GMC306A Tri-Axial Digital Geomagnetic Sensor

General Introduction

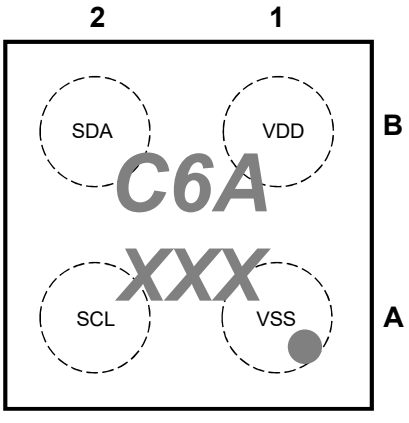
GMC306A is a low-power digital geomagnetic sensor for consumer e-compass applications. A highly sensitive Hall-effect magnetic sensor is directly integrated with the signal conditioning IC in a monolithic wafer process. The 4-pin wafer level chip scale package (WL-CSP) measures only $0.8\times0.8\times0.5mm^3$. This small package size dramatically increases the design flexibility to developers of compact mobile devices. GMC306A can work harmoniously with the 3-axis digital accelerometer like GMEMS's GMA303 for directional information. The magnetometer detects the terrestrial magnetism to be compensated by the tilt angle determined from the accelerometer for providing precise navigation heading. GMEMS can provide further software and hardware support for such fusion application. Please contact GMEMS for more information.

Features

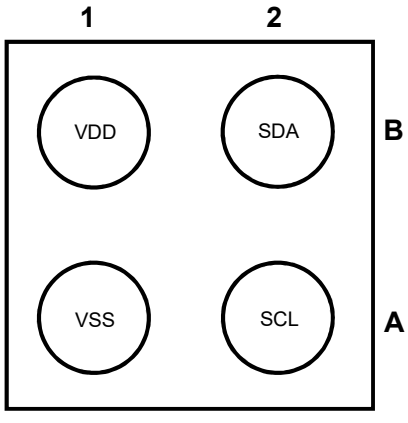
- 3-axis geomagnetic sensor for consumer e-compass application
- Built-in 16-bit ADC with sensitivity 0.15μT/LSB
- Extended dynamic range of ±4914uT gives extra large room for the sensor placement
- I2C digital interface supporting standard and fast mode
- Operation voltage: +1.65V ~ +1.95V
- Power consumption:
  - Continuous measurement: typical 1.2mA@100HZ ODR
  - Power down current: 1uA
- Various operation modes including power-down, single and continuous measurement
- Self-test function with internal magnetic source
- RoHS compliance 4-pin WL-CSP package. Footprint: 0.8mm × 0.8mm, height: 0.5mm.

Applications

Navigation heading, gaming, augmented reality and LBS applications, smart user interface



Top View



Bottom View

Specifications

Table 1: Pin Descriptions

Pin#	Name	Description
A1	VSS	Ground pin
B1	VDD	Core circuit power supply in
B2	SDA	I2C data pin Input: Schmidt trigger Output: open drain
A2	SCL	I2C clock pin Input: Schmidt trigger

Table 2: Operating Range

Parameter	Symbol	Min.	Typ.	Max.	Unit
Supply voltage	VDD	1.65	1.8	1.95	V
Operating temperature	TA	-30	—	+85	°C

Table 3: Absolute Maximum Rating

Parameter	Symbol	Min.	Max.	Unit
Power supply voltage	VDD	-0.3	+2.34	V
Signal input voltage	VIS	-0.3	VDD + 0.3	V
Signal input current	IIS	—	±10	mA
Storage temperature	TST	-40	+125	°C

Table 4: Magnetic Characteristics

Parameter	Symbol	Condition	Min.	Typ.	Max.	Unit
X, Y, Z Digital output	DBW		—	16	—	bits
Measurement time	TMEAS	Time for single x, y and z axis measurement (100Hz)	—	—	9.9	ms
Magnetic field resolution	BRES	Ta=25°C	—	0.15	—	uT/LSB
Magnetic field range	BRAN	Ta=25°C	-4914	—	+4914	uT

Table 5: DC Characteristics

Parameter	Symbol	Pin	Note	Min.	Typ.	Max.	Unit
Input high level voltage	VIH	SCL SDA		0.7×VDD	—	VDD+0.3	V
Input low level voltage	VIL	SCL SDA		-0.3	—	0.3×VDD	V
Input current	IIN	SCL SDA	Vin=VSS or VDD	-10	—	10	uA
Input hysteresis voltage	VHYS	SCL SDA		10%VDD	— —	— —	V
Output low level voltage	VOL	SDA	IOL≦3mA	—	—	20%VDD	V
Current consumption	IDD1	VDD	Power-down mode VDD=1.8V, Ta=25°C	—	1	—	uA
	IDD2		During magnetic sensor is operating	—	2	—	mA
	IDD3		During self-test mode	—	4.5	—	mA

Table 6: AC Characteristics

Parameter	Symbol	Pin	Description	Min.	Typ.	Max.	Unit
Supply voltage rise time	TRISE	VDD	From VOFF to VDD	—	—	50	ms
Initialization time	TINIT		From time VDD reaches its level to time the IC completes entering the power-down mode by POR circuits	—	—	10	ms
Supply of voltage	VOFF	VDD	VDD voltage to ensure the POR circuits to restart	—	—	0.2	V
Supply volt. off duration	TOFF	VDD	Duration of supply off voltage to ensure the POR circuits to restart	100	—	—	us

