High-stability Gyro Sensor: XV4311BD

Features

- SafeSPI serial interface
- Angular rate output (16-bit / 24-bit)
- Excellent bias stability over temperature
- Operating temperature range -40 °C to +105 °C
- Built-in temperature sensor
- Bias instability 0.9°/h (Typ.)
- Comply with AEC-Q100 / Support evaluation of hardware elements in ISO26262

Applications

- Anti-vibration and attitude control for industrial applications etc.
- Localization system for ADAS/autonomous vehicle applications (Yaw axis improvement)

Typical performance

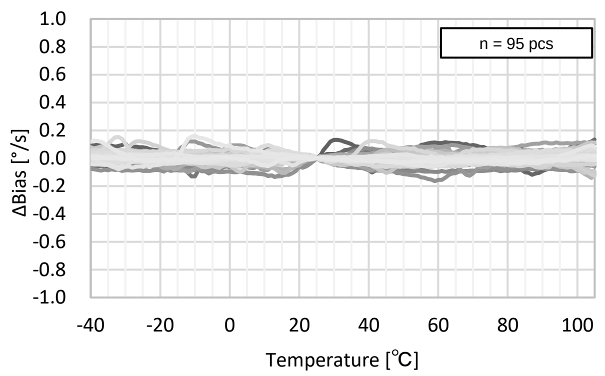


Figure. Bias variation over temperature

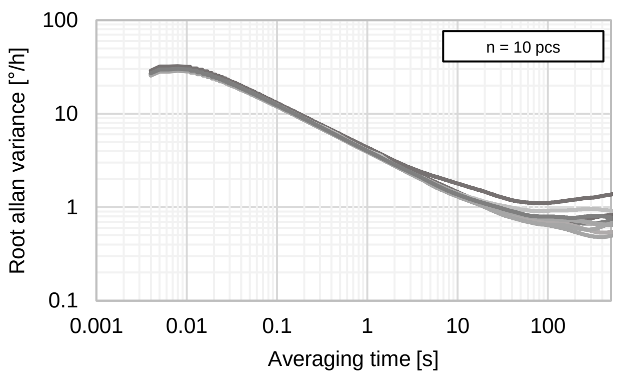


Figure. Root allan variance

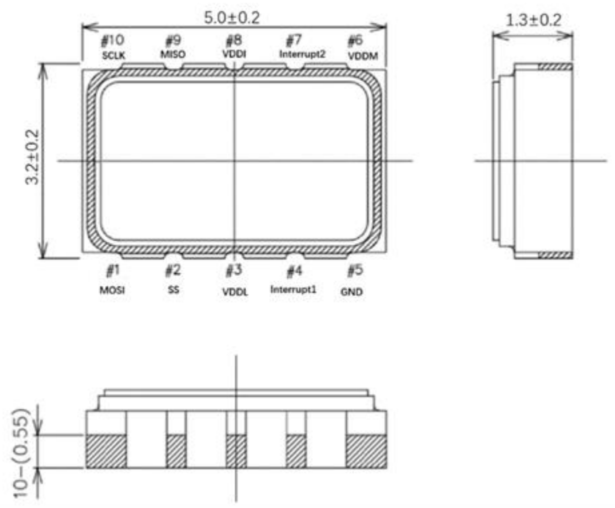
Description

The XV4311BD has superior performance characteristics especially with bias output stability and low noise. Epson achieves these performances by using Epson's original quartz sensor element.

This sensor has digital output interface (SafeSPI).

In addition, user-selectable low pass filters are available for wide range of cut-off frequencies. The XV4311BD is suitable for various applications from consumer electronics such as automotive devices to industrial equipment.

Outline drawing and terminal assignment



Unit: mm

Contents

List of Figures

List of Tables

Revision history

Rev. No.	Date of revision	Page	Revised content
1.0	July. 16, 2025	-	New release

Symbols

Pb Free	• **A lead-free product.**
RoHS Compliant	• **Compliant with the EU RoHS directive.** * About products without the Pb-Free label Product terminals are lead-free but the internal components of the product contain lead (high melting point solder lead as well as the lead contained in the glass of an electronic component are both not applicable under the EU RoHS directive).
For Automotive	• **Indicates a product intended for use in an automobile (body, information systems, etc.). The product has been designed and manufactured in accordance with a quality assurance program suited for the on-board environment of an automobile.**
Automotive Safety	• **Indicates a product intended for use to further the safe operation of an automobile (driving, stopping, turning). The product has been designed and manufactured in accordance with a quality assurance program suited for the on-board safety of an automobile.**

Notice of the document

NOTICE : PLEASE READ CAREFULLY BELOW BEFORE THE USE OF THIS DOCUMENT

1. The content of this document is subject to change without notice. Before purchasing or using Epson products, please contact with sales representative of Seiko Epson Corporation ("Epson") for the latest information and be always sure to check the latest information published on Epson's official web sites and resources.
2. This document may not be copied, reproduced, or used for any other purposes, in whole or in part, without Epson's prior consent.
3. Information provided in this document including, but not limited to application circuits, programs and usage, is for reference purpose only. Epson makes no guarantees against any infringements or damages to any third parties' intellectual property rights or any other rights resulting from the information. This document does not grant you any licenses, any intellectual property rights or any other rights with respect to Epson products owned by Epson or any third parties.
4. Epson has prepared this document carefully to be accurate and dependable, but Epson does not guarantee that the information is always accurate and complete. Epson assumes no responsibility for any damages you incurred due to any misinformation in this document.
5. Epson products listed in this document and our associated technologies shall not be used in any equipment or systems that laws and regulations in Japan or any other countries prohibit to manufacture, use or sell. Furthermore, Epson products and our associated technologies shall not be used for the purposes of military weapons development (e.g. mass destruction weapons), military use, or any other military applications. If exporting Epson products or our associated technologies, please be sure to comply with the Foreign Exchange and Foreign Trade Control Act in Japan, Export Administration Regulations in the U.S.A (EAR) and other export-related laws and regulations in Japan and any other countries and to follow their required procedures.
6. Epson assumes no responsibility for any damages (whether direct or indirect) caused by or in relation with your non-compliance with the terms and conditions in this document or for any damages (whether direct or indirect) incurred by any third party that you give, transfer or assign Epson products.
7. For more details or other concerns about this document, please contact our sales representative.
8. Company names and product names listed in this document are trademarks or registered trademarks of their respective companies.

●Disclaimer

1. Epson products are designed for use in general electronic equipment applications that do not require extremely high reliability or safety.
2. Epson does not represent or warrant that its products will not cause a failure for any particular application, except for cases where the failure is a direct result caused by defects in materials and workmanship of this product.
If a product fails due to defects in materials and workmanship, to the maximum extent permitted by law, we will, at our sole discretion, refund or replace the affected product.
3. When products for used directly or indirectly in certain devices or applications (ex. Nuclear power, aerospace, infrastructure facilities, medical equipment, etc.) which are connected to or affect safety of human life or property, Customer is solely responsible for determining if the products and respective specifications are suitable for the intended use in particular customer applications.
Customer shall implement necessary and proper safety design and measures (including redundant design, malfunction prevention design, etc.) to ensure reliability and safety before using the products in/with customer's Equipment.
4. For the products designed for automotive applications, the products comply with AEC-Q100 or AEC-Q200. Products do not comply with ISO 26262 (Products are not categorized to ASIL A, B, C and D).
5. No dismantling, analysis, reverse engineering, modification, alteration, adaptation, reproduction, etc., of Epson products is allowed.
Furthermore, any defects caused by this are not covered by the warranty.

1. Block diagram

The block diagram of the sensor is shown in Figure 1.1.

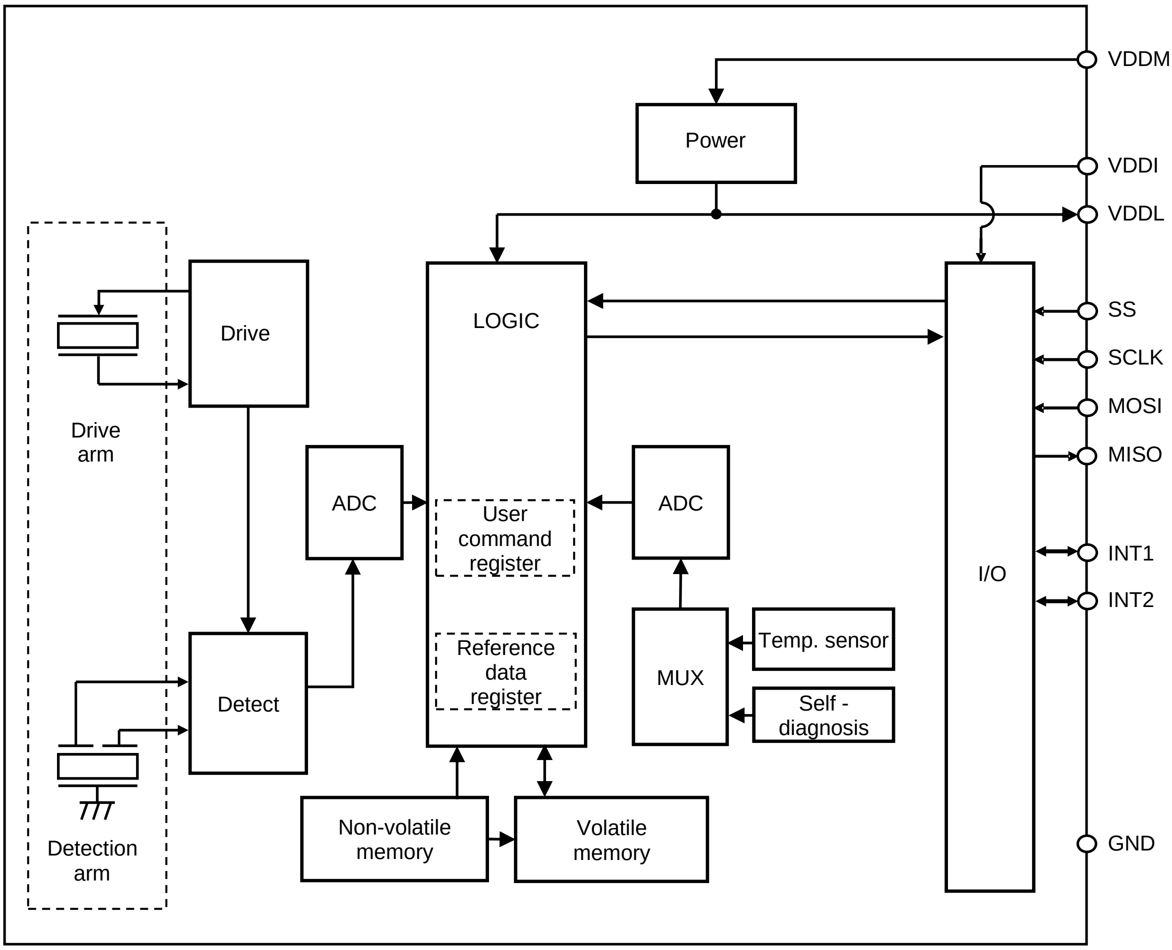


Figure 1.1 Functional block diagram

2. Function explanation

2.1. Angular rate output

The 16-bit / 24-bit angular velocity output data is provided in the 2's complement expression. To use 24-bit output mode, it is necessary to switch to 24-bit mode with 1C address and then read twice with SafeSPI. Please refer to Section 6.

