bit words and are written in 8-bit words. The byte order of each 16-bit register is little endian, but the byte order of the 16-bit data transferred over the digital interface is big endian.

Table 7.1 shows the register map, and Section 7.1 through Section 7.15 describes the registers in details.

The “-” sign in the register assignment table in Section 7.1 through Section 7.15 means “reserved”.

Write a “0” to reserved bits during a write operation.

During a read operation, a reserved bit can return, either 0 or 1 (“don’t care”).

Writing to a read-only register is prohibited.

Table 7.1 Register Map

Name	R/W	Flash Backup	Address	Default	Function
FLAG(ND/EA)	R		0x00	0x0000	ND flag/EA flag
TEMP_OUT	R		0x02	0xFFFF	Temperature sensor output
XGYRO_OUT	R		0x04	0xFFFF	X-axis Gyroscope output
YGYRO_OUT	R		0x06	0xFFFF	Y-axis Gyroscope output
ZGYRO_OUT	R		0x08	0xFFFF	Z-axis Gyroscope output
XACCL_OUT	R		0x0A	0xFFFF	X-axis Accelerometer output
YACCL_OUT	R		0x0C	0xFFFF	Y-axis Accelerometer output
ZACCL_OUT	R		0x0E	0xFFFF	Z-axis Accelerometer output
GPIO	R/W		0x11,0x10	0x0600	GPIO
COUNT	R		0x12	0x0000	Sampling counter value
BURST	R		0x20	0xFFFF	UART burst mode
SIG_CTRL	R/W	○	0x33,0x32	0xFE00	Data Ready signal control
MSC_CTRL	R/W	○	0x35,0x34	0x0006	Other control
SMPL_CTRL	R/W	○	0x37,0x36	0x0403	Sampling control
MODE_CTRL	R/W	○	0x39,0x38	0x0404	Operation mode/Filter control
UART_CTRL	R/W	○	0x3B,0x3A	0x0000	UART control
DIAG_STAT	R		0x3C	0x0000	Diagnosis result
GLOB_CMD	R/W		0x3F,0x3E	0x0000	System control
COUNT_CTRL	R/W		0x51,0x50	0x0000	Counter value transmission control

7.1 FLAG(ND/EA) Register

Addr (Hex)	Bit15	Bit14	Bit13	Bit12	Bit11	Bit10	Bit9	Bit8	R/W
01h	ND (Temp)	ND (XGyro)	ND (YGyro)	ND (ZGyro)	ND (XACCL)	ND (YACCL)	ND (ZACCL)	—	R

Addr (Hex)	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0	R/W
00h	—	—	—	—	—	—	—	EA	R

bit[15:9] ND(New Data) flag

When one of the temperature, angular rate (XGYRO_OUT, YGYRO_OUT, ZGYRO_OUT), or acceleration (XACCL_OUT, YACCL_OUT, ZACCL_OUT) registers gets a new measurement output, the corresponding ND flag is set to “1”. When the new measurement output is read from the register, the flag is reset to “0”.

bit[0] EA(All Error) flag

If there is at least one “error” in the diagnosis result register (DIAG_STAT[3Ch,3Dh]), the flag is set to “1” (error exists).

7.2 TEMP_OUT Register

Addr (Hex)	Bit15	. . .	Bit0	R/W
02h	TEMP_OUT			R

bit[15:0] Temperature sensor output data

This register returns the output of the built-in temperature sensor.
Output data is in 16-bit two’s complement format.

Please refer to the below formula for conversion to temperature in Celsius. Please refer to Table 2.3 Sensor Specification for the scale factor value..

$$T\,[^\circ C] = SF * (a + 15214) + 25$$

SF : Scale Factor

a: Temperature sensor output data (decimal)

NOTE: The reference value is used for internal temperature compensation. There is no guarantee that the value gives an absolute value of the internal temperature.

7.3 GYRO_OUT Register

Addr (Hex)	Bit15	. . .	Bit0	R/W
04h	XGYRO_OUT			R
06h	YGYRO_OUT			R
08h	ZGYRO_OUT			R

bit[15:0] Gyroscope output data

Returns the 3-axis gyroscope data for X, Y, and Z as referenced in Figure 3.1 Outline Dimensions (millimeters).
The output data is in 16-bit two's complement format. Please refer to the below formula for conversion to angular rate in degrees/second. Please refer to Table 2.3 Sensor Specification for the Scale Factor value.

G [deg/s]= SF * b

SF : Scale Factor
b: Gyroscope output data (decimal)

7.4 ACCL_OUT Register

Addr (Hex)	Bit15	. . .	Bit0	R/W
0Ah	XACCL_OUT			R
0Ch	YACCL_OUT			R
0Eh	ZACCL_OUT			R

bit[15:0] Accelerometer output data

Returns the 3-axis acceleration data for X, Y, and Z as referenced in Figure 3.1 Outline Dimensions (millimeters).
The output data is in 16-bit two's complement format. Please refer to the below formula for conversion to linear acceleration in milli-G. Please refer to Table 2.3 Sensor Specification for the Scale Factor value.