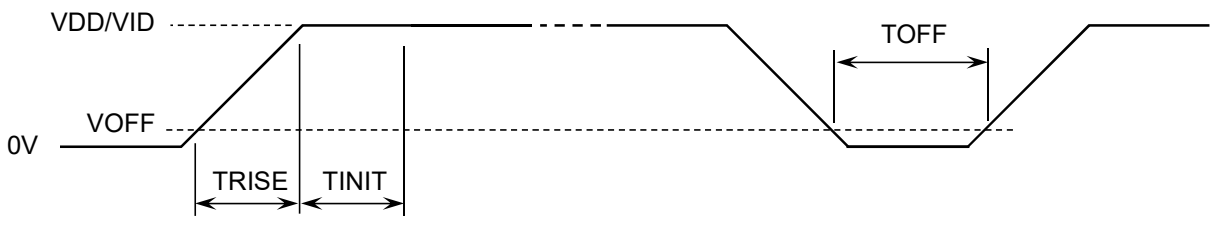


Figure 1: AC Characteristics

Block Diagram and Connection

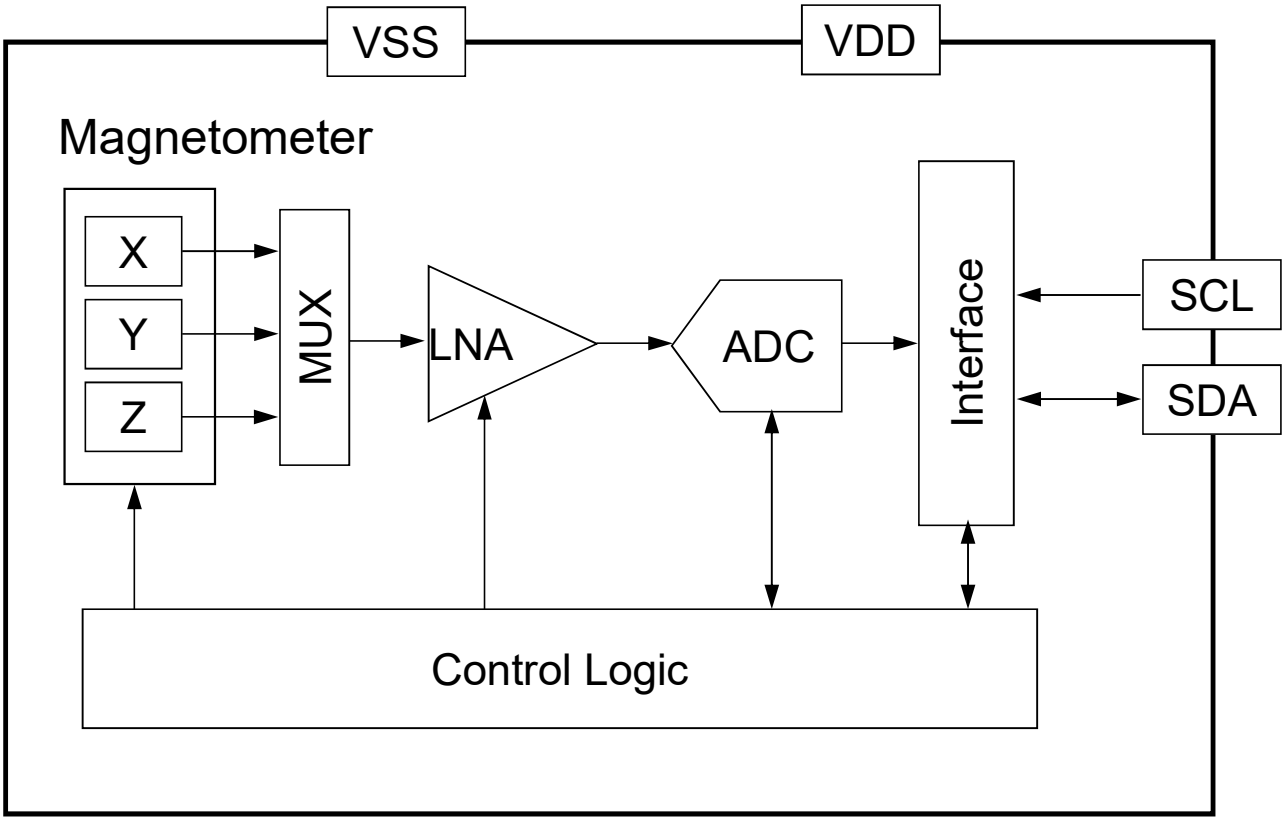


Figure 2: GMC306A Block Diagram

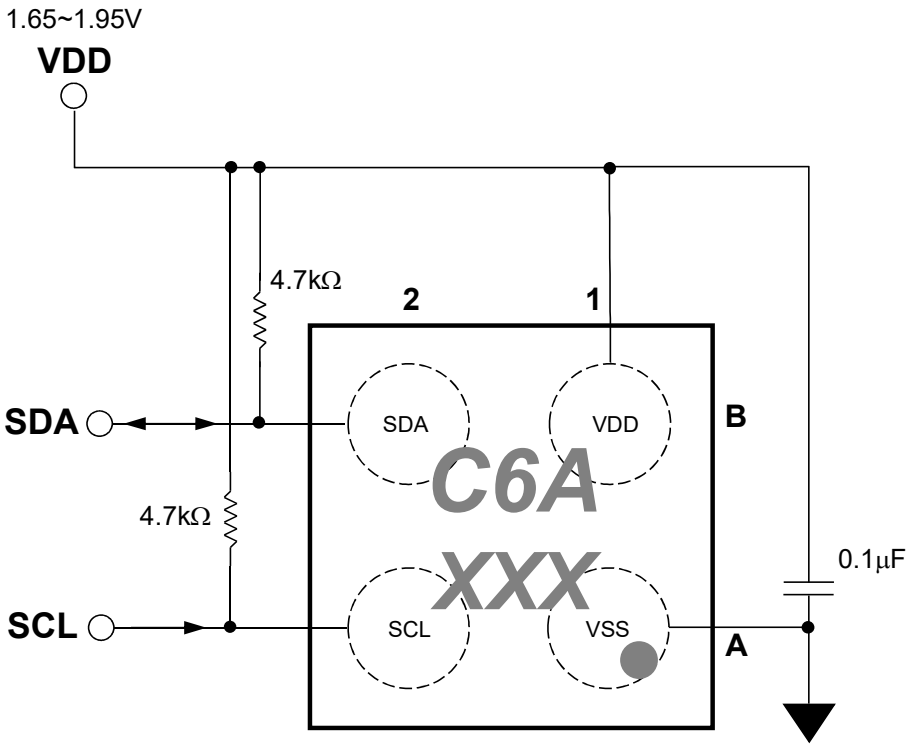


Figure 3: GMC306A I2C Connection Example

Functional Description

Power States

When VDD is turned on, all registers in GMC306A are initialized to default values by POR circuit and GMC306A transits to power-down mode.

Table 7: Power States

State	VDD	Power State
1	OFF (0V)	OFF (0V) It doesn't affect external interface.
2	1.65 to 1.95V	ON

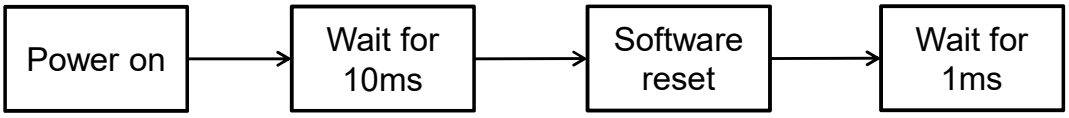
Reset Functions

Power-on reset circuit (POR) will be active until VDD reaches the effective operation voltage, about 1.4V as taken from the design reference. After the POR circuit deactivate, all registers will be initialized to default values and then GMC306A transits to power-down mode.