2.2. Detection axis and output polarity

This product detects an angular rate of a rotational movement. The correlation between a detecting axis of the angular rate and an output polarity is shown in Figure 2.1.

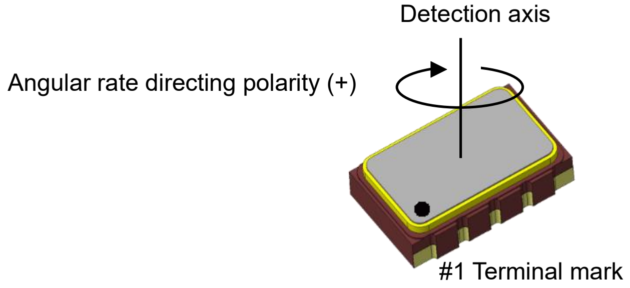


Figure 2.1 Detection axis and detection polarity

2.3. Interface

This sensor is specified to the SafeSPI – Serial Peripheral Interface for Automotive Safety.

2.4. Temperature sensor output

The 16-bit temperature output data is provided in the 2's complement expression. Output data rate is 1 kHz.

2.5. Diagnosis output

The 16-bit failure diagnosis output data is provided. Please refer to Section 8.1.

3. Electrical characteristics

3.1. Absolute maximum rating

Table 3.1 Absolute maximum rating

Parameter	Symbol	Min.	Typ.	Max.	Unit	Condition
Supply voltage	V_{DDM}	-0.3	-	+4.0	V	GND = 0 V
Supply voltage for interface	V_{DDI}	-0.3	-	+4.0	V	GND = 0 V
Storage temperature	T_{STG}	-40	-	+105	°C	
SS	SS	-0.3	-	4.0	V	GND = 0 V
SCLK	SCLK	-0.3	-	4.0	V	GND = 0 V
MOSI	MOSI	-0.3	-	4.0	V	GND = 0 V
Conditions for soldering	-	+350 °C, 3 s			-	

3.2. Operating conditions

Table 3.2 Operating conditions

Parameter	Symbol	Min.	Typ.	Max.	Unit	Condition
Supply voltage	V_{DDM}	+2.7	-	+3.6	V	GND = 0 V
Supply voltage for interface	V_{DDI}	+1.65	-	+3.6	V	GND = 0 V
Operating temperature	Ta	-40	-	+105	°C	
Supply voltage Start-Up time	t_{Pu}	0.01	-	100	ms	V_{DDM} 0 % to 90 %
SafeSPI clock frequency	f_{SCLK}	-	-	10	MHz	
Output data rate	ODR	-	11.6	-	kHz	ADC

(Note) Using a communication clock frequency that is an integer multiple of the drive frequency may result in fluctuations in the angular rate output.

(Note) Acquiring angular rate data at a frequency that is an integer divide from the drive frequency can result in fluctuations in the angular rate output. Refer to Table 3.5 for supported drive frequencies.

3.3. DC characteristics

Table 3.3 DC characteristics

(V_{DDM} = 2.7 V ~ 3.6 V, V_{DDI} = 1.65 V ~ 3.6 V, GND = 0 V, Ta = -40 °C ~ +105 °C)

Parameter	Symbol	Min.	Typ.	Max.	Unit	Condition
Logic input voltage	V_{IH}	V_{DDI} × 0.7	-	-	V	
	V_{IL}	-	-	V_{DDI} × 0.3	V	
Logic output voltage	V_{OH}	V_{DDI} - 0.4	-	-	V	V_{DDI} = Min., Load +1 mA
	V_{OL}	-	-	+0.4	V	V_{DDI} = Min., Load -1 mA

3.4. Operating sequence at Start-Up

Table 3.4 Operating sequence at Start-Up

(V_{DDM} = 2.7 V ~ 3.6 V, V_{DDI} = 1.65 V ~ 3.6 V, GND = 0 V, Ta = -40 °C ~ +105 °C)

Parameter	Symbol	Condition	Min.	Typ.	Max.	Unit
Serial communication wait time	t_{IF}	-	1	-	-	ms
Temperature sensor data read start time	t_{TSEN}	-	-	-	160	ms
Start-Up time	t_{STA}	Output code ±1 °/s	—	-	250	ms

(Note) Execute serial communication after t_{IF}.
(Note) Execute temperature sensor data acquisition after t_{TSEN}.
(Note) Execute angular rate data acquisition after t_{STA}.

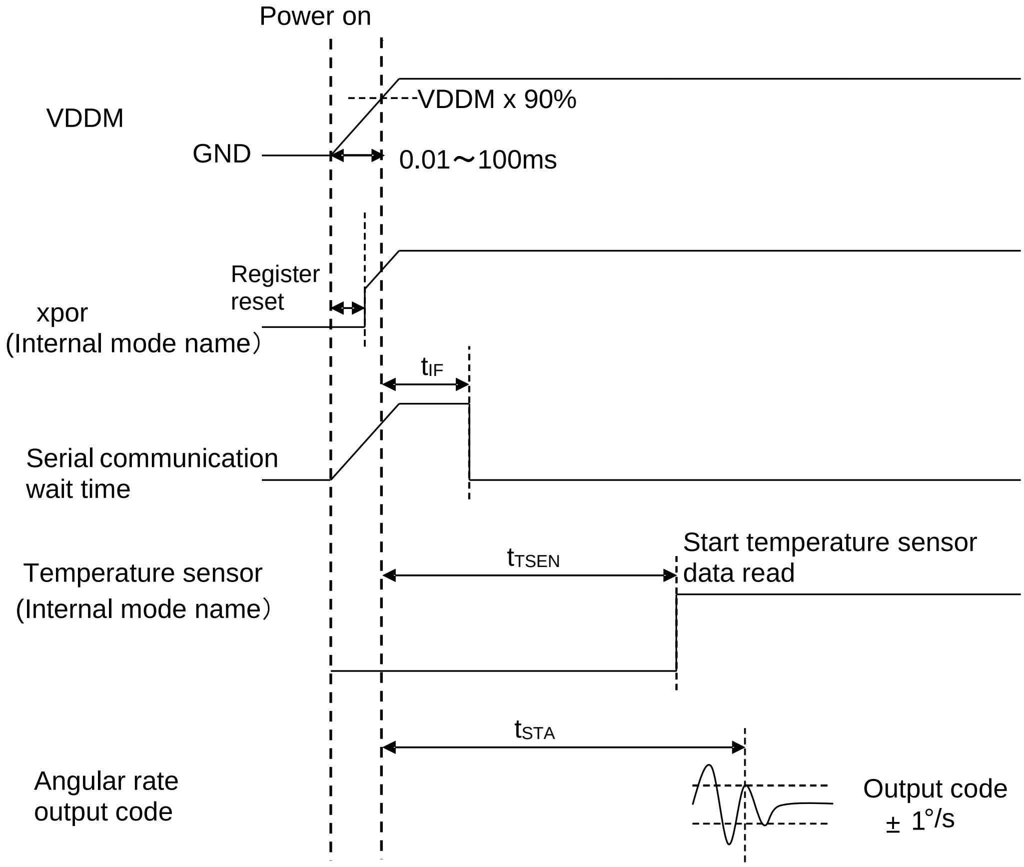


Figure 3.1 Operation sequence at Start-Up

3.5. Gyro sensor characteristics

Table 3.5 Gyro sensor characteristics

(V_{DDM} = 2.7 V ~ 3.6 V, V_{DDI} = 1.65 V ~ 3.6 V, GND = 0 V, Ta = -40 °C ~ +105 °C,
The following are characteristic values at the time of shipment

Parameter	Symbol	Condition	Min.	Typ.	Max.	Unit
Drive frequency	F_d	Frequency code J	50.450	51.025	51.600	kHz
Detuning frequency	D_f		0.7	0.9	1.1	kHz
Scale factor	S_o	16-bit, FS = 1 setting	-	264	-	LSB/(°/s)
		16-bit, FS = 1/4 setting	-	66	-	
		24-bit, FS = 1 setting	-	67584	-	
		24-bit, FS = 1/4 setting	-	16896	-	
Scale factor tolerance	S_p	Ta = +25 °C	-2	-	+2	%
		include after shipment	-4	-	+4	%
Scale factor variation over temperature	S_{pt}	V_{DDM} = 3.3 V, Ta = +25 °C reference	-3	-	+3	%
Bias	ZRL	Ta = +25 °C	-	0	-	LSB
Bias tolerance	ZRL	Ta = +25 °C	-1	-	+1	°/s
		include after shipment	-2	-	+2	°/s
Bias variation over temperature	ZRL_t	V_{DDM} = 3.3 V, Ta = +25 °C reference	-0.25	-	+0.25	°/s
Bias temperature coefficient	ZRL_s	V_{DDM} = 3.3 V, Average of absolute value, ΔT = 1 ºC	-	0.0019	-	(°/s)/ºC
Rate range	I	16-bit, FS = 1 setting	-115	-	+115	°/s
		16-bit, FS = 1/4 setting	-460	-	+460	
Non-linearity	Nl		-0.05	-	+0.05	%FS
Cross-axis sensitivity	CS	Ta = +25 °C	-5	-	+5	%
Current consumption	I_{op1}		-	-	2.5	mA
Sleep current	I_{op3}		-	3	60	µA
Noise density	N_d	@ 10 Hz, LPF default setting, Ta = +25 °C	-	0.0015	-	(°/s)/√Hz
Angle random walk	Arw	Ta = +25 °C	-	0.065	-	°/√h
Bias instability *1	Bs	Ta = +25 °C, Bottom value of Allan variance. Device powered 20 seconds before measuring.	-	0.9	-	°/h
	Bs /0.664	Ta = +25 °C, Divided by 0.664.	-	1.4	-	°/h

*1. Based on estimates from test values with Allan variance τ = 10 s.