A [mG]= SF * c

SF : Scale Factor
c: Acceleration sensor output data (decimal)

7.5 GPIO Register

Addr (Hex)	Bit15	Bit14	Bit13	Bit12	Bit11	Bit10	Bit9	Bit8	R/W
11h	—	—	—	—	—	GPIO _DATA3	GPIO _DATA2	GPIO _DATA1	R/W

Addr (Hex)	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0	R/W
10h	—	—	—	—	—	GPIO _DIR3	GPIO _DIR2	GPIO _DIR1	R/W

bit[10:8] GPIO_DATA

If the corresponding **GPIO_DIR** bit is set to “output”, the value set in the **GPIO_DATA** is output to the GPIO port.
If the corresponding **GPIO_DIR** bit is set to “input”, the input level of the GPIO port is returned by reading the **GPIO_DATA**.
1 :High Level
0 :Low Level

bit[2:0] GPIO_DIR

Each bit controls the bitwise direction of the GPIO port.
1: Output
0: Input
NOTE: The GPIO1 shares the pin with the Data Ready signal. Use **DRDY_ON** of MSC_CTRL[34h] bit[2] to switch between the GPIO1 and the Data Ready signal. When “0” is written to the **DRDY_ON**, the pin functions as GPIO1.

7.6 COUNT Register

Addr (Hex)	Bit15	. . .	Bit0	R/W
12h	COUNT			R

bit[15:0] COUNT

This register returns the sampling counter value of the built-in A/D converter.
NOTE: The time unit of the counter value is 500 usec / count. Example: If the data output rate equals 1000Sps, the counter value changes as 2,4,6, ... , 0xFFFE, 0, 2, ...

7.7 BURST Register

Addr (Hex)	Bit15	. . .	Bit0	R/W
20h	BURST_READ			R

bit[15:0] BURST_READ

By reading from this address, the ND flag/EA flag, temperature sensor output, tri-axis gyroscope output, tri-axis accelerometer output, and GPIO data are transmitted consecutively.
NOTE: When the SPI interface is used, accessing this register is prohibited.
NOTE: For information about the data transmission format, see 6.2.2 UART Read Timing (Burst Mode) and 6.3 Data Packet Format.

7.8 SIG_CTRL Register

Addr (Hex)	Bit15	Bit14	Bit13	Bit12	Bit11	Bit10	Bit9	Bit8	R/W
33h	ND_EN (Temp)	ND_EN (XGyro)	ND_EN (YGyro)	ND_EN (ZGyro)	ND_EN (XACCL)	ND_EN (YACCL)	ND_EN (ZACCL)	—	R/W

Addr (Hex)	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0	R/W
32h	—	POL _CTRL (XGyro)	POL _CTRL (YGyro)	POL _CTRL (ZGyro)	POL _CTRL (XACCL)	POL _CTRL (YACCL)	POL _CTRL (ZACCL)	—	R/W

bit[15:9] ND_EN

Enables or disables the ND flags of FLAG[00h] bit[15:9].
1: Enable
0: Disable

bit[6:1] POL_CTRL

Specifies whether to bitwise invert the output value of the following registers: angular rate (**XGYRO_OUT**, **YGYRO_OUT**, **ZGYRO_OUT**) and acceleration (**XACCL_OUT**, **YACCL_OUT**, **ZACCL_OUT**).
1: Inverted
0: Not-inverted
NOTE: **ND_EN** setting is invalid, when UART automatic mode is active.

7.9 MSC_CTRL Register

Addr (Hex)	Bit15	Bit14	Bit13	Bit12	Bit11	Bit10	Bit9	Bit8	R/W
35h	—	—	CAL_GYRO		FLASH _TEST	SELF _TEST	—	—	R/W

Addr (Hex)	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0	R/W
34h	—	—	—	—	—	DRDY _ON	DRDY _POL	—	R/W

NOTE: The **CAL_GYRO**, **FLASH_TEST**, and **SELF_TEST** can not be executed at the same time. When executing them in succession, confirm the execution of the previous command is finished by waiting until the bit changes from “1” to “0” and then execute the next command.

bit[13:12] CAL_GYRO

Write to the bits to execute commands related to the calibration of the gyroscope. After this command is executed, wait until these bits goes back to “00” and then read the **CAL_ERR** of DIAG_STAT[3Ch] bit[7] to check the result.
01: Execute the calibration of the gyroscope. After the execution is completed, the bits automatically goes back to “00”.
10: Reset the result of the calibration of the gyroscope to the factory default. After the execution is completed, the bits automatically goes back to “00”.
11: (Not used)
00: (Not used)

bit[11] FLASH_TEST

Write "1" to execute the data consistency test for the non-volatile memory. The read value of the bit is "1" during the test and "0" after the test is completed. After writing "1" to this bit, wait until this bit goes back to "0" and then read the **FLASH_ERR** of DIAG_STAT[3Ch] bit[2] to check the result.

bit[10] SELF_TEST

Write "1" to execute the self test to check if the gyroscope and the accelerometer are working properly. The read value of the bit is "1" during the test and "0" after the test is completed. After writing "1" to this bit, wait until this bit goes back to "0" and then read the **ST_ERR_ALL** of DIAG_STAT[3Ch] bit[1] to check the result.

bit[2] DRDY_ON

Selects the function of the GPIO1 terminal for either GPIO1 or Data Ready.
1: Data Ready signal
0: GPIO1

bit[1] DRDY_POL

Selects the polarity of the Data Ready signal when selected in **DRDY_ON** above.
1: Active high
0: Active low

7.10 SMPL_CTRL Register

Addr (Hex)	Bit15	. . .	Bit8	R/W
37h	DOUT_RATE			R/W

Addr (Hex)	Bit7	. . .	Bit0	R/W
36h	—			—

bit[15:8] DOUT_RATE

Specifies the data output rate.
The following lists the data output rate option with the recommended number of filter taps.