GMC306A has two types of reset as summarized below:

- Power-on reset (POR): When VDD rise is detected, POR circuit kicks in to reset GMC306A.
- Software reset: GMC306A is reset by setting SRST bit. And the fuse ROM value will be automatically loaded as well.

Power on Sequence



Operation Modes

GMC306A has the following nine operation modes, which can be set by the MODE[4:0] bits.

1. Power-down mode: MODE[4:0] = “00h”
   - When power is turned ON, sensor is put in power-down mode..
   - Return to power-down mode before changing operation mode.
2. Single measurement mode: MODE[4:0] = “01h”
   - Sensor will take one-time measurement and returns to power-down mode automatically.
3. Continuous measurement mode 1: MODE[4:0] = “02h”
   - Sensor will take periodic measurement at 10Hz ODR.
4. Continuous measurement mode 2: MODE[4:0] = “04h”
   - Sensor will take periodic measurement at 20Hz ODR.
5. Continuous measurement mode 3: MODE[4:0] = “06h”
   - Sensor will take periodic measurement at 50Hz ODR.
6. Continuous measurement mode 4: MODE[4:0] = “08h”
   - Sensor will take periodic measurement at 100Hz ODR.
7. Continuous measurement mode 5: MODE[4:0] = “0Ch”
   - Sensor will take periodic measurement at 200Hz ODR.
8. Continuous measurement mode 6: MODE[4:0] = “0Eh”
   - Sensor will take periodic measurement at 5Hz ODR.
9. Self-test mode: MODE[4:0] = “10h”
   - Sensor will activate self-test and output the result before automatically returning to power-down mode.
10. Fuse ROM access mode: MODE[4:0] = “1Fh”
    - Download all data from Fuse ROM to registers automatically.

When power is turned ON, MODE[4:0] is reset to “00h” and GMC306A is in power-down mode. When a specified value is set to MODE[4:0], GMC306A transits to the specified mode and starts operation. If user wants to change operation mode, be sure to return to power-down mode and wait for at least 100us (TWAIT) before setting another mode. The operation mode transition is illustrated in the below diagram.

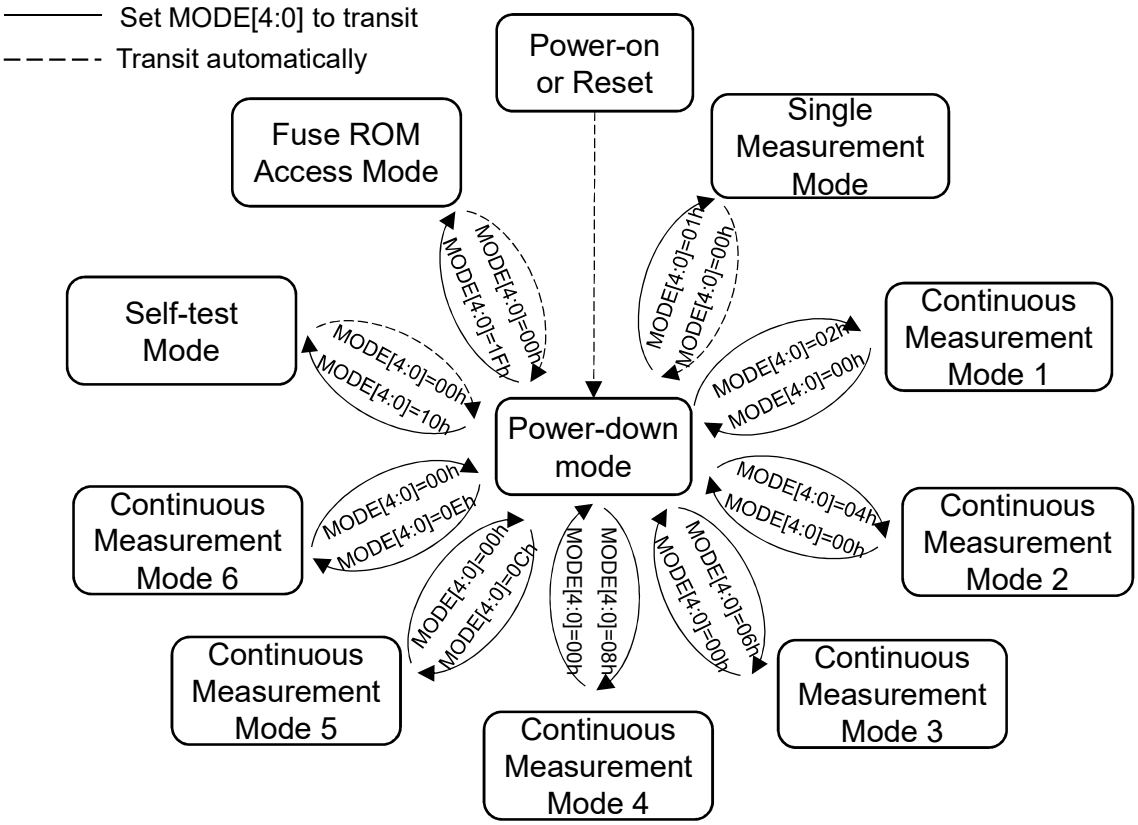


Figure 4: GMC306A State Transition Diagram

User Registers

User Register Map

Table 8: User Register Map Table

Addr.	Name	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Access	Default
00h	ST1	0	0	0	0	0	POR	DOR	DRDY	R	NA
01h	HXH	HX[15:8]								R	0x00
02h	HXL	HX[7:0]								R	0x00
03h	HYH	HY[15:8]								R	0x00
04h	HYL	HY[7:0]								R	0x00
05h	HZH	HZ[15:8]								R	0x00
06h	HZL	HZ[7:0]								R	0x00
07h	TMPS	0								R	0x00
08h	ST2	0	0	0	0	0	0	0	HOFL	R	0x00
10h	CNTL1	0	FILON	0	MODE[4:0]					R/W	0x00
11h	CNTL2	0	0	0	0	0	0	0	SRST	W	0x00
12h	CNTL3	MDS[1:0]		0	1	0	1	0	1	R/W	0x15
50h	CMPID	CMPID[7:0]								R	0x43
51h	DEVID	DEVID[7:0]								R	0x00
52h	INFO	INFO[7:0]								R	0x00
53h	ASAX	COEFX[7:0]								R	NA
54h	ASAY	COEFY[7:0]								R	NA
55h	ASAZ	COEFZ[7:0]								R	NA

Description of Registers

Register 00h: Status Register 1

Addr.	Name	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Access	Default
00h	ST1	0	0	0	0	0	POR	DOR	DRDY	R	NA

DRDY is the magnetic measurement data ready bit. Bit set represents measurement results are ready to read. DRDY will be cleared when any of the data registers (HX to TMPS) or ST2 register is read. The measured data is stored to the data registers (HX to HZ) and DRDY bit is set when the measurement period complete, as illustrated in the Figure 5.