3.6. Temperature sensor characteristics

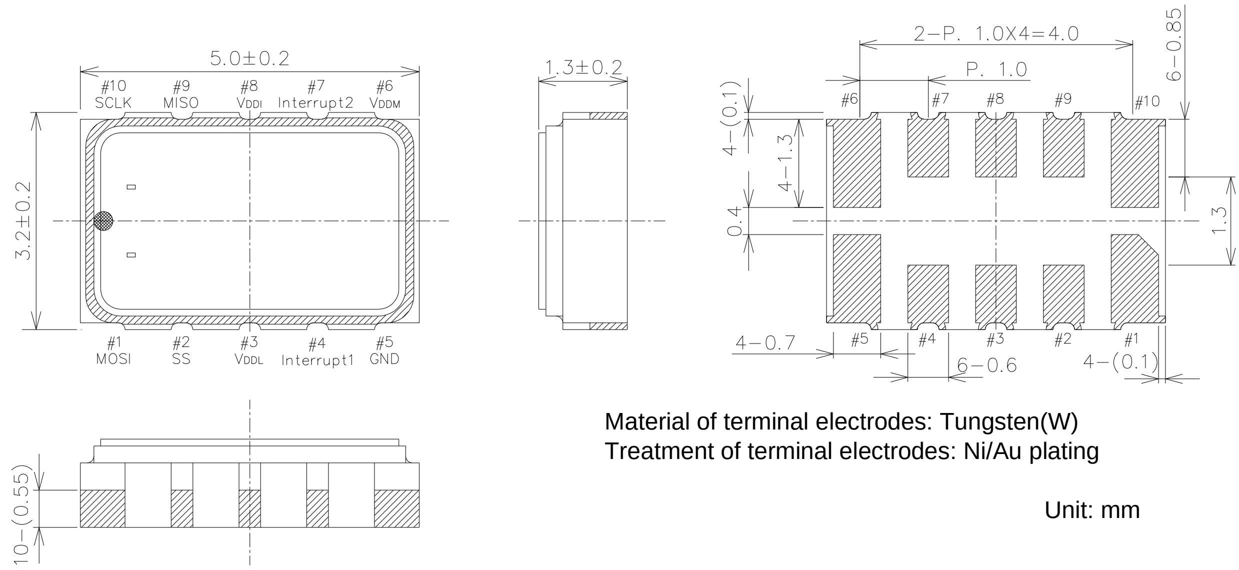
Table 3.6 Temperature sensor characteristics

(V_{DDM} = 2.7 V ~ 3.6 V, V_{DDI} = 1.65 V ~ 3.6 V, GND = 0 V, Ta = -40 °C ~ +105 °C,
The following are characteristic values at the time of shipment)

Parameter	Symbol	Condition	Min.	Typ.	Max.	Unit
Output code	T_{out}	Ta = +25 °C, 16-bit output	2560	3200	3840	LSB
Temperature error	T_{acc}	Ta = +25 °C	-5	-	+5	°C
Temperature coefficient	T_{sen}	Ta = +25 °C	115.2	128.0	140.8	LSB/°C

4. Dimensions and pin description

4.1. Outline dimensions



Material of terminal electrodes: Tungsten(W)
Treatment of terminal electrodes: Ni/Au plating

Unit: mm

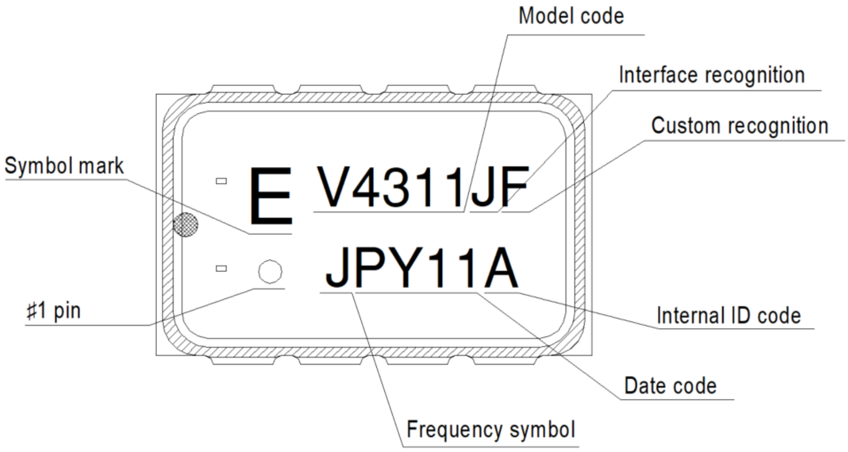
Figure 4.1 Outline dimensions

4.2. Pin name and description

Table 4.1 Pin name and description

Pin number	Pin name	Input/Output	Pin description
#1	MOSI	Input	SafeSPI communications mode: serial data input
#2	SS	Input	SafeSPI communications mode: slave select
#3	V_{DDL}	Output	Internal regulator voltage output Connect to the bypass capacitor C5. Refer to Figure 10.1 to Figure 10.3.
#4	Interrupt1 (INT1)	Input/Output	Selectable pin. Refer to Section 7.10. ・Trigger latch input ・Saturation flag output ・Data ready ouput
#5	GND	-	GND
#6	V_{DDM}	-	Power supply voltage Connect to the bypass capacitor C1, C2. Refer to Figure 10.1 to Figure 10.3.
#7	Interrupt2 (INT2)	Input/Output	Selectable pin. Refer to Section 7.10. ・Trigger latch input ・Saturation flag output ・Data ready ouput
#8	V_{DDI}	-	Power supply voltage for digital interface Connect to the bypass capacitor C3, C4. Refer to Figure 10.1 to Figure 10.3.
#9	MISO	Output	SafeSPI communications mode: serial data output
#10	SCLK	Input	SafeSPI serial clock

4.3. Marking description



Frequency symbol	Drive frequency
J	51.0 kHz

Figure 4.2 Marking descripiton

4.4. Pin equivalent circuits

The equivalent circuit for SS, SCLK, MOSI, MISO and INT2 is shown in Figure 4.3.

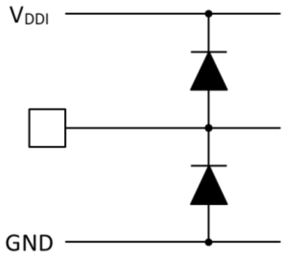


Figure 4.3 The equivalent circuit: SS, SCLK, MISO and INT2

The equivalent circuit for V_{DDL} and INT1 is shown in Figure 4.4.

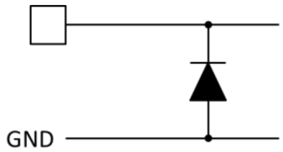


Figure 4.4 The equivalent circuit: V_{DDL} and INT1

The equivalent circuit for V_{DDM} and V_{DDI} is shown in Figure 4.5.

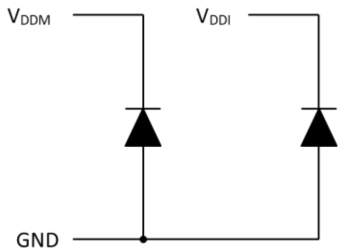


Figure 4.5 The equivalent circuit: V_{DDM} and V_{DDI}

4.5. Soldering pattern

An example of a recommended soldering pattern for this product is shown in Figure 4.6. It is recommended to give due consideration to ensure optimal design aspects such as mounting density and solder mount reliability.