0x01 :1000Sps	TAP>=2
0x02 : 500Sps	TAP>=4
0x03 : 250Sps	TAP>=8
0x04 : 125Sps	TAP>=16
0x05 : 62.5Sps	TAP>=32
0x06 : 31.25Sps	TAP>=64
0x07 : 15.625Sps	TAP=128

7.11 MODE_CTRL Register

Addr (Hex)	Bit15	Bit14	Bit13	Bit12	Bit11	Bit10	Bit9	Bit8	R/W
39h	—	—	—	—	—	MODE _STAT	MODE_CMD		R/W *1

Addr (Hex)	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0	R/W
38h	—	—	—	—	—	TAP			R/W

*1 : Only MODE_STAT is read-only.

bit[10] MODE_STAT

This read-only status bit shows the current operation mode.
1: Configuration mode
0: Sampling mode

bit[9:8] MODE_CMD

Executes commands related to the operation mode.
01: Go to the Sampling mode. After the mode transition is completed, the bits automatically goes back to “00”.
10: Go to the Configuration mode. After the mode transition is completed, the bits automatically goes back to “00”.
11: (Not used)
00: (Not used)

bit[2:0] TAP

Configures the number of taps of the moving average filter.
001 : 2
010 : 4
011 : 8
100 : 16
101 : 32
110 : 64
111 : 128
For details about the filter characteristics, see Figure 4.7.
For information about the recommended setting for the number of filter taps, see the description of the **DOUT_RATE** of the SMPL_CTRL[36h] bit[15:8].

7.12 UART_CTRL Register

Addr (Hex)	Bit15	. . .	Bit8	R/W
3Bh	—			—

Addr (Hex)	Bit7	. . .	Bit1	Bit0	R/W
3Ah	—			UART _AUTO	R/W

bit[0] UART_AUTO

Enables or disables the UART Auto mode function.
1 : UART Auto mode is selected
0 : UART Manual mode is selected

If UART Auto mode is selected, register values such as FLAG, temperature, angular rate (XGYRO_OUT, YGYRO_OUT, ZGYRO_OUT), acceleration (XACCL_OUT, YACCL_OUT, ZACCL_OUT), and GPIO are continuously transmitted according to the data output rate set in SMPL_CTRL[36h] register.

In UART manual mode, register data is transmitted as a response to a register read command.

NOTE: For information about the data transmission format in the UART Auto mode, see 6.2.4 UART Auto Mode and 6.3 Data Packet Format.
NOTE: In the UART Auto mode, the Data Ready signal is fixed to the “inactive” level.
NOTE: When the SPI interface is used, set this register value to 0.

7.13 DIAG_STAT Register

Addr (Hex)	Bit15	Bit14	Bit13	Bit12	Bit11	Bit10	Bit9	Bit8	R/W
3Dh	—	ST_ERR (XGyro)	ST_ERR (YGyro)	ST_ERR (ZGyro)	ST_ERR (ACCL)	—	—	—	R

Addr (Hex)	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0	R/W
3Ch	CAL _ERR	HARD _ERR		SPI _OVF	UART _OVF	FLASH _ERR	ST_ERR _ALL	FLASH _BU_ER R	R

NOTE: When the host reads the diagnosis result, all the results (including the EA flag in the FLAG register) will be cleared to 0.

bit[14:11] ST_ERR (SelfTest ERRor)

Shows the result of the **SELF_TEST** (internal self test) of MSC_CTRL[34h] bit[10].
1: Error occurred
0: No error

bit[7] CAL_ERR

Shows the result of the **CAL_GYRO** of MSC_CTRL[34h] bit[13:12].
1: Error occurred
0: No error

bit[6:5] HARD_ERR

Shows the result of the hardware check at the startup.
Other than 00 : Error occurred
00 : No error

If this error occurred, the IMU is faulty.

bit[4] SPI_OVF (SPI OVer Flow)

Shows an error occurred if the device received too many commands from the SPI interface in short period of time.
1: Error occurred
0: No error

If this error occurred, adjust the interval of the spi command transmission and the SPI clock setting.

bit[3] UART_OVF (UART OVer Flow)

Shows an error occurred if the data transmission rate is faster than the UART baud rate.
1: Error occurred
0: No error

If this error occurred, adjust the UART baud rate setting and the **DOUT_RATE** setting of SMPL_CTRL[36h] bit[15:8].

bit[2] FLASH_ERR

Shows the result of the **FLASH_TEST** of MSC_CTRL[34h] bit[11].
Or, if data readout from the non-volatile memory failed, error is indicated.
1: Error occurred
0: No error

bit[1] ST_ERR_ALL (SelfTest ERRor All)

Shows the logical sum of the bit[14:11] of this register.
1: Error occurred
0: No error

bit[0] FLASH_BU_ERR (FLASH BackUp ERRor)

Shows the result of the **FLASH_BACKUP** of GLOB_CMD[3Eh] bit[3].
1: Error occurred
0: No error

7.14 GLOB_CMD Register

Addr (Hex)	Bit15	Bit14	Bit13	Bit12	Bit11	Bit10	Bit9	Bit8	R/W
3Fh	—	—	—	—	—	NOT _READY	—	—	R

Addr (Hex)	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0	R/W
3Eh	SOFT _RST	—	—	—	FLASH _BACKUP	—	—	—	R/W

bit[10] NOT_READY

Shows whether the IMU is currently ready. Immediately after power on, this bit is "1" and becomes "0" when the IMU is ready. After the power on, wait until the Power-On Start-Up Time is over and then wait until this bit becomes "1" before starting the measurement. This bit is read-only.
1: Not ready
0: Ready

bit[7] SOFT_RST

Write "1" to execute software reset. After the software reset is completed, the bit automatically goes back to "0".

bit[3] FLASH_BACKUP

Write "1" to save the current values of the control registers with the ○ mark in the "Flash Backup" column of Table 7.1 to the non-volatile memory. After the execution is completed, the bit automatically goes back to "0". After writing "1" to this bit, wait until this bit goes back to "0" and then read the **FLASH_BU_ERR** of DIAG_STAT[3Ch] bit[0] to check the result.