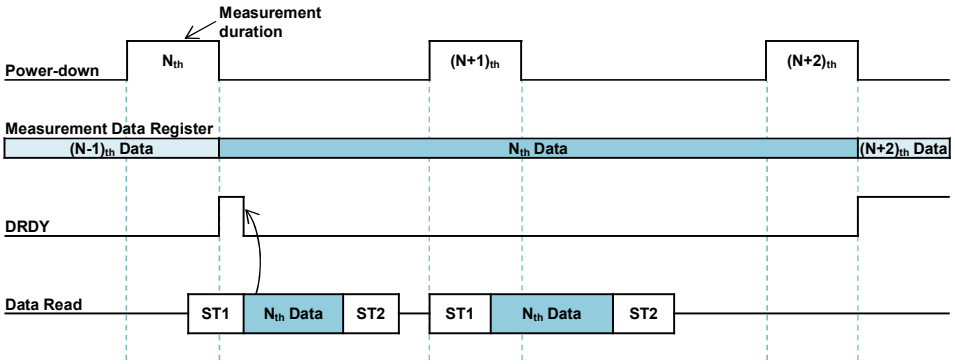


Figure 5: DRDY bit and measurement data read

DOR is the data over-run/skip bit. Bit set represent magnetic measurement data is over-run or skipped. DOR will be cleared when any of the data registers (HX to TMPS) or ST2 register is read. As illustrated in the Figure 6, when N_{th} data is not read before the $(N+1)_{th}$ measurement complete, the DOR bit is set, indicating the Nth data is over-run by the $(N+1)_{th}$ measurement result.

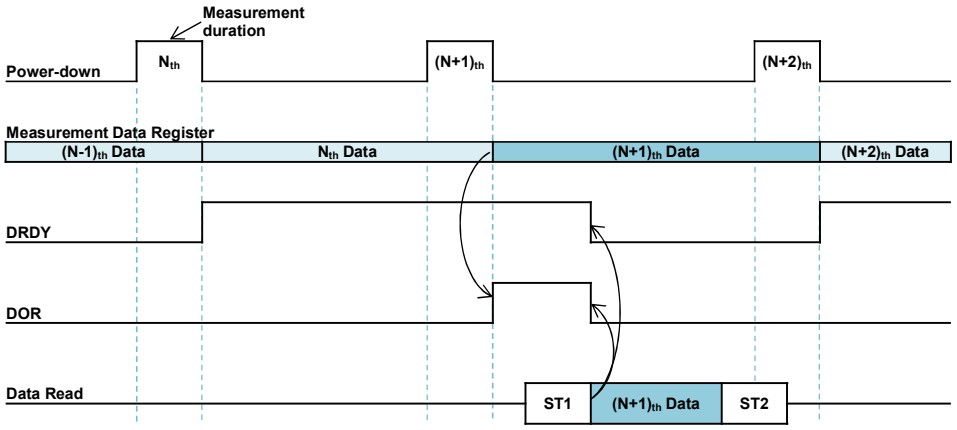


Figure 6: DOR bit and data over-run

However if the data read start right after N_{th} measurement complete but does not manage to finish before $(N+1)_{th}$ measurement end, N_{th} measurement data is protected from being over-run by the $(N+1)_{th}$ data. In such case the DRDY will not be set after the complete of $(N+1)_{th}$ measurement because data registers are protected from being updated. Instead the DOR will be set to indicate the $(N+1)_{th}$ data is skipped, as illustrated in the Figure 7.

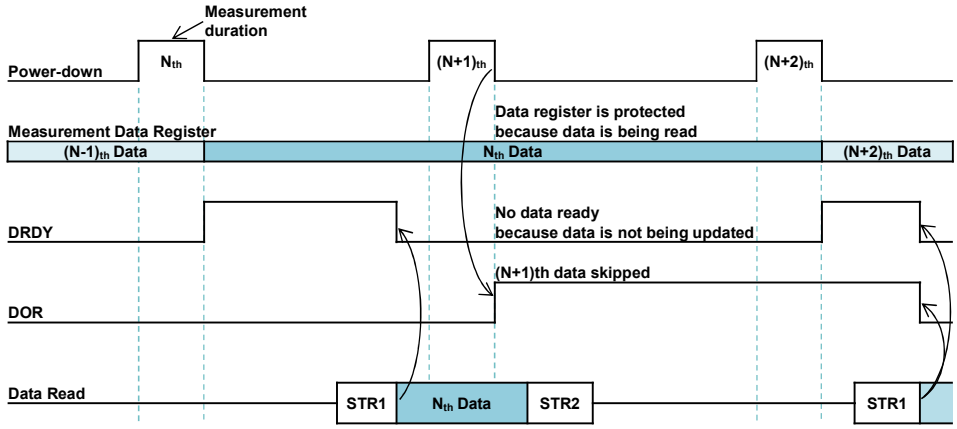


Figure 7: DOR bit and data skip

POR is the power-on event bit. POR bit is set when there were a power-on sequence and a power-supply glitch event. Because all registers have been reset to the power-on default states, it is advised to re-run the user initialization again. Read ST1 register can unset the POR bit.

Register 01h to 06h: Magnetic Measurement Data Registers

Addr.	Name	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Access	Default
01h	HXH	HX[15:8]								R	NA
02h	HXL	HX[7:0]								R	NA
03h	HYH	HY[15:8]								R	NA
04h	HYL	HY[7:0]								R	NA
05h	HZH	HZ[15:8]								R	NA
06h	HZL	HZ[7:0]								R	NA

HX[15:0], HY[15:0] and HZ[15:0] are magnetic measurement data registers of X-/Y-/Z-axis respectively. When measurement period complete, measured data is stored to these magnetic measurement data registers using two's complement format. Measurement range for each axis is from -32760to +32760. The DRDY and DOR bits of the ST1 register will be cleared to 1'b0 after reading any of the data registers.