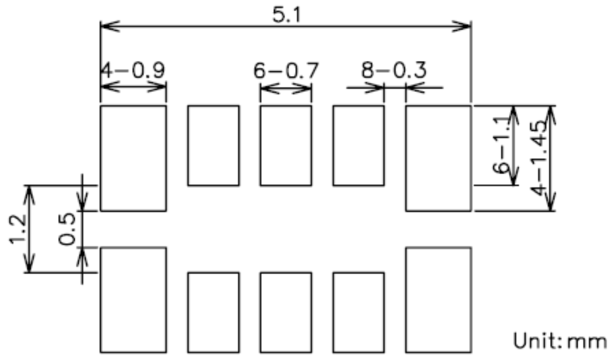


Figure 4.6 Recommended PCB land pattern

5. Typical performance characteristics

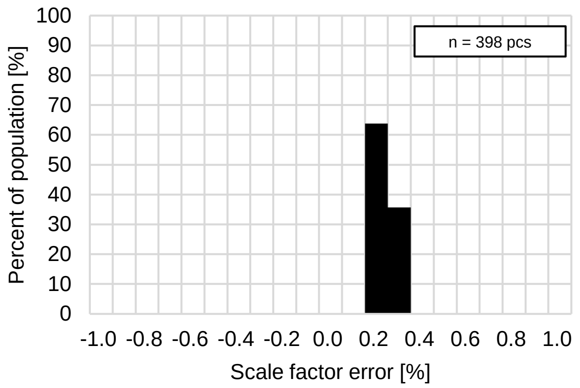


Figure 5.1 Scale factor tolerance at Ta = +25 ºC

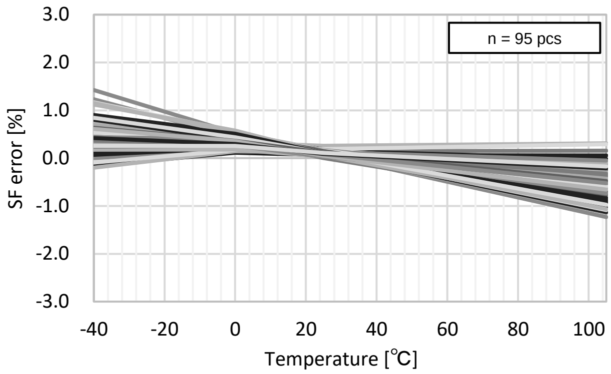


Figure 5.2 Scale factor variation over temperature

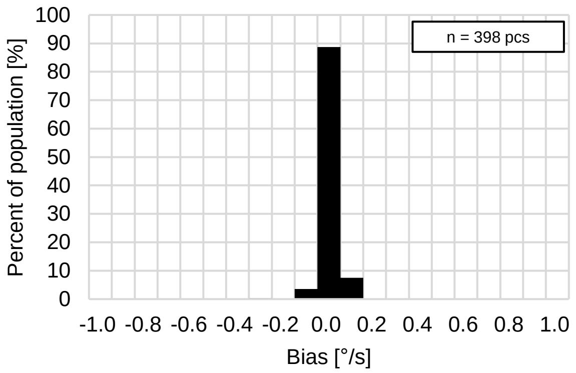


Figure 5.3 Bias tolerance at Ta = +25 ºC

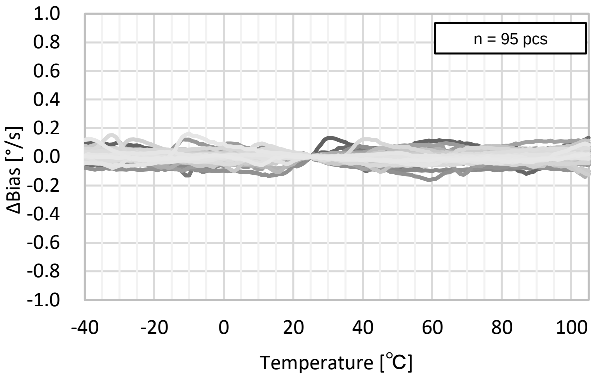


Figure 5.4 Bias variation over temperature

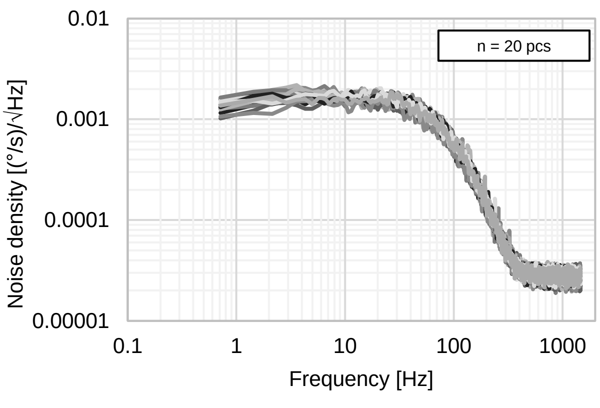


Figure 5.5 Noise density

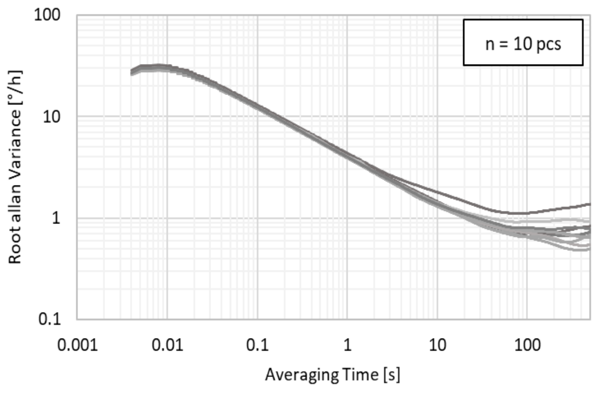


Figure 5.6 Root allan variance

6. Serial interface

Access to the sensor is done through serial communication.

After the serial communication wait time t_{IF} described in Section 3.4 has elapsed after turning on the power supply V_{DDM}, SafeSPI communication is enabled by setting the slave select signal (SS) to logic "L" level.

6.1. SafeSPI communication

SafeSPI communication is a 32-bit wide serial communication that conforms to the SafeSPI specification.

Access this mode with CPOL= 1, CPHA= 1. It does not support the mode in which data is acquired at the falling edge of the clock. Additionally, this SPI only supports SafeSPI's "in-frame protocols". It does not support "out-of-frame protocols".

6.1.1. Communication format

The basic communication format is shown below. When SS is brought down, the first 2 bits (bit31/bit30) SA[1:0] become the address of the slave device (Gyro). For MOSI, set the slave address determined at the time of shipment. Furthermore, if the slave address is set correctly, SA[1:0] will be outputted from bit24/bit23 of MISO. The slave address of this model is 00.

Please set the following bits29 to bit5 for each function described below. CC2:0 of bit4-bit2 becomes CRC data in the transmission data. CRC is used as an error detection method in data communication.

During serial data transfer, SS must be kept at logic "L" level. If SS is set to logic "H" level, the serial data transfer will be canceled.

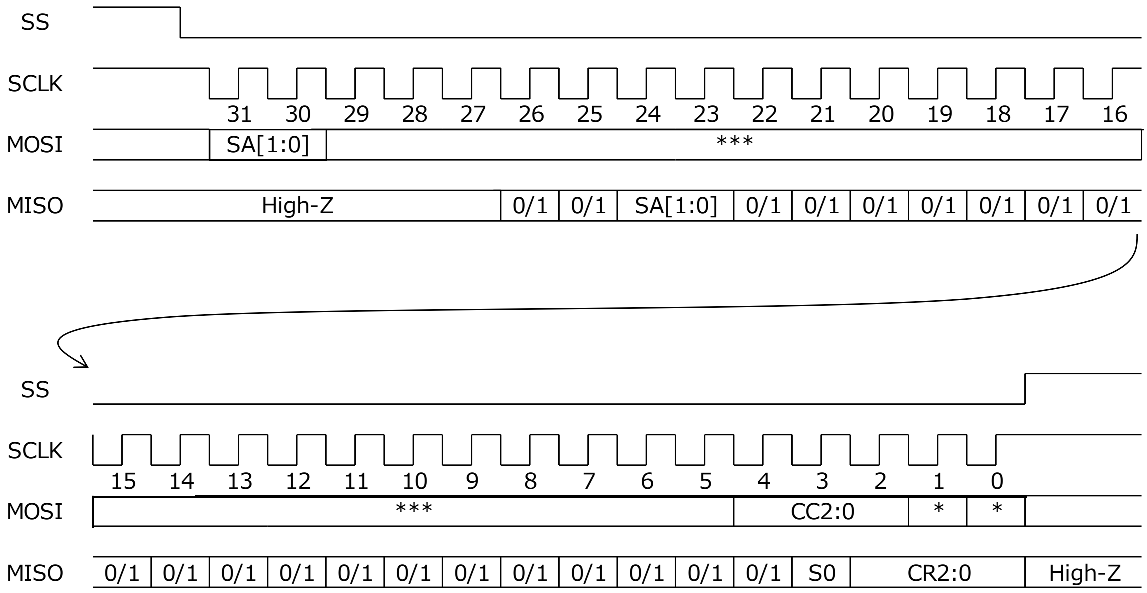


Figure 6.1 SafeSPI communication format

Five types of communication formats are supported: register writing, register reading, angular velocity reading, temperature reading, and failure diagnosis result reading.

6.1.2. Register write

For register writing, please set bit29-bit27 to "001". If set correctly, “001” will be outputted from bit22-bit20 of MISO. Bit26-bit20 and bit18 are bits that do not affect register writing. There is no problem with either setting "0" or "1" (however, it will affect CRC calculation). Please set bit19 to “0”. Bit17-bit13 (P/U and REG_ADD[3:0]) are the register address. Set the address of the register you want to access. Bit12-bit5 (REG_DATA[7:0]) is the register setting value by MOSI. Please refer to the register map and transfer the value you want to set. Bits12-bit5 output the data (REG_OUT[7:0]) before writing the register address set by MISO. S0 is the failure diagnosis result of the gyro sensor. The result of the failure diagnosis in detail is written in Figure 6.8.

The reliability of the communication format is checked by the CRC data (CC2:0), and if it is normal, the setting value is written to the internal register at the rising edge of the bit1 clock. For CRC data, please refer to "CRC communication error check" described later.

Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MOSI	SA[1:0]		**0**	**0**	**1**	*	*	*	*	*	*	*	0	*	P/U	REG ADD[3:0]				REG DATA[7:0]								CC2:0			*	*
MISO	High-Z					0	0	SA[1:0]		**0**	**0**	**1**	0	0	0	0	0	0	0	REG OUT[7:0]								0	S0	CR2:0		

Figure 6.2 Register write sequence

6.1.3. Register read

For register reading, unlike register writing, set bit19 to “1”. Other settings are the same as register writes (bit12-bit5 settings do not affect register reads). Register value is outputted from bit12-bit5 of MISO.

Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MOSI	SA[1:0]		**0**	**0**	**1**	*	*	*	*	*	*	*	**1**	*	P/U	REG ADD[3:0]				*								CC2:0			*	*
MISO	High-Z					0	0	SA[1:0]		**0**	**0**	**1**	0	0	0	0	0	0	0	REG OUT[7:0]								0	S0	CR2:0		

Figure 6.3 Register read sequence

6.1.4. Sensor data read

The various data read sequences are shown below.

Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MOSI	SA[1:0]		0	1	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	CC2:0			*	*
MISO	High-Z					0	1	SA[1:0]		0	1	0	GYRO DATA[15:0]																S0	CR2:0		

Figure 6.4 16-bit mode Angular velocity readout sequence

Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MOSI	SA[1:0]		0	1	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	CC2:0			*	*
MISO	High-Z					0	1	SA[1:0]		0	1	0	GYRO DATA[23:8]																S0	CR2:0		

Figure 6.5 24-bit mode Angular velocity MSB readout sequence

Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MOSI	SA[1:0]		0	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	CC2:0			*	*
MISO	High-Z					0	1	SA[1:0]		0	1	1	GYRO DATA[15:0]																S0	CR2:0		

Figure 6.6 24-bit mode Angular velocity LSB readout sequence

Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MOSI	SA[1:0]		1	0	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	CC2:0			*	*
MISO	High-Z					0	1	SA[1:0]		1	0	1	TEMP DATA[15:0]																S0	CR2:0		

Figure 6.7 Temperature readout sequence

Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MOSI	SA[1:0]		1	1	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	CC2:0			*	*
MISO	High-Z					1	0	SA[1:0]		1	1	0	Failure FLAG[15:0]																S0	CR2:0		

Figure 6.8 Failure diagnosis result readout sequence

When reading sensor data, set the command corresponding to the data you want to read in bit29-bit27.The sensor data set is outputted from bit19-bit4 of MISO.

S0 outputs the result of the reduction or calculation on the output from the fault diagnosis result readout.

Table 6.1 Sensor data read command register

Bit[29:27]	R/W	Output data
001	R/W	Register access
010	R	Angular velocity readout (both 24-bit and 16-bit mode MSB)
011	R	Angular velocity readout (24-bit mode LSB)
101	R	Temperature readout
110	R	Failure diagnosis result readout

(Note) In the 24-bit mode, be sure to read the MSB side (010) before reading the LSB side (011).

(Note) It is necessary to switch to 24-bit mode with 1C address. Please refer to Section 7.8.

(Note) In the 24-bit mode, for the output Gyro data [23:0],

1) When reading the MSB side (Bit[29:27] is 3'b010), Gyro data[23:8] is outputted.

2) When reading the LSB side (Bit[29:27] is 3'b011), Gyro data[15:0] is outputted.

Additional calculations are required when processing to 24-bit. (Example: (MSB<<8)+(LSB&0x00FF))

Overlapping output bits ensure the data reliability.

6.1.5. CRC communication error check

This communication is equipped with CRC (Cyclic Redundancy Check) as a communication error check. CC2:0 is the value for CRC calculation using the value of bit31-bit5 transmitted by MOSI. CC2:0 is used in the register write sequence, and by comparing the CC2:0 data sent from bit4-bit2 with the CRC data calculated inside the IC, it is determined whether the data has been sent normally. If the comparison results match and it is determined that the data was successfully transmitted, a register write is performed. If the comparison result is a mismatch, no register write is performed. If you want to check if a register write was performed afterward,

1) Read the register at the target address
2) Read the “SafeSPI input data comparison CRC result storage register” data, which will be described later.

Please check either of these.

CR2:0 is the value for CRC calculation using the value of bit26-bit3 sent from MISO. It can be used to determine whether data from this IC is being received normally. For in-frame formats, a 3-bit CRC with polynomial 0x5 (x3 + x1 + x0) is used with a starting value of 3‘b111 and a target value of 3’b000.

For detailed CRC calculation method, please refer to the SafeSPI specification.

6.1.6. Operations

Table 6.2 Example of reading sensor data

Sensor data	Hex command	Binary command
Angular velocity (both 24-bit and 16-bit mode MSB)	0x10000018	00 010 000000000000000000000 110 00
Angular velocity (24-bit mode LSB)	0x18000000	00 011 000000000000000000000 000 00
Temperature	0x28000008	00 101 000000000000000000000 010 00
Failure diagnosis result	0x3000000c	00 110 000000000000000000000 011 00

Table 6.3 Example of register access

Sensor data	W/R	Write data	Hex command	Binary command
Sleep control [Address: 0x06]	Write	0x59	0x0800CB38	00 001 0000000 0 0 0 0110 01011001 110 00
	Read	-	0x0808C018	00 001 0000000 1 0 0 0110 00000000 110 00
Sleep-In [Address: 0x05]	Write	0x01	0x0800A03C	00 001 0000000 0 0 0 0101 00000001 111 00
	Read	-	0x0808A01C	00 001 0000000 1 0 0 0101 00000000 111 00
Sleep-Out [Address: 0x05]	Write	0x00	0x0800A010	00 001 0000000 0 0 0 0101 00000000 100 00
	Read	-	0x0808A01C	00 001 0000000 1 0 0 0101 00000000 111 00
Software control [Address: 0x1A]	Write	0x59	0x08034B20	00 001 0000000 0 0 1 1010 01011001 000 00
	Read	-	0x080B4000	00 001 0000000 1 0 1 1010 00000000 000 00
Software reset [Address: 0x1B]	Write	0x01	0x08036038	00 001 0000000 0 0 1 1011 00000001 110 00
16-bit read format [Address: 0x1C]	Write	0x00	0x08038004	00 001 0000000 0 0 1 1100 00000000 001 00
	Read	-	0x080B8008	00 001 0000000 1 0 1 1100 00000000 010 00
24-bit read format [Address: 0x1C]	Write	0x04	0x08038098	00 001 0000000 0 0 1 1100 00000100 110 00
	Read	-	0x080B8008	00 001 0000000 1 0 1 1100 00000000 010 00