7.15 COUNT_CTRL Register

Addr (Hex)	Bit15	. . .	Bit8	R/W
51h	—			—

Addr (Hex)	Bit7	. . .	Bit1	Bit0	R/W
50h	—			COUNT _CTRL	R/W

bit[0] COUNT_CTRL

Configures whether the sampling counter value attachment function is enabled in the UART burst mode/auto mode. The sampling count interval is 500usec/count.
1: The sampling counter value attachment function is enabled.
0: The sampling counter value attachment function is disabled.

8. Sample Program Flow

Recommended procedures to use the IMU are as follows.

8.1 SPI Flow

8.1.1 Power-on sequence (SPI)

Power-on sequence is as follows.
(a) power-on.
(b) Wait 800ms.
(c) Wait until NOT_READY bit goes to 0. NOT_READY is GLOB_CMD[3Eh]'s bit[10].

```
TXdata={0x3E00}/ RXdata={0x----}.          /* GLOB_CMD read command */
TXdata={0x0000}/ RXdata={GLOB_CMD}. /* get response */
Confirm NOT_READY bit.
When NOT_READY becomes 0, it ends. Otherwise , please repeat (c).
```

(d) Confirm HARD_ERR bits. HARD_ERR is DIAG_STAT[3Ch]'s bit[6:5].

```
TXdata={0x3C00}/ RXdata={0x----}.          /* DIAG_STAT read command */
TXdata={0x0000}/ RXdata={DIAG_STAT}.  /* get response */
Confirm HARD_ERR is 00.
If HARD_ERR is 00, the IMU is OK. Otherwise, the IMU is broken.
```

-:don’t care

8.1.2 Register read and write (SPI)

[Read Example]
To read a 16bit-data from a register(addr=0x38).

```
TXdata={0x3800}/ RXdata={0x----}.          /* command */
TXdata={0x----}/ RXdata={0x0404}.          /* response */
-:don't care
```

0x04 in high byte of RXdata is Configuration mode.
0x04 in low byte of RXdata is TAP=16.
Please note that read data unit is 16bit, and Most Significant Bit first in 16bit SPI.

[Write Example]
To write a 8bit-data into a register(addr=0x39).

```
TXdata={0xB901}/ RXdata={0x----}.          /* command */
There is no response at Write.
-:don’t care
```

By sending this command, the IMU moves to Sampling mode.
Please note that write data unit is 8bit.

8.1.3 Sampling data (SPI)

[Sample Flow 1 (SPI)]

```
Power-on sequence. Please refer to Chapter 8.1.1.
TXdata={0xB704}/ RXdata={0x----}.          /* 125SPS */
TXdata={0xB804}/ RXdata={0x----}.          /* TAP=16 */
TXdata={0xBA00}/ RXdata={0x----}.          /* disable UART auto mode, just in case. */
```

```
  TXdata={0xB901}/ RXdata={0x----}.             /* move to Sampling mode */
  receive sampling data.
    (a)Wait until Data Ready signal is asserted.
    (b)
      TXdata={0x0000}/ RXdata={0x----}.         /* FLAG read command */
      TXdata={0x0200}/ RXdata={FLAG}.                   /* TEMP_OUT read command */
      TXdata={0x0400}/ RXdata={TEMP_OUT}.               /* XGYRO_OUT read command */
      TXdata={0x0600}/ RXdata={XGYRO_OUT}.              /* YGYRO_OUT read command */
      TXdata={0x0800}/ RXdata={YGYRO_OUT}.              /* ZGYRO_OUT read command */
      TXdata={0x0A00}/ RXdata={ZGYRO_OUT}.              /* XACCL_OUT read command */
      TXdata={0x0C00}/ RXdata={XACCL_OUT}.              /* YACCL_OUT read command */
      TXdata={0x0E00}/ RXdata={YACCL_OUT}.              /* ZACCL_OUT read command */
      TXdata={0x1000}/ RXdata={ZACCL_OUT}.              /* GPIO read command */
      TXdata={0x----}/ RXdata={GPIO}.
    repeat from (a) to (b).
  TXdata={0xB902}/ RXdata={0x----}.             /* return to Configulation mode */

  -:don't care
```

notes
For SPI, please remember to wait until Data Ready signal is asserted.