Measurement Data (each axis)[15:0]		Magnetic Flux Density (uT)
Two's complement (Hex)	Decimal	
7FF8	32760	4914 (max)
…	…	…
0001	1	0.15
0000	0	0
FFFF	-1	-0.15

…	…	…
8008	-32760	-4914 (min)

Register 08h: Status Register 2

Addr.	Name	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Access	Default
18h	ST2	0	0	0	0	0	0	0	HOFL	R	NA

HOFL is the magnetic sensor overflow bit. Bit set means magnetic sensor overflow occurs. GMC306A limits the sum of absolute values of each axis to 4914uT, i.e. $\|X\|+\|Y\|+\|Z\|<4914\text{uT}$. Even the measurement data registers are not saturated, magnetic sensor may overflow. In such case the measurement data is not correct and the HOFL bit will be set. HOFL bit will be cleared when the next measurement period starts. After reading this register, the DRDY and DOR bit are cleared to 1'b0.

Register 10h: Control Register 1

Addr.	Name	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Access	Default
10h	CNTL1	0	FILON	0	MODE[4:0]					R/W	00h

FILON is the noise suppression filter control bit. GMC306A has built-in low-pass filter to improve noise performance. Set FILON to 1'b1 to enable the filter.

MODE[4:0] set the following operation modes. Other settings are prohibited.

- MODE[4:0]=00h: Power-down mode
- MODE[4:0]=01h: Single measurement mode
- MODE[4:0]=02h: Continuous measurement mode 1
- MODE[4:0]=04h: Continuous measurement mode 2
- MODE[4:0]=06h: Continuous measurement mode 3
- MODE[4:0]=08h: Continuous measurement mode 4
- MODE[4:0]=0Ch: Continuous measurement mode 5
- MODE[4:0]=0Eh: Continuous measurement mode 6
- MODE[4:0]=10h: Self-test mode
- MODE[4:0]=1Fh: Fuse ROM access mode

Power-down Mode

Set MODE[4:0] to 00h to enter power-down mode. All internal circuits are turned off, but all registers remain accessible and register values are retained. GMC306A will automatically enter power-down mode after power-on or by SRST reset, as shown in the Figure 4.

Single Measurement Mode

GMC306A will make a single measurement once and automatically transit to the power-down mode every time when entering the single measurement mode by setting MODE[4:0]=01h. Measurement data is then stored to the measurement data registers (HX to HZ) and DRDY bit set. The measurement result is available to access anytime before another measurement starts. Depending on the timing, the current result may be over-run by the next measurement, Figure 8, or the next measurement data is skipped, Figure 9.

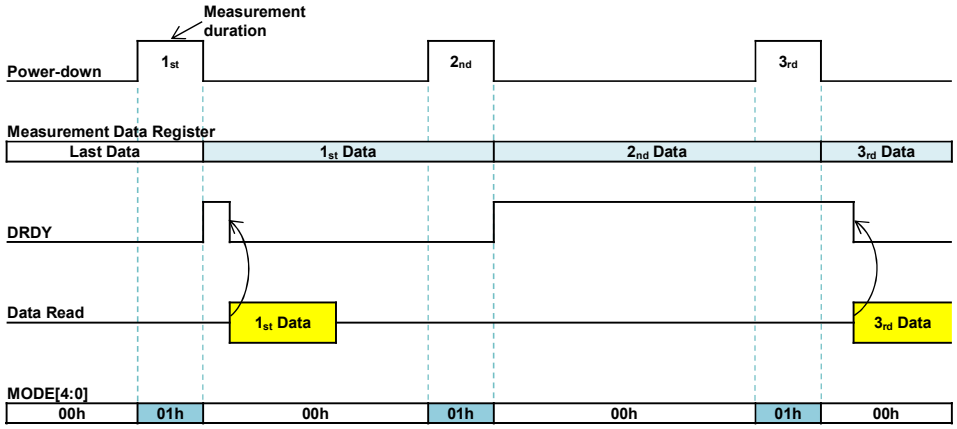


Figure 8: Single measurement and data over-run

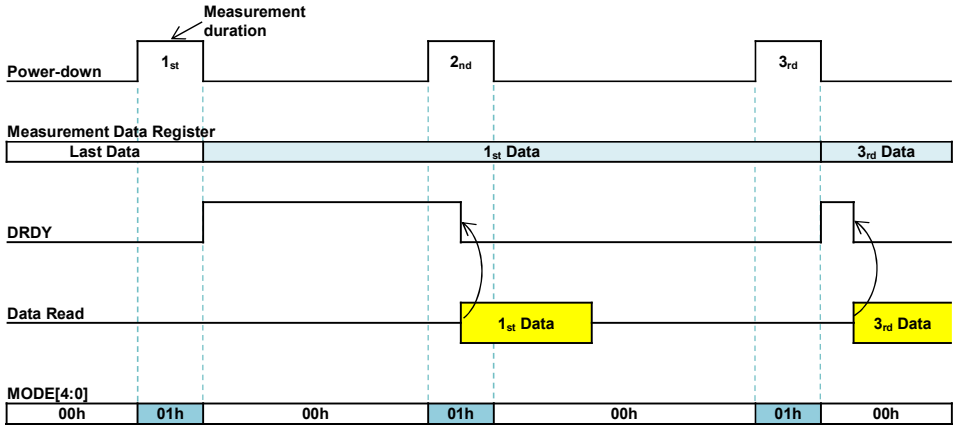


Figure 9: Single measurement and data skip

Continuous Measurement Mode

When put into the continuous measurement mode by setting MODE[4:0]=02h/04/06h/08/0C/0Eh, GMC306A will make periodic data measurement with five ODR options of 10/20/50/100/200/5Hz respectively. The measurement data will be stored to the measurement data registers (HX to HZ) after the current measurement is finished, and DRDY bit is set accordingly. All circuit except the OSC is turned off intermittently until next measurement due. DRDY bit can be cleared by reading any of the data registers (HX to TMPS) or ST2 register. The timing of normal continuous mode is illustrated in the Figure 10.

To switch between operation mode, user needs to return to power-down mode by setting MODE[4:0]=00h and then set to another operation mode, as shown in the Figure 4.