Table 6.4 Example of DSP setting

DSP setting address [0x0c]				Write data	Hex command	Binary command
SelFSR	EnbNF	LpfOrder	LpfFc			
2'b00 +/- 115 [°/s]	Enable 1'b1	2nd	1 Hz	0x20	0x08018404	00 001 0000000 0 0 0 1100 00100000 001 00
			10 Hz	0x21	0x08018428	00 001 0000000 0 0 0 1100 00100001 010 00
			25 Hz	0x22	0x0801845C	00 001 0000000 0 0 0 1100 00100010 111 00
			50 Hz	0x23	0x08018470	00 001 0000000 0 0 0 1100 00100011 100 00
			100 Hz	0x24	0x08018498	00 001 0000000 0 0 0 1100 00100100 110 00
			200 Hz	0x25	0x080184B4	00 001 0000000 0 0 0 1100 00100101 101 00
			400 Hz	0x26	0x080184C0	00 001 0000000 0 0 0 1100 00100110 000 00
			500 Hz	0x27	0x080184EC	00 001 0000000 0 0 0 1100 00100111 011 00
		3rd	1 Hz	0x28	0x08018510	00 001 0000000 0 0 0 1100 00101000 100 00
			10 Hz	0x29	0x0801853C	00 001 0000000 0 0 0 1100 00101001 111 00
			25 Hz	0x2A	0x08018548	00 001 0000000 0 0 0 1100 00101010 010 00
			50 Hz	0x2B	0x08018564	00 001 0000000 0 0 0 1100 00101011 001 00
			100 Hz	0x2C	0x0801858C	00 001 0000000 0 0 0 1100 00101100 011 00
			200 Hz	0x2D	0x080185A0	00 001 0000000 0 0 0 1100 00101101 000 00
			400 Hz	0x2E	0x080185D4	00 001 0000000 0 0 0 1100 00101110 101 00
			500 Hz	0x2F	0x080185F8	00 001 0000000 0 0 0 1100 00101111 110 00
		4th	1 Hz	0x30	0x08018600	00 001 0000000 0 0 0 1100 00110000 000 00
			10 Hz	0x31	0x0801862C	00 001 0000000 0 0 0 1100 00110001 011 00
			25 Hz	0x32	0x08018658	00 001 0000000 0 0 0 1100 00110010 110 00
			50 Hz	0x33	0x08018674	00 001 0000000 0 0 0 1100 00110011 101 00
			100 Hz	0x34	0x0801869C	00 001 0000000 0 0 0 1100 00110100 111 00
			200 Hz	0x35	0x080186B0	00 001 0000000 0 0 0 1100 00110101 100 00
			400 Hz	0x36	0x080186C4	00 001 0000000 0 0 0 1100 00110110 001 00
			500 Hz	0x37	0x080186E8	00 001 0000000 0 0 0 1100 00110111 010 00
	Disable 1'b0	2nd	1 Hz	0x00	0x0801800C	00 001 0000000 0 0 0 1100 00000000 011 00
			10 Hz	0x01	0x08018020	00 001 0000000 0 0 0 1100 00000001 000 00
			25 Hz	0x02	0x08018054	00 001 0000000 0 0 0 1100 00000010 101 00
			50 Hz	0x03	0x08018078	00 001 0000000 0 0 0 1100 00000011 110 00
			100 Hz	0x04	0x08018090	00 001 0000000 0 0 0 1100 00000100 100 00
			200 Hz	0x05	0x080180BC	00 001 0000000 0 0 0 1100 00000101 111 00
			400 Hz	0x06	0x080180C8	00 001 0000000 0 0 0 1100 00000110 010 00
			500 Hz	0x07	0x080180E4	00 001 0000000 0 0 0 1100 00000111 001 00
		3rd	1 Hz	0x08	0x08018118	00 001 0000000 0 0 0 1100 00001000 110 00
			10 Hz	0x09	0x08018134	00 001 0000000 0 0 0 1100 00001001 101 00
			25 Hz	0x0A	0x08018140	00 001 0000000 0 0 0 1100 00001010 000 00
			50 Hz	0x0B	0x0801816C	00 001 0000000 0 0 0 1100 00001011 011 00
			100 Hz	0x0C	0x08018184	00 001 0000000 0 0 0 1100 00001100 001 00
			200 Hz	0x0D	0x080181A8	00 001 0000000 0 0 0 1100 00001101 010 00
			400 Hz	0x0E	0x080181DC	00 001 0000000 0 0 0 1100 00001110 111 00
			500 Hz	0x0F	0x080181F0	00 001 0000000 0 0 0 1100 00001111 100 00
		4th	1 Hz	0x10	0x08018208	00 001 0000000 0 0 0 1100 00010000 010 00
			10 Hz	0x11	0x08018224	00 001 0000000 0 0 0 1100 00010001 001 00
			25 Hz	0x12	0x08018250	00 001 0000000 0 0 0 1100 00010010 100 00
			50 Hz	0x13	0x0801827C	00 001 0000000 0 0 0 1100 00010011 111 00
			100 Hz	0x14	0x08018294	00 001 0000000 0 0 0 1100 00010100 101 00
			200 Hz	0x15	0x080182B8	00 001 0000000 0 0 0 1100 00010101 110 00
			400 Hz	0x16	0x080182CC	00 001 0000000 0 0 0 1100 00010110 011 00
			500 Hz	0x17	0x080182E0	00 001 0000000 0 0 0 1100 00010111 000 00
2'b10 +/- 460 [°/s]	Enable 1'b1	2nd	1 Hz	0xa0	0x08019408	00 001 0000000 0 0 0 1100 10100000 010 00
			10 Hz	0xa1	0x08019424	00 001 0000000 0 0 0 1100 10100001 001 00
			25 Hz	0xa2	0x08019450	00 001 0000000 0 0 0 1100 10100010 100 00
			50 Hz	0xa3	0x0801947C	00 001 0000000 0 0 0 1100 10100011 111 00
			100 Hz	0xa4	0x08019494	00 001 0000000 0 0 0 1100 10100100 101 00
			200 Hz	0xa5	0x080194B8	00 001 0000000 0 0 0 1100 10100101 110 00
			400 Hz	0xa6	0x080194CC	00 001 0000000 0 0 0 1100 10100110 011 00
			500 Hz	0xa7	0x080194E0	00 001 0000000 0 0 0 1100 10100111 000 00
		3rd	1 Hz	0xa8	0x0801951C	00 001 0000000 0 0 0 1100 10101000 111 00
			10 Hz	0xa9	0x08019530	00 001 0000000 0 0 0 1100 10101001 100 00
			25 Hz	0xaA	0x08019544	00 001 0000000 0 0 0 1100 10101010 001 00
			50 Hz	0xaB	0x08019568	00 001 0000000 0 0 0 1100 10101011 010 00
			100 Hz	0xaC	0x08019580	00 001 0000000 0 0 0 1100 10101100 000 00
			200 Hz	0xaD	0x080195AC	00 001 0000000 0 0 0 1100 10101101 011 00
			400 Hz	0xaE	0x080195D8	00 001 0000000 0 0 0 1100 10101110 110 00
			500 Hz	0xaF	0x080195F4	00 001 0000000 0 0 0 1100 10101111 101 00
		4th	1 Hz	0xb0	0x0801960C	00 001 0000000 0 0 0 1100 10110000 011 00
			10 Hz	0xb1	0x08019620	00 001 0000000 0 0 0 1100 10110001 000 00
			25 Hz	0xb2	0x08019654	00 001 0000000 0 0 0 1100 10110010 101 00
			50 Hz	0xb3	0x08019678	00 001 0000000 0 0 0 1100 10110011 110 00
			100 Hz	0xb4	0x08019690	00 001 0000000 0 0 0 1100 10110100 100 00
			200 Hz	0xb5	0x080196BC	00 001 0000000 0 0 0 1100 10110101 111 00
			400 Hz	0xb6	0x080196C8	00 001 0000000 0 0 0 1100 10110110 010 00
			500 Hz	0xb7	0x080196E4	00 001 0000000 0 0 0 1100 10110111 001 00
	Disable 1'b0	2nd	1 Hz	0x80	0x08019000	00 001 0000000 0 0 0 1100 10000000 000 00
			10 Hz	0x81	0x0801902C	00 001 0000000 0 0 0 1100 10000001 011 00
			25 Hz	0x82	0x08019058	00 001 0000000 0 0 0 1100 10000010 110 00
			50 Hz	0x83	0x08019074	00 001 0000000 0 0 0 1100 10000011 101 00
			100 Hz	0x84	0x0801909C	00 001 0000000 0 0 0 1100 10000100 111 00
			200 Hz	0x85	0x080190B0	00 001 0000000 0 0 0 1100 10000101 100 00
			400 Hz	0x86	0x080190C4	00 001 0000000 0 0 0 1100 10000110 001 00
			500 Hz	0x87	0x080190E8	00 001 0000000 0 0 0 1100 10000111 010 00
		3rd	1 Hz	0x88	0x08019114	00 001 0000000 0 0 0 1100 10001000 101 00
			10 Hz	0x89	0x08019138	00 001 0000000 0 0 0 1100 10001001 110 00
			25 Hz	0x8A	0x0801914C	00 001 0000000 0 0 0 1100 10001010 011 00
			50 Hz	0x8B	0x08019160	00 001 0000000 0 0 0 1100 10001011 000 00
			100 Hz	0x8C	0x08019188	00 001 0000000 0 0 0 1100 10001100 010 00
			200 Hz	0x8D	0x080191A4	00 001 0000000 0 0 0 1100 10001101 001 00
			400 Hz	0x8E	0x080191D0	00 001 0000000 0 0 0 1100 10001110 100 00
			500 Hz	0x8F	0x080191FC	00 001 0000000 0 0 0 1100 10001111 111 00
		4th	1 Hz	0x90	0x08019204	00 001 0000000 0 0 0 1100 10010000 001 00
			10 Hz	0x91	0x08019228	00 001 0000000 0 0 0 1100 10010001 010 00
			25 Hz	0x92	0x0801925C	00 001 0000000 0 0 0 1100 10010010 111 00
			50 Hz	0x93	0x08019270	00 001 0000000 0 0 0 1100 10110011 110 00
			100 Hz	0x94	0x08019298	00 001 0000000 0 0 0 1100 10010100 110 00
			200 Hz	0x95	0x080192B4	00 001 0000000 0 0 0 1100 10010101 101 00
			400 Hz	0x96	0x080192C0	00 001 0000000 0 0 0 1100 10010110 000 00
			500 Hz	0x97	0x080192EC	00 001 0000000 0 0 0 1100 10010111 011 00
read					0x08098000	00 001 0000000 1 0 0 1100 00000000 000 00

Table 6.5 Example of register access for trigger latch function, trigger pin setting in INT2 and Saturation flag in INT1

Register access	W/R	Write data	Hex command	Binary command
SelONT [Address: 0x1E]	Write	0x84	0x0803D088	00 001 0000000 0 0 1 1110 10000100 010 00
	Read	-	0x080BC014	00 001 0000000 1 0 1 1110 00000000 101 00
Trigger data latch [Address: 0x0B]	Write	0x40	0x0801680C	00 001 0000000 0 0 0 1011 01000000 011 00
	Read	-	0x08096010	00 001 0000000 1 0 0 1011 00000000 100 00
Saturation flag control [Address: 0x02]	Write	0x0D	0x080041A4	00 001 0000000 0 0 0 0010 00001101 001 00
	Read	-	0x0808400C	00 001 0000000 1 0 0 0010 00000000 011 00

Table 6.6 Example of register access for command latch function

Register access	W/R	Write data	Hex command	Binary command
Command data latch [Address: 0x0B]	Write	0x20	0x08016414	00 001 0000000 0 0 0 1011 00100000 101 00
	Read	-	0x08096010	00 001 0000000 1 0 0 1011 00000000 100 00
Data latch [Address: 0x15]	Write	0x01	0x0802A034	00 001 0000000 0 0 1 0101 00000001 101 00
	Read	-	0x080AA014	00 001 0000000 1 0 1 0101 00000000 101 00
Latch data release [Address: 0x15]	Write	0x00	0x0802A018	00 001 0000000 0 0 1 0101 00000000 110 00
	Read	-	0x080AA014	00 001 0000000 1 0 1 0101 00000000 101 00

Table 6.7 Example of register access for DRY setting in INT2 and Saturation flag in INT1

Register access	W/R	Write data	Hex command	Binary command
SelONT [Address: 0x1E]	Write	0x14	0x0803C280	00 001 0000000 0 0 1 1110 00010100 000 00
	Read	-	0x080BC014	00 001 0000000 1 0 1 1110 00000000 101 00
Saturation flag control [Address: 0x02]	Write	0x0D	0x080041A4	00 001 0000000 0 0 0 0010 00001101 001 00
	Read	-	0x0808400C	00 001 0000000 1 0 0 0010 00000000 011 00

6.1.7. Example

[Example of command]

in-frame, command	0x 00 00 00 04	OK
in-frame, command	0x FF FF FF F7	OK
in-frame, command	0x 0F 0F 0F 13	OK
in-frame, command	0x 0F F2 C8 E7	OK
in-frame, response	0x 00 00 00 06	*OK*
in-frame, response	0x FF FF FF FC	*OK*
in-frame, response	0x 0F 0F 0F 0A	*OK*
in-frame, response	0x 0F F2 C8 FE	*OK*

[Sample program]

```
class CRCGenerator:
    def __init__(self, data):
        self.tmpDat_a = data
        self.intermediate_CRCs = [0] * 30   # 27 + 3

    def calculate_crc(self):

        self.intermediate_CRCs[0] = (1 << 2) + ((1 ^ 1) << 1) + (1 ^ self.tmpDat_a[0])
        for i in range(1, 30):
            prevCRC = self.intermediate_CRCs[i - 1]
            bitShifted = self.tmpDat_a[i]
            self.intermediate_CRCs[i] = (((prevCRC>>1)&1)<<2) + (((prevCRC&1)^((prevCRC>>2)&1))<< 1) +
(((prevCRC>>2)&1) ^ bitShifted)
            print(f"CRC{i}: {self.intermediate_CRCs[i]}")

        return self.intermediate_CRCs[29]

def int_to_bit_array(n, length=32):
    return [(n >> i) & 1 for i in range(length-1, -1, -1)]


def main():
    data = [0] * 32   # Example of 32-bit data input
    data = int_to_bit_array(value)
    print(f"data: {data}")

    generator = CRCGenerator(data)
    CRC = generator.calculate_crc()
    # print(f"CRC: {CRC}")


if __name__ == "__main__":
    main()
```