[Sample Flow 2 (SPI)]
To read only sensing data of temperature, gyroscope and accelerometer.

```
  Power-on sequence. Please refer to Chapter 8.1.1.
  TXdata={0xB704}/ RXdata={0x----}.             /* 125SPS */
  TXdata={0xB804}/ RXdata={0x----}.             /* TAP=16 */
  TXdata={0xBA00}/ RXdata={0x----}.             /* disable UART auto mode, just in case. */
  TXdata={0xB901}/ RXdata={0x----}.             /* move to Sampling mode */
  receive sampling data.
    (a)Wait until Data Ready signal is asserted.
    (b)
      TXdata={0x0200}/ RXdata={0x----}.         /* TEMP_OUT read command */
      TXdata={0x0400}/ RXdata={TEMP_OUT}.               /* XGYRO_OUT read command */
      TXdata={0x0600}/ RXdata={XGYRO_OUT}.              /* YGYRO_OUT read command */
      TXdata={0x0800}/ RXdata={YGYRO_OUT}.              /* ZGYRO_OUT read command */
      TXdata={0x0A00}/ RXdata={ZGYRO_OUT}.              /* XACCL_OUT read command */
      TXdata={0x0C00}/ RXdata={XACCL_OUT}.              /* YACCL_OUT read command */
      TXdata={0x0E00}/ RXdata={YACCL_OUT}.              /* ZACCL_OUT read command */
      TXdata={0x----}/ RXdata={ZACCL_OUT}.
    repeat from (a) to (b).
  TXdata={0xB902}/ RXdata={0x----}.             /* return to Configulation mode */

  -:don't care
```

notes
For SPI, please remember to wait until Data Ready signal is asserted.

8.1.4 Selftest (SPI)

Selftest is as follows.

Power-on sequence. Please refer to Chapter 8.1.1.
(a) Send self test command.

```
  TXdata={0xB504}/ RXdata={0x----}.             /* Selftest command */
```

(b) Wait until selftest has finished.
Wait until SELF_TEST bit goes to 0. SELF_TEST is MSC_CTRL[34h]'s bit[10].
TXdata={0x3400}/ RXdata={0x----}. /* MSC_CTRL read command */
TXdata={0x0000}/ RXdata={MSC_CTRL}. /* get response */
Confirm SELF_TEST bit.
When SELF_TEST becomes 0, it ends. Otherwise , please repeat (b).

(c) Confirm the result.
Confirm ST_ERR bits. ST_ERR is DIAG_STAT[3Ch]'s bit[14:11].
TXdata={0x3C00}/ RXdata={0x----}. /* DIAG_STAT read command */
TXdata={0x0000}/ RXdata={DIAG_STAT}. /* get response */
Confirm each ST_ERR is 0.
If each ST_ERR is 0, the result is OK. Otherwise, the result is NG.
-:don't care

8.1.5 Calibration (SPI)

Calibration is as follows.

Power-on sequence. Please refer to Chapter 8.1.1.
(a) Send calibration command.
TXdata={0xB510}/ RXdata={0x----}. /* Calibration command */

(b) Wait until calibration has finished.
Wait until CAL_GYRO_BIAS bits goes to "00". CAL_GYRO_BIAS is MSC_CTRL[34h]'s bit[13:12].
TXdata={0x3400}/ RXdata={0x----}. /* MSC_CTRL read command */
TXdata={0x0000}/ RXdata={MSC_CTRL}. /* get response */
Confirm CAL_GYRO_BIAS bits.
When CAL_GYRO_BIAS becomes "00", it ends. Otherwise , please repeat (b).

(c) Confirm the result.
Confirm CAL_ERR bit. CAL_ERR is DIAG_STAT[3Ch]'s bit[7].
TXdata={0x3C00}/ RXdata={0x----}. /* DIAG_STAT read command */
TXdata={0x0000}/ RXdata={DIAG_STAT}. /* get response */
Confirm each CAL_ERR is 0.
If CAL_ERR is 0, the result is OK. Otherwise, the result is NG.
-:don't care

8.1.6 Calibration Reset (SPI)

Calibration-reset to the factory-state is as follows.

Power-on sequence. Please refer to Chapter 8.1.1.
(a) Send calibration-reset command.
TXdata={0xB520}/ RXdata={0x----}. /* Calibration-reset command */

(b) Wait until calibration-reset has finished.
Wait until CAL_GYRO_BIAS bits goes to "00". CAL_GYRO_BIAS is MSC_CTRL[34h]'s bit[13:12].
TXdata={0x3400}/ RXdata={0x----}. /* MSC_CTRL read command */
TXdata={0x0000}/ RXdata={MSC_CTRL}. /* get response */
Confirm CAL_GYRO_BIAS bits.
When CAL_GYRO_BIAS becomes "00", it ends. Otherwise , please repeat (b).

(c) Confirm the result.
Confirm CAL_ERR bit. CAL_ERR is DIAG_STAT[3Ch]'s bit[7].

```
TXdata={0x3C00}/ RXdata={0x----}.        /* DIAG_STAT read command */
TXdata={0x0000}/ RXdata={DIAG_STAT}. /* get response */
```

Confirm CAL_ERR is 0.
If CAL_ERR is 0, the result is OK. Otherwise, the result is NG.
-:don’t care

8.1.7 Software Reset (SPI)

Software reset is as follows.

Power-on sequence. Please refer to Chapter 8.1.1.
(a) Send software reset command.

```
TXdata={0xBE80}/ RXdata={0x----}.        /* Software reset command */
```

(b) Wait 800ms.
-:don’t care

8.1.8 Flash Test (SPI)

Flash test is as follows.