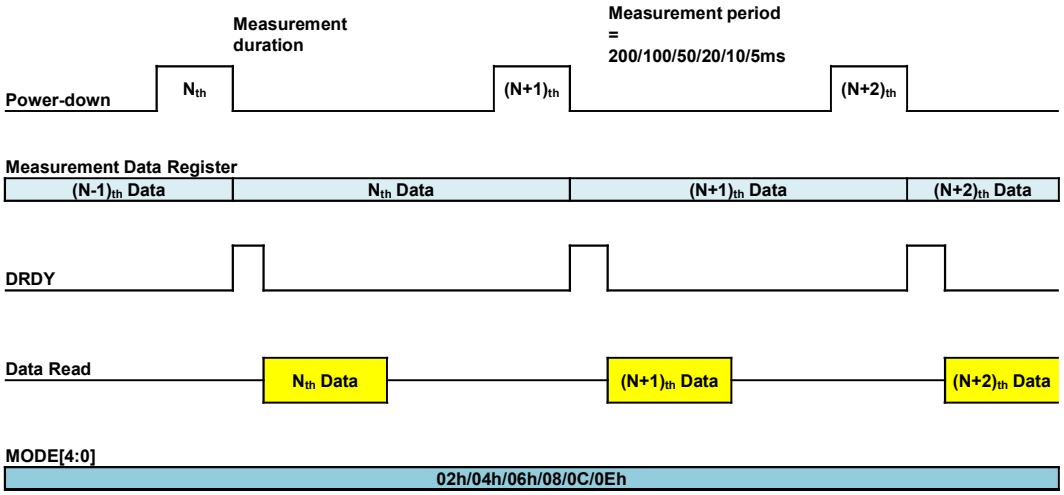


Figure 10: Normal continuous measurement mode

Self-test Mode

Self-test mode is used to check if the magnetic sensor is working normally. GMC306A will start the self-test sequence when setting MODE[4:0]=10h, and automatically transits to power-down mode when complete. At first the built-in internal magnetic source will generate a magnetic field for measurement. After the measurement process is finished, the measurement data is stored in the measurement data registers (HX to HZ) and set the DRDY bit. User can access the measurement result for judgment with the same procedure as the single measurement mode. When the reading is in the range of the following table, GMC306A is working normally.

	HX[15:0]	HY[15:0]	HZ[15:0]
Criteria	-40<HX<40	-40<HY<40	-640<HZ<-160

Fuse ROM Access Mode

GMC306A has fuse ROM for storing calibration data. When MODE[4:0] is set to 1Fh, all magnetic coefficient data of fuse ROM is read. After reading fuse ROM is finished, operation mode returns to power-down mode automatically.

Register 11h: Control Register 2

Addr.	Name	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Access	Default
11h	CNTL2	0	0	0	0	0	0	0	SRST	R/W	0x00

SRST is the soft reset bit. When set, all registers are reset to default values. After reset, SRST bit is cleared automatically.

Register 12h: Control Register 3

Addr.	Name	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Access	Default
12h	CNTL3	MDS[1:0]		0	1	0	1	0	1	R/W	0x15

MDS is the measurement duration selection bits as shown in the below table.

MDS[1:0]	Measurement Duration (ms)	Maximum ODR (Hz)
2'b00	3.6	200
2'b01	1.8	200
2'b10	7.2	100
2'b11	—	—

Register 50h & 51h: Product Identification Registers

Addr.	Name	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Access	Default
50h	CMPID	CMPID[7:0]								R	0x43
51h	DEVID	DEVID[7:0]								R	0x00

CMPID and DEVID are product identification registers and are fixed to 0x43 and 0x00 respectively.

Register 52h: Information Register

Addr.	Name	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Access	Default
52h	INFO	INFO[7:0]								R	0x00

INFO is the information register storing miscellaneous device information.

Register 53h~55h: Magnetic Coefficient Registers

Addr.	Name	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Access	Default
53h	ASAX	COEFX[7:0]								R	NA
54h	ASAY	COEFY[7:0]								R	NA
55h	ASAZ	COEFZ[7:0]								R	NA

ASAX, ASAY and ASAZ are magnetic sensor sensitivity coefficient value for X-, Y- and Z-axis respectively. The coefficient is used for the sensitivity adjustment by the following equation:

$$H_{adj} = H \times \left(\frac{ASA}{128} + 1 \right)$$

where

H : the measuremet data read out from the measurement data registers

ASA : the sensitivity adjustment value

H_{adj} : the adjusted measurement data

Digital Interface

I2C Interface General Description

The I2C interface is compliant with standard and fast I2C standard. The devices support the 7-bit control functions and SDA and SCL facilitate communication between GMC306A and master with clock rates up to 400kHz.

The 7-bit device slave address can be selected by the Fuse ROM option bit as summarized in the below table.

Fuse ROM Option Bit	7-bit Slave Address
1'b0 (default)	0x0C
1'b1	0x0D

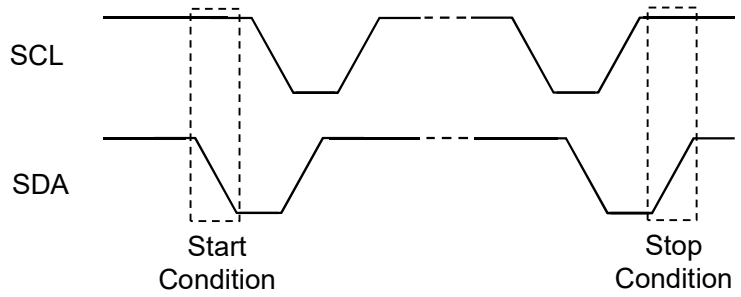
The I2C bus takes master clock through SCL pin and exchanges serial data via SDA. SDA is a bidirectional (input/output) connection. Both are open-drain connection and must be connected externally to VID via a pull-up resistor. The I2C interface supports multiple read and write. When using multiple read/write, the internal I2C address pointer will automatically increase by 1 for the next access.

I2C Access Format: Standard and Fast Mode

One data bit is transferred for each SCL cycle. The SDA must not change level when the SCL is high. The level changes in SDA while SCL is high are reserved control signals. The SDA and SCL remain high when I2C bus is idle.

Data transfer begins by bus master indicating a start condition (ST) of a falling edge on SDA when SCL is high. The master terminates transmission and frees the bus by issuing a STOP condition (SP). Stop condition is a rising edge on SDA while SCL is high. The bus remains active if a repeated START (SR) condition is generated instead of a STOP condition. Figure 11 illustrates the START and STOP condition.