6.2. Timing specifications

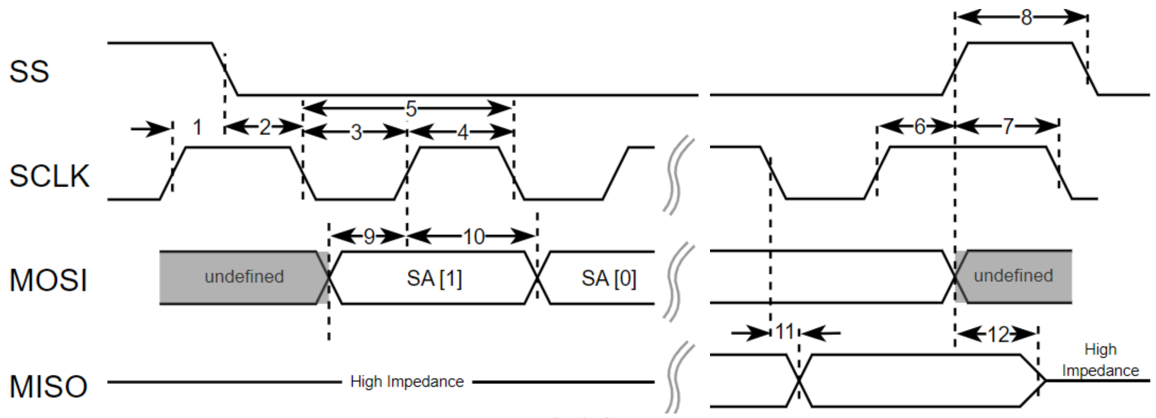


Figure 6.9 SafeSPI timing diagram

Table 6.8 SafeSPI AC specifications

(V_{DDM} = 2.7 V ~ 3.6 V, V_{DDI} = 1.65 V ~ 3.6 V, GND = 0 V, Ta = -40 °C ~ +105 °C)

Parameter	Symbol	Condition	VDDI ≤ 2.4 V		VDDI > 2.4 V		Unit
			Min	Max	Min	Max	
SCK disable lead time	1		10	-	10	-	ns
SCK enable lead time	2		15	-	15	-	ns
SCK low time	3		90	-	40	-	ns
SCK high time	4		90	-	40	-	ns
SCK cycle time	5		200	-	100	-	ns
SCK enable lag time	6		20	-	20	-	ns
SCK disable lag time	7		10	-	10	-	ns
Sequential transfer delay	8		30	-	30	-	ns
MOSI data setup time	9		10	-	10	-	ns
MOSI data hold time	10		10	-	10	-	ns
MISO data valid time	11	Max. C_L = 30 pF	-	80	-	50	ns

6.3. Time constraints for issuing commands

6.3.1. SafeSPI communication

Table 6.9 Time constraints for issuing commands in SPI communication

(V_{DDM} = 2.7 V ~ 3.6 V, V_{DDI} = 1.65 V ~ 3.6 V, GND = 0 V, Ta = -40 °C ~ +105 °C)

Parameter	Symbol	Min.	Typ.	Max.	Unit
Sleep-In execution wait time	t_{SLPIN}	10	-	-	µs
Sleep-Out execution wait time (Note)	t_{SLPOUT}	10	-	-	µs

(Note) After sending the Sleep-In command, send the the Sleep-Out command after the command execution wait time has elapsed (t_{SLPOUT}).

7. User command register

Table 7.1 User command register

Address	Register	R/W	Function
0x00	Reserved		
0x01	Reserved		
0x02	SatFlgCtl	R/W	Saturation flag control
0x03	Reserved		
0x04	Reserved		
0x05	Status	R/W	Sleep-In
0x06	ProtState	R/W	Sleep-In control
0x07	SafeSPICrcRd	R	SafeSPI CRC result history
0x08	TempRd	R	Temperature data output
0x09	SafeSPICntRd	R	SafeSPI communication clock count
0x0A	DatAccOn	R	Angular velocity data output
0x0B	DatLatchCom	R/W	Data latch
0x0C	SelFSR	R/W	DSP settings
0x0D	Status read		
0x0E	Reserved		
0x0F	Reserved		
0x10	Reserved		
0x11	Reserved		
0x12	Reserved		
0x13	Reserved		
0x14	Reserved		
0x15	DatLatchCom	R/W	Command data latch
0x16	Reserved		
0x17	Reserved		
0x18	Reserved		
0x19	Reserved		
0x1A	ProtSoftR	R/W	Software reset control
0x1B	SoftReset	R/W	Software reset
0x1C	OutFormat	R/W	Select OutFormat
0x1D	SelMISO	R/W	MISO pin control
0x1E	SelINT	R/W	INT1/INT2 pin control
0x1F	Reserved		

R: Register read

R / W: Register read and register write

(Note) Do not change the reserved registers, writing to these registers may damage the device.

7.1. Saturation flag control

The Saturation flag can be controlled using the register SatFlgCtl at address “0x02” in Table 7.2. Regarding to its output setting, refer to Section 7.10.

Table 7.2 Saturation flag control

Address	Bit	Register	Default	R/W	Function	Settings
0x02	7	Reserved	0	R	Reserved	Reserved
	6	Reserved	0	R	Reserved	Reserved
	5	Reserved	0	R	Reserved	Reserved
	4	Reserved	0	R	Reserved	Reserved
	3	SatFlgCtl	0	R/W	Saturation flag output select	0xD: INT1 0xE: INT2 (Refer to Section 7.10)
	2		0	R/W		
	1		0	R/W		
	0		0	R/W		

7.2. Sleep-In / Sleep-Out control

The software reset is executed in the following procedure.

1. Set to ”0x59” in the the address ”0x06” register. Sleep-In control signal is valid.
2. Set to ”0x01” in the the address ”0x05” register. Sleep-In is executed.
3. Set to ”0x00” in the the address ”0x05” register. Sleep-Out is executed and the status returns to normal mode.

During the Sleep-In, only register access is possible, and angular velocity data and temperature sensor data is unavailable.

If you transfer from Sleep-In to Sleep-Out, the DSP function is initialized. If you change the DSP characteristics, you should execute Sleep-In and Sleep-Out.

Table 7.3 Sleep-In /Sleep-Out control

Address	Bit	Register	Default	R/W	Function	Settings
0x05	7	Reserved	0	R	Reserved	Reserved
	6	Reserved	0	R	Reserved	Reserved
	5	Reserved	0	R	Reserved	Reserved
	4	Reserved	0	R	Reserved	Reserved
	3	Reserved	0	R	Reserved	Reserved
	2	Reserved	0	R	Reserved	Reserved
	1	Reserved	0	R	Reserved	Reserved
	0	SlpIn	0	R/W	Sleep-In control	0: Sleep-Out 1: Sleep-In
0x06	7	ProtState[7]	0	R/W	Sleep-In control enable	When 0x59 is written, Sleep-In control is valid.
	6	ProtState[6]	0	R/W		
	5	ProtState[5]	0	R/W		
	4	ProtState[4]	0	R/W		
	3	ProtState[3]	0	R/W		
	2	ProtState[2]	0	R/W		
	1	ProtState[1]	0	R/W		
	0	ProtState[0]	0	R/W		

7.3. DSP setting

This register can select the scale factor range, notch filter control, LPF order and LPF cutoff frequency.

Table 7.4 DSP setting

Address	Bit	Register	Default	R/W	Function	Settings
0x0C	7	SelFSR[1]	0	R/W	Full scale range select	SelFSR[1:0] 00 : +/-115°/s (Default) 01 : Not available 10 : +/-460°/s 11 : Not available
	6	SelFSR[0]	0	R/W		
	5	EnbNF	1	R/W	Notch filter for the detuning frequency	0 : Disable 1 : Enable (Default)
	4	LpfOrder[1]	0	R/W	LPF order select	LpfOrder [1:0] 00 : 2nd 01 : 3rd(Default) 10 : 4th 11 : Not available
	3	LpfOrder[0]	1	R/W		
	2	LpfFc[2]	0	R/W	LPF f_c select	LpfFc[2:0] 000 : 1Hz 001 : 10Hz 010 : 25Hz 011 : 50Hz(Default) 100 : 100Hz 101 : 200Hz 110 : 400Hz 111 : 500Hz
	1	LpfFc[1]	1	R/W		
	0	LpfFc[0]	1	R/W		

(Note) When changing settings, set the initial values except for the changed bits. Note that settings can be changed at the same time for bits in the same register (same address).

(Note) It is recommended to initialize the DSP registers by Sleep-In / Sleep-Out before using the sensor. Please refer to the Section7.2.

7.4. Status read

This register can monitor the status in the sensor.

Table 7.5 Sensor status flag

Address	Bit	Register	Default	R/W	Function	Settings
0x0D	7	Reserved	0	R	Reserved	Reserved
	6	Reserved	0	R	Reserved	Reserved
	5	Reserved	0	R	Reserved	Reserved
	4	Reserved	0	R	Reserved	Reserved
	3	datStatus[3]	0	R	Status monitor flag	H: Normal operation L: Other status
	2	datStatus[2]	0	R	Status monitor flag	H: Test mode L: Other status
	1	datStatus[1]	0	R	Status monitor flag	H: Sleep mode L: Other status
	0	datStatus[0]	0	R	Status monitor flag	H: Initialized term L: Other status

7.5. Communication check

SafeSPI input data comparison CRC result (address: 0x07) is a register that stores the comparison result of CC2:0. By reading this register, it is possible to check the comparison result between the CRC data sent to CC2:0 and the CRC calculated inside the IC. Details of register data are shown below.

Table 7.6 SafeSPI input data comparison CRC results

Address	Bit	Register name	Initial value	R/W	Function	Setting details
0x07	7	CRC_7	0	R	CC2:0 Comparing results 7	Compare H: OK L: NG
	6	CRC_6	0	R	CC2:0 Comparing results 6	
	5	CRC_5	0	R	CC2:0 Comparing results 5	
	4	CRC_4	0	R	CC2:0 Comparing results 4	
	3	CRC_3	0	R	CC2:0 Comparing results 3	
	2	CRC_2	0	R	CC2:0 Comparing results 2	
	1	CRC_1	0	R	CC2:0 Comparing results 1	
	0	CRC_0	0	R	CC2:0 Comparing results 0	

When this register is read, the CC2:0 comparison result from the previous communication is stored in bit 0, and the time before the previous communication was stored in bit 1. Since the comparison results are shifted for each communication, it is possible to check the comparison results for the past 8 times.