Power-on sequence. Please refer to Chapter 8.1.1.
(a) Send flash test command.

```
TXdata={0xB508}/ RXdata={0x----}.        /* Flash test command */
```

(b) Wait until flash test has finished.
Wait until FLASH_TEST bit goes to 0. FLASH_TEST is MSC_CTRL[34h]'s bit[11].

```
TXdata={0x3400}/ RXdata={0x----}.        /* MSC_CTRL read command */
TXdata={0x0000}/ RXdata={MSC_CTRL}. /* get response */
```

Confirm FLASH_TEST bit.
When FLASH_TEST becomes 0, it ends. Otherwise , please repeat (b).

(c) Confirm the result.
Confirm FLASH_ERR bits. FLASH_ERR is DIAG_STAT[3Ch]'s bit[2].

```
TXdata={0x3C00}/ RXdata={0x----}.        /* DIAG_STAT read command */
TXdata={0x0000}/ RXdata={DIAG_STAT}. /* get response */
```

Confirm FLASH_ERR is 0.
If FLASH_ERR is 0, the result is OK. Otherwise, the result is NG.
-:don't care

8.1.9 Flash Backup (SPI)

Flash backup is as follows.

Power-on sequence. Please refer to Chapter 8.1.1.
(a) Send flash backup command.

```
TXdata={0xBE08}/ RXdata={0x----}.        /* Flash backup command */
```

(b) Wait until flash backup has finished.
Wait until FLASH_BACKUP bit goes to 0. FLASH_BACKUP is GLOB_CMD[3Eh]'s bit[3].

```
TXdata={0x3E00}/ RXdata={0x----}.        /* GLOB_CMD read command */
TXdata={0x0000}/ RXdata={GLOB_CMD}. /* get response */
```

Confirm FLASH_BACKUP bit.

When FLASH_BACKUP becomes 0, it ends. Otherwise , please repeat (b).

(c) Confirm the result.
Confirm FLASH_BU_ERR bits. FLASH_BU_ERR is DIAG_STAT[3Ch]'s bit[0].
TXdata={0x3C00}/ RXdata={0x----}. /* DIAG_STAT read command */
TXdata={0x0000}/ RXdata={DIAG_STAT}. /* get response */
Confirm FLASH_BU_ERR is 0.
If FLASH_BU_ERR is 0, the result is OK. Otherwise, the result is NG.
-:don't care

8.2 UART Flow

8.2.1 Power-on sequence (UART)

Power-on sequence is as follows.
(a) power-on.
(b) Wait 800ms.
(c) Wait until NOT_READY bit goes to 0. NOT_READY is GLOB_CMD[3Eh]'s bit[10].
TXdata={0x3E,0x00,0x0d}. /* GLOB_CMD read command */
TXdata={0x3E,MSByte,LSByte,0x0d}. /* get response */
Confirm NOT_READY bit.
When NOT_READY becomes 0, it ends. Otherwise , please repeat (c).
(d) Confirm HARD_ERR bits. HARD_ERR is DIAG_STAT[3Ch]'s bit[6:5].
TXdata={0x3C,0x00,0x0d}. /* DIAG_STAT read command */
TXdata={0x3C,MSByte,LSByte,0x0d}. /* get response */
Confirm HARD_ERR is 00.
If HARD_ERR is 00, the IMU is OK. Otherwise, the IMU is faulty.

8.2.2 Register read and write (UART)

[Read Example]
To read a 16bit-data from a register(addr=0x38).
TXdata={0x38,0x00,0x0d}. /* command */
RXdata={0x38,0x04,0x04,0x0d} /* response */

0x04 in 2nd byte of RXdata is Configuration mode.
0x04 in 3rd byte of RXdata is TAP=16.

Please note that read data unit is 16bit, and Most Significant Byte first.

[Write Example]
To write a 8bit-data into a register(addr=0x39).
TXdata={0xB9,0x01,0x0d}. /* command */
RXdata= w/o response

By sending this command, the IMU moves to Sampling mode.
Please note that write data unit is 8bit.

8.2.3 Sampling data (UART)

[Sample Flow 1 (UART auto mode)]

```
Power-on sequence. Please refer to Chapter 8.2.1.
TXdata={0xB7,0x04,0x0d}.               /* 125SPS */
TXdata={0xB8,0x04,0x0d}.               /* TAP=16 */
TXdata={0xBA,0x01,0x0d}.               /* UART Auto mode */
TXdata={0xB9,0x01,0x0d}.               /* move to Sampling mode */
  receive sampling data.
  (a)RXdata={0x20, FLAG_Hi, FLAG_Lo, Temp_Hi, Temp_Lo,
                GX_Hi, GX_Lo, GY_Hi, GY_Lo, GZ_Hi, GZ_Lo,
                AX_Hi, AX_Lo, AY_Hi, AY_Lo, AZ_Hi, AZ_Lo,
                GPIO_Hi, GPIO_Lo, 0x0d}
  repeat (a).
TXdata={0xB9,0x02,0x0d}.               /* return to Configulation mode */
```

```
[Sample Flow 2 (UART burst mode)]
 Power-on sequence. Please refer to Chapter 8.2.1.
 TXdata={0xB7,0x04,0x0d}.               /* 125SPS */
 TXdata={0xB8,0x04,0x0d}.               /* TAP=16 */
 TXdata={0xBA,0x00,0x0d}.               /* UART manual mode */
 TXdata={0xB9,0x01,0x0d}.               /* move to Sampling mode */
 (a)Wait until Data Ready signal is asserted.
 (b)TXdata={0x20,0x00,0x0d}.      /* burst command */
 (c)RXdata={0x20, FLAG_Hi, FLAG_Lo, Temp_Hi, Temp_Lo,
               GX_Hi, GX_Lo, GY_Hi, GY_Lo, GZ_Hi, GZ_Lo,
               AX_Hi, AX_Lo, AY_Hi, AY_Lo, AZ_Hi, AZ_Lo,
               GPIO_Hi, GPIO_Lo, 0x0d}
 repeat from (a) to (c).
 TXdata={0xB9,0x02,0x0d}.               /* return to Configulation mode */
```

notes
  Please remember to wait until Data Ready signal is asserted.