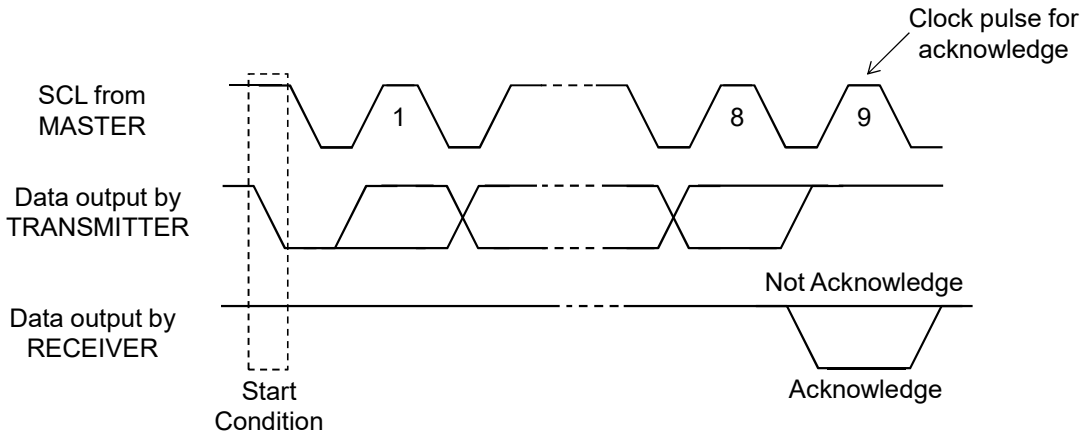
Figure 11: I2C START and STOP condition



After a start condition (ST), the 7-bit slave address + RW bit must be sent by master. If the slave address does not match with GMC306A, there is no acknowledge and the following data transfer will not affect GMC306A. If the slave address corresponds to GMC306A, it will acknowledge by pulling SDA to low and the SDA line should be let free by bus master to enable the data transfer. The master should let the SDA high (no pull down) and generate a high SCL

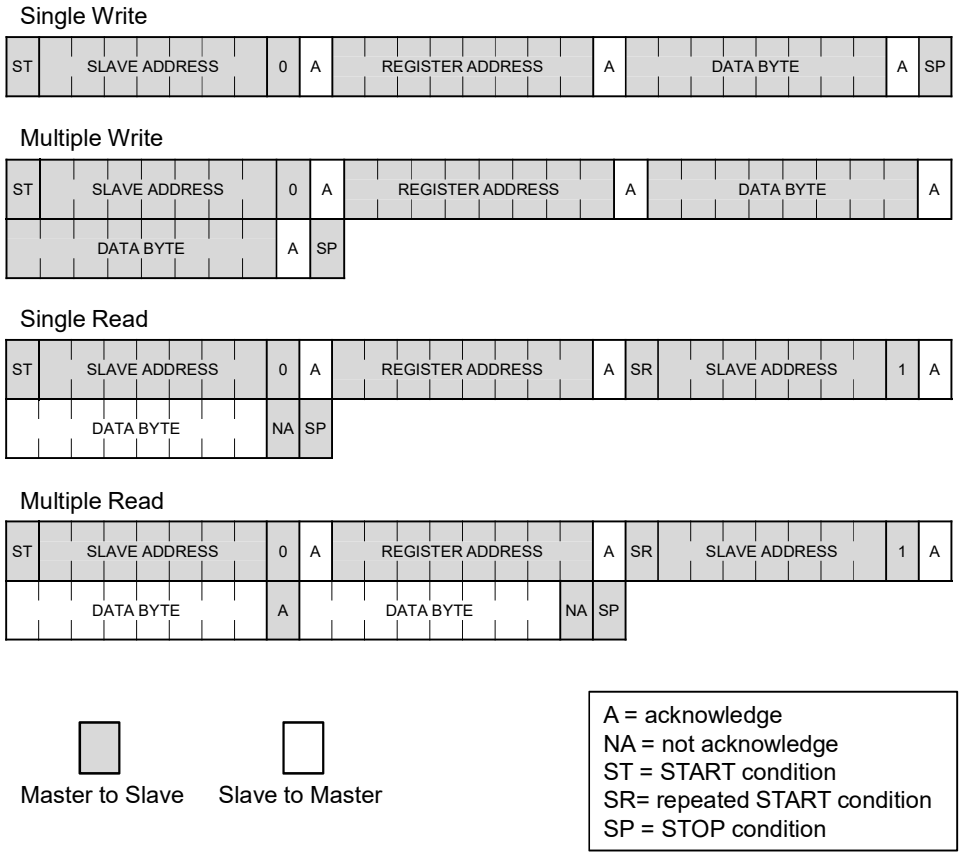
pulse for GMC306A acknowledge. Figure 12 illustrates the acknowledge signal sequence.

Figure 12: Acknowledge signal sequence



A write to GMC306A includes transmission of a START condition, the slave address with R/W bit=1'b0, one byte of data to specify the register address to write, subsequent one or more bytes of data, and finally a STOP condition. "Single Write" and "Multiple Write" in Figure 13 illustrates the frame format of single and multiple write to GMC306A respectively.

Figure 13: I2C access format: standard and fast mode



A read from GMC306A starts with transmission of a START condition, the slave address with R/W bit=1'b0, and one byte of data to specify the register address to read. A repeated START

condition and the slave address with R/W bit=1'b1 are transmitted subsequently. The slave address with R/W bit=1'b1 initiates a read operation. GMC306A acknowledge receipt of the read operation command by pulling SDA low during the 9th SCL clock and begin transmitting the contents starting from the specified register address. The master must acknowledge all correctly received bytes except the last byte. The final byte must be followed by a not acknowledge from the master and the STOP condition. "Single Read" and "Multiple Read" in Figure 13 illustrates the frame format for reading single or multiple byte from GMC306A.

I2C Specifications

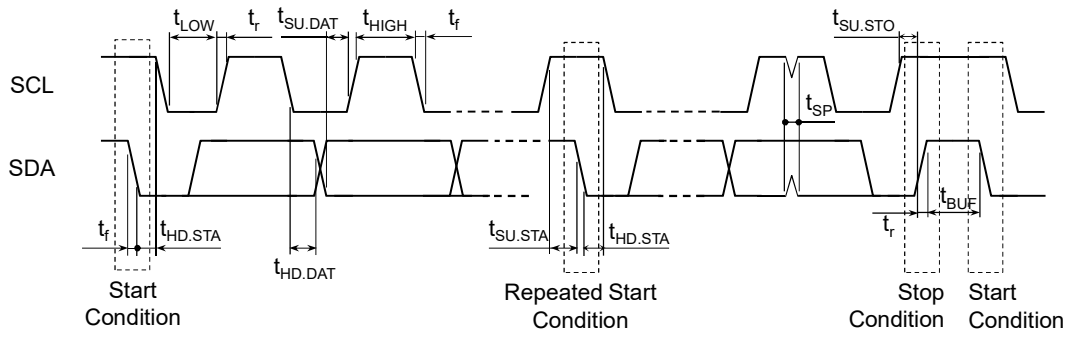
Table 9: I2C Timing Specification: Standard Mode