[Notes]
  Please note that read data unit is 16bit, and Most Significant Byte first.
  Please note that write data unit is 8bit.
  GX_Hi: means MSByte of GyroX data
  GX_Lo: means LSByte of GyroX data

8.2.4 Selftest (UART)

Selftest is as follows.

```
Power-on sequence. Please refer to Chapter 8.2.1.
(a) Send self test command.
 TXdata={0xB5,0x04,0x0d}.        /* Selftest command */

(b) Wait until selftest has finished.
 Wait until SELF_TEST bit goes to 0. SELF_TEST is MSC_CTRL[34h]'s bit[10].
  TXdata={0x34,0x00,0x0d}.        /* MSC_CTRL read command */
  RXdata={0x34,MSByte,LSByte,0x0d}.      /* get response */
  Confirm SELF_TEST bit.
  When SELF_TEST becomes 0, it ends. Otherwise , please repeat (b).

(c) Confirm the result.
 Confirm ST_ERR bits. ST_ERR is DIAG_STAT[3Ch]'s bit[14:11].
```

TXdata={0x3C,0x00,0x0d}. /* DIAG_STAT read command */
RXdata={0x3C,MSByte,LSByte,0x0d}. /* get response */
Confirm each ST_ERR is 0.
If each ST_ERR is 0, the result is OK. Otherwise, the result is NG.

8.2.5 Calibration (UART)

Calibration is as follows.

Power-on sequence. Please refer to Chapter 8.2.1.
(a) Send calibration command.
TXdata={0xB5,0x10,0x0d}. /* Calibration command */

(b) Wait until calibration has finished.
Wait until CAL_GYRO_BIAS bits goes to “00”. CAL_GYRO_BIAS is MSC_CTRL[34h]'s bit[13:12].
TXdata={0x34,0x00,0x0d}. /* MSC_CTRL read command */
RXdata={0x34,MSByte,LSByte,0x0d}. /* get response */
Confirm CAL_GYRO_BIAS bits.
When CAL_GYRO_BIAS becomes “00”, it ends. Otherwise , please repeat (b).

(c) Confirm the result.
Confirm CAL_ERR bit. CAL_ERR is DIAG_STAT[3Ch]'s bit[7].
TXdata={0x3C,0x00,0x0d}. /* DIAG_STAT read command */
RXdata={0x3C,MSByte,LSByte,0x0d}. /* get response */
Confirm CAL_ERR is 0.
If CAL_ERR is 0, the result is OK. Otherwise, the result is NG.

8.2.6 Calibration Reset (UART)

Calibration-reset to the factory-state is as follows.

Power-on sequence. Please refer to Chapter 8.2.1.
(a) Send calibration-reset command.
TXdata={0xB5,0x20,0x0d}. /* Calibration-reset command */

(b) Wait until calibration-reset has finished.
Wait until CAL_GYRO_BIAS bits goes to “00”. CAL_GYRO_BIAS is MSC_CTRL[34h]'s bit[13:12].
TXdata={0x34,0x00,0x0d}. /* MSC_CTRL read command */
RXdata={0x34,MSByte,LSByte,0x0d}. /* get response */
Confirm CAL_GYRO_BIAS bits.
When CAL_GYRO_BIAS becomes “00”, it ends. Otherwise , please repeat (b).

(c) Confirm the result.
Confirm CAL_ERR bit. CAL_ERR is DIAG_STAT[3Ch]'s bit[7].
TXdata={0x3C,0x00,0x0d}. /* DIAG_STAT read command */
RXdata={0x3C,MSByte,LSByte,0x0d}. /* get response */
Confirm CAL_ERR is 0.
If CAL_ERR is 0, the result is OK. Otherwise, the result is NG.

8.2.7 Software Reset (UART)

Software reset is as follows.

Power-on sequence. Please refer to Chapter 8.2.1.
(a) Send software reset command.
  TXdata={0xBE,0x80,0x0d}.   /* Software reset command */
(b) Wait 800ms.

8.2.8 Flash Test (UART)

Flash test is as follows.

Power-on sequence. Please refer to Chapter 8.2.1.
(a) Send flash test command.
  TXdata={0xB5,0x08,0x0d}.   /* Flash test command */

(b) Wait until flash test has finished.
  Wait until FLASH_TEST bit goes to 0. FLASH_TEST is MSC_CTRL[34h]'s bit[11].
    TXdata={0x34,0x00,0x0d}.   /* MSC_CTRL read command */
    RXdata={0x34,MSByte,LSByte,0x0d}.   /* get response */
    Confirm FLASH_TEST bit.
    When FLASH_TEST becomes 0, it ends. Otherwise , please repeat (b).