Parameter	Symbol	Minimum	Typical	Maximum	Unit
SCL clock frequency	f_{SCL}	—	—	100	kHz
Clock low period	t_{LOW}	4.7	—	—	μs
Clock high period	t_{HIGH}	4	—	—	μs
Start hold time	$t_{HD.STA}$	4	—	—	μs
Start setup time	$t_{SU.STA}$	4.7	—	—	μs
Data-in hold time	$t_{HD.DAT}$	0	—	—	μs
Data-in setup time	$t_{SU.DAT}$	250	—	—	ns
Stop setup time	$t_{SU.STO}$	4	—	—	μs
Rise time	t_r	—	—	1	μs
Fall time	t_f	—	—	0.3	μs

Table 10: I2C Timing Specification: Fast Mode

Parameter	Symbol	Minimum	Typical	Maximum	Unit
SCL clock frequency	f_{SCL}	—	—	400	kHz
Clock low period	t_{LOW}	1.3	—	—	μs
Clock high period	t_{HIGH}	0.6	—	—	μs
Bus free to new start	t_{BUF}	1.3	—	—	μs
Start hold time	$t_{HD.STA}$	0.6	—	—	μs
Start setup time	$t_{SU.STA}$	0.6	—	—	μs
Data-in hold time	$t_{HD.DAT}$	0	—	—	μs
Data-in setup time	$t_{SU.DAT}$	100	—	—	ns
Stop setup time	$t_{SU.STO}$	0.6	—	—	μs
Rise time	t_r	—	—	0.3	μs
Fall time	t_f	—	—	0.3	μs
Spike width	t_{SP}	—	—	50	μs

Figure 14: I2C Timing Diagram: Standard and Fast Mode



Package

Outline Dimension

Unit: mm

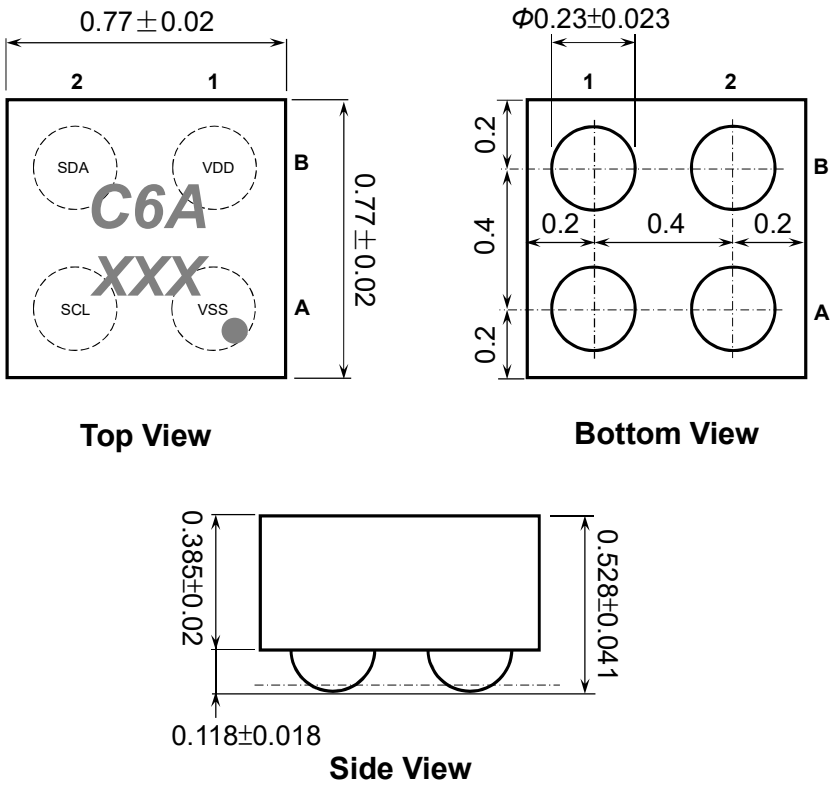


Figure 15: Package Outline Dimension

Axes Orientation

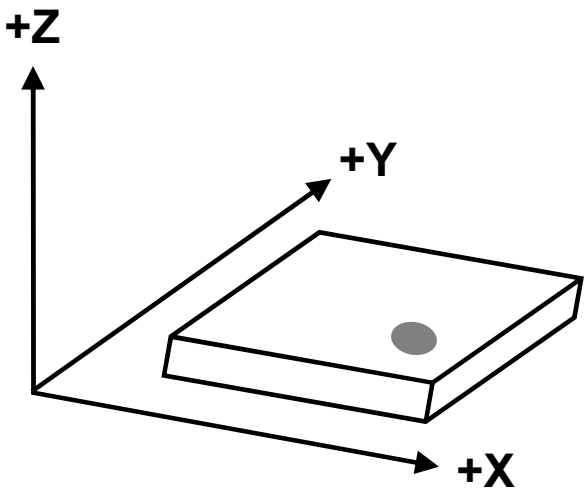


Figure 16: GMC306A Axes Orientation

RoHS Compliance

GMEMS WLCSP sensors are compliant with Restrictions on Hazardous Substances (RoHS), having halide-free molding compound (green) and lead-free terminations. Reflow profiles applicable to those processes can be used successfully for soldering the devices.

Recommended PCB Foot Print Layout

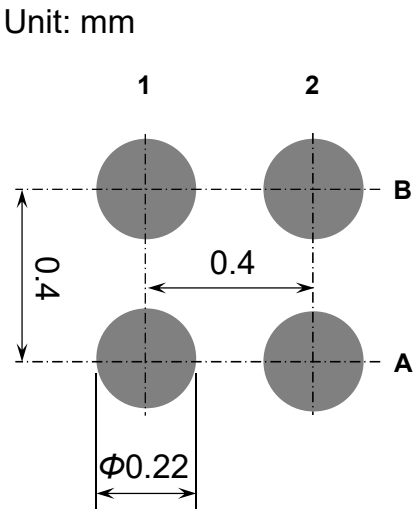


Figure 17: Layout Recommendation for PCB Land Pad

Moisture Sensitivity Level

GMC306A package MSL rating is Level 3.

Document History and Modification

Revision No.	Description	Date
V0.1	Preliminary version first release	2018/1/12