(c) Confirm the result.
  Confirm FLASH_ERR bits. FLASH_ERR is DIAG_STAT[3Ch]'s bit[2].
    TXdata={0x3C,0x00,0x0d}.   /* DIAG_STAT read command */
    RXdata={0x3C,MSByte,LSByte,0x0d}.   /* get response */
    Confirm FLASH_ERR is 0.
    If FLASH_ERR is 0, the result is OK. Otherwise, the result is NG.

8.2.9 Flash Backup (UART)

Flash backup is as follows.

Power-on sequence. Please refer to Chapter 8.2.1.
(a) Send flash backup command.
  TXdata={0xBE,0x08,0x0d}.   /* Flash backup command */

(b) Wait until flash backup has finished.
  Wait until FLASH_BACKUP bit goes to 0. FLASH_BACKUP is GLOB_CMD[3Eh]'s bit[3].
    TXdata={0x3E,0x00,0x0d}.   /* GLOB_CMD read command */
    RXdata={0x3E,MSByte,LSByte,0x0d}.   /* get response */
    Confirm FLASH_BACKUP bit.
    When FLASH_BACKUP becomes 0, it ends. Otherwise , please repeat (b).

(c) Confirm the result.
  Confirm FLASH_BU_ERR bits. FLASH_BU_ERR is DIAG_STAT[3Ch]'s bit[0].
    TXdata={0x3C,0x00,0x0d}.   /* DIAG_STAT read command */
    RXdata={0x3C,MSByte,LSByte,0x0d}.   /* get response */
    Confirm FLASH_BU_ERR is 0.
    If FLASH_BU_ERR is 0, the result is OK. Otherwise, the result is NG.

9. Handling Notes

9.1 Cautions for attaching

- When you connect the header to the socket of this product, make sure you do not insert the header in the reverse orientation. If you do, the IMU may be damaged permanently. In addition, if you attach the product to the equipment, etc. using the IMU connection harness provided as a standard accessory, connect the IMU connection harness to the product first, and then attach it to the equipment, etc.
- When you attach the product to a housing, equipment, jig, or tool, make sure you attach it properly so that no mechanical stress is added to create a distortion such as a warp or twist. In addition, tighten the screws firmly but not too firmly because the mount of the product may break. Use screw locking techniques as necessary.
- When you set up the product, make sure the equipment, jigs, tools, and workers maintain a good ground in order not to generate high voltage leakage. If you add overcurrent or static electricity to the product, the product may be damaged permanently.
- When you install the product, make sure metallic or other conductors do not enter the product. Otherwise, malfunction or damage of the product may result.
- If excessive shock is added to the product when, for example, the product falls, the quality of the product may be degraded. Make sure the product does not fall when you handle it.
- Before you start using the product, test it in the actual equipment under the actual operating environment.
- Since the product has capacitors inside, Inrush Current will happen when power-on. Evaluate in the actual environment in order to check the effect of the supply voltage down by inrush current in the system.

9.2 Other cautions

- If water enters the product, malfunction or damage of the product may result. If the product can be exposed to water, the system must have a waterproof structure. We do not guarantee the operation of the product when the product is exposed to condensation, dust, oil, corrosive gas (salt, acid, alkaline, or the like) , or direct sunlight.
- This product is not designed to be radiation resistant.
- Never use this product if the operating condition is over the absolute maximum rating. If you do, the characteristics of the product may never recover.
- If the product is exposed to excessive exogenous noise or the like, degradation of the precision, malfunction, or damage of the product may result. The system needs to be designed so that the noise itself is suppressed or the system is immune to the noise.
- Mechanical vibration or shock, continuous mechanical stress, rapid temperature change, or the like may cause cracks or disconnections at the various connecting parts.
- Take sufficient safety measure for the equipment this product is built into.
- This product is not designed to be used in the equipment that demands extremely high reliability and where its failure may threaten human life or property (for example, aerospace equipment, submarine repeater, nuclear power control equipment, life support equipment, medical equipment, transportation control equipment, etc.). Therefore, Seiko Epson Corporation will not be liable for any damages caused by the use of the product for those applications.
- Do not add shock or vibration to the packing box. Do not spill water over the packing box. Do not store or use the product in the environment where dew condensation occurs due to rapid temperature change.
- Do not put mechanical stress on the product while it is stored.
- Do not store the product in a location subject to High Temperature, high humidity, under direct sunlight, corrosive gas or dust.
- Do not alter or disassemble the product.

10. PART NUMBER / ORDERING INFO.

The following is the ordering code for the IMU:

Product	Ordering code	Comments
M-G350PD11	E91E600A11	IMU+ Assembly components (Hernes/FPC Cable, Fastener, etc)
M-G350PD10	E91E600A10	IMU only

Note: The assembly components are intended for evaluation purpose only. The customer assumes all risk, if the assembly components are used in the design of the final product.

11. Evaluation Tools

Evaluation tools can be provided for the IMU. For details, contact our representatives.

Product	Ordering Code	Comments
PCB Board	E92E600010	
USB Interface Board	E92E600020	Work with (Sample) Logger Software

Revision History

Attachment-1

Rev. No.	Date	Page	Category	Contents
Rev. 20121023	Oct./2012	All	new	Newly established
Rev.20140929	Sep./2014	Cover, Page1, 3, 4, 6	Revise	Corrections, Additions
		Page42	Revise	Product Part Number Information Update
		Back Cover	Revise	Contact Information Update
Rev.20150807	Aug./2015	Page46	Revise	Ordering Code Update
Rev.20151218	Dec/2015	Back Cover	Revise	Contact information update
		3	Revise	Delete 1 σ , Bias Instability

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