SafeSPI communication count (address: 0x09) counts the number of times SafeSPI communicated. This count value is incremented only when SS goes low and communication ends normally with 32 clocks. For example, if the SS changes from L to H at a clock number of 31 or 33, it will not be counted up. By reading this value, it is possible to check whether communication was successful during debugging, etc.

The following shows the clock count number of SafeSPI communication and the SafeSPICntRd status.

Table 7.7 SafeSPI communication clock count and SafeSPICntRd status

Clock count number	SafeSPICntRd status	Remarks (register write conditions)
0~30	Don't count up	No register writes are performed
31	Don't count up	If the CRC is normal, register writing is performed.
32(normal)	Count up	If the CRC is normal, register writing is performed.
33	Don't count up	If the CRC is normal, register writing is performed.

7.6. Data latch control

The data latch function is a function that can latch the angular velocity data at any timing and read the latch data. The data latch function can be enabled by using the register with the address "0x0B" shown in Table 7.8. The trigger data latch function is enabled by setting “EnbIntLatch” to “1”. Also, the command data latch function is enabled by setting “EnbCmdTrg” to “1”.

It is shown in the normal angular velocity readout timing chart at Figure 7.1. When the data latch function is disabled, when the command for reading the angular velocity request is inputted the data at the time is outputted as described in Figure 7.1.

On the other hand, the data latch function latches internal data at any time using a trigger signal or command. Latch data will be read as angular velocity data in the subsequent angular velocity reading. Note that the latched read data will not be updated unless a new latch operation is performed.

Table 7.8 Data latch setting

Address	Bit	Register	Default	R/W	Function	Settings
0x0B	7	Reserved	0	R/W	Reserved	Reserved
	6	EnbIntLatch	0	R/W	Trigger latch enabled	0: Disable(Default) 1: Enable
	5	EnbCmdTrg	0	R/W	Command data latch function enabled	0: Disable(Default) 1: Enable
	4	Reserved	0	R	Reserved	Reserved
	3	Reserved	0	R	Reserved	Reserved
	2	Reserved	0	R	Reserved	Reserved
	1	Reserved	0	R	Reserved	Reserved
	0	Reserved	0	R	Reserved	Reserved

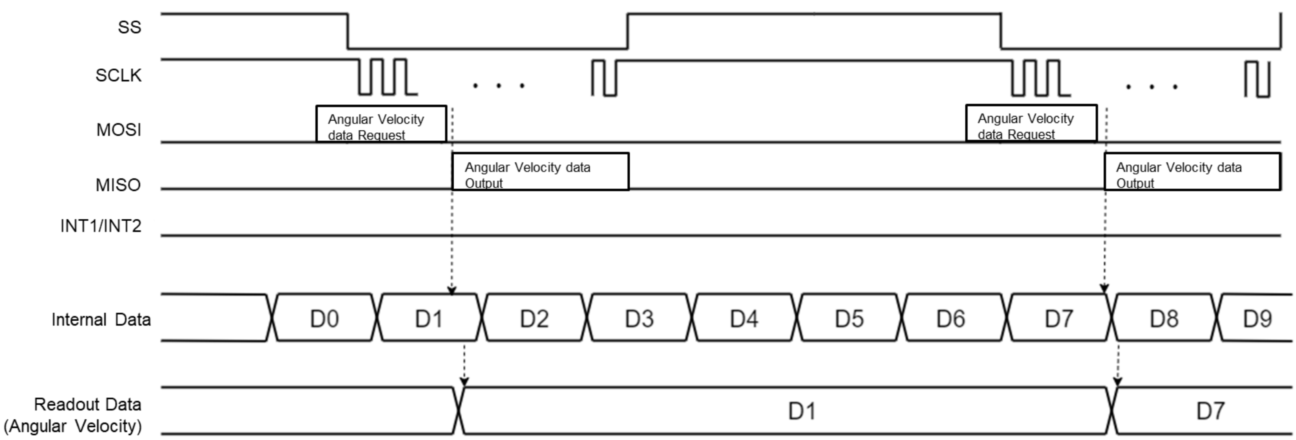


Figure 7.1 Normal angular rate read timing chart

7.6.1. Trigger data latch function

It is shown the timing chart of the trigger data latch function in the Figure 7.2. When the H pulse trigger signal is inputted to INT1/INT2, the Internal data of the angular velocity data is latched. After the data is latched, the latched data is outputted when the angular velocity request is inputted. After that, the read data is not updated unless a new trigger signal is inputted.

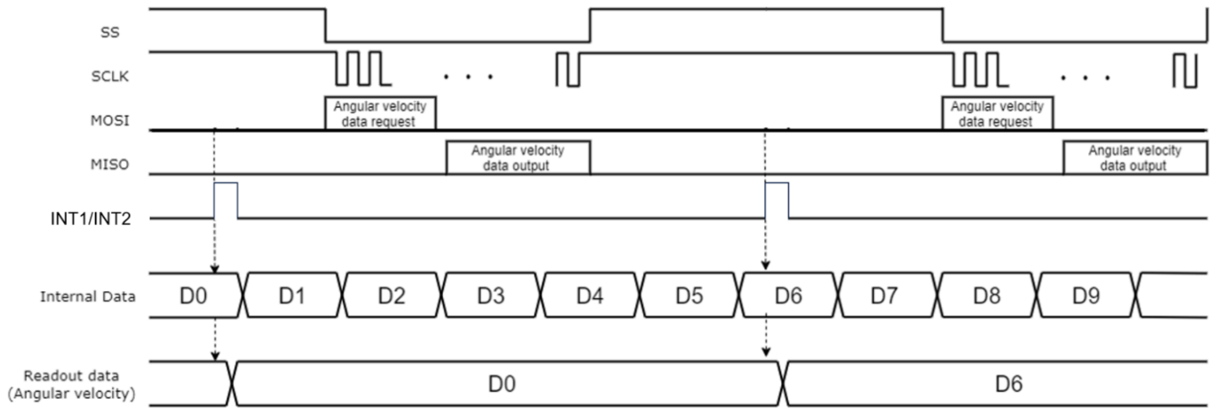


Figure 7.2 Trigger data latch timing chart

7.6.2. Command data latch function

The command data latch function is to latch the internal angular rate data by setting DatLatchCom of the address "0x15" in "1"(Table 7.9). After the data is latched, the latched data is outputted when the angular velocity request is inputted. After that, the read data will not be updated unless a new latch command is executed. Therefore, if you want to latch the data again, set DatLatchCom to "0" once, and then set DatLatchCom to "1".

Table 7.9 Data latch command control

Address	Bit	Register	Default	Type	Function	Settings
0x15	7	Reserved	0	R	Reserved	Reserved
	6	Reserved	0	R	Reserved	Reserved
	5	Reserved	0	R	Reserved	Reserved
	4	Reserved	0	R	Reserved	Reserved
	3	Reserved	0	R	Reserved	Reserved
	2	Reserved	0	R	Reserved	Reserved
	1	Reserved	0	R	Reserved	Reserved
	0	DatLatchCom	0	R/W	Command data latch	0→1: Data latch execution

(Note 1) When changing the setting, set the initial value except for the change bit. If the bits are in the same register (same address), the settings can be changed at the same time.
(Note 2) Do not change the Reserved register and use the default value.

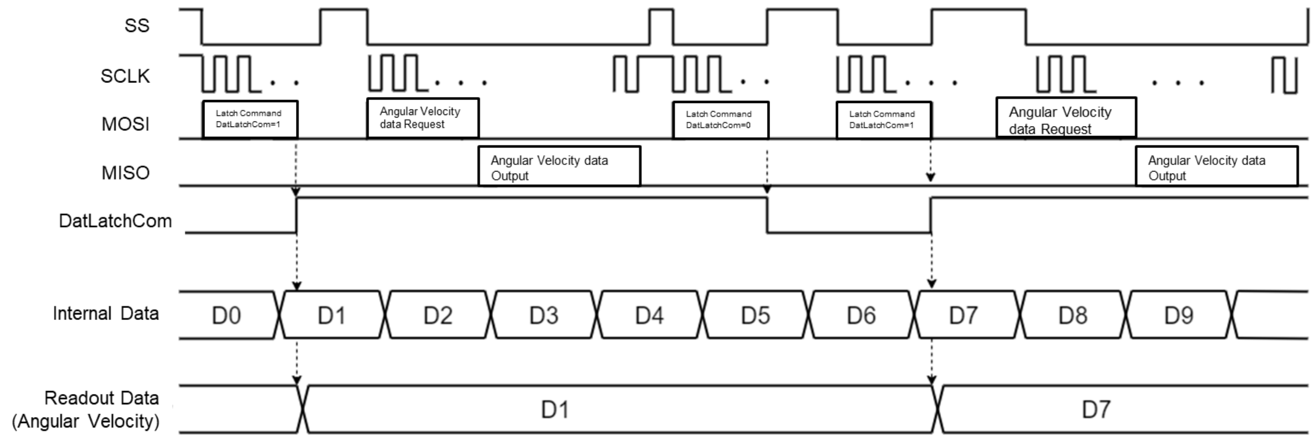


Figure 7.3 Data command latch timing chart

7.7. Software reset control / Software reset

The software reset is executed in the following procedure.

1. Set to ”0x59” in the the address ”0x1A” register. Softawre reset signal is valid.
2. Set to ”0x01” in the the address ”0x1B” register. Softawre reset is executed and the data in the the address ”0x1B” return to ”0x00”.

The user command register shown in Table 7.1 is initialized (set to the default value).

Table 7.10 Software reset control

Address	Bit	Register	Default	Type	Function	Settings
0x1A	7	ProtSoftR[7]	0	R/W	Software reset control.	0x59 Software reset signal is valid.
	6	ProtSoftR[6]	0	R/W		
	5	ProtSoftR[5]	0	R/W		
	4	ProtSoftR[4]	0	R/W		
	3	ProtSoftR[3]	0	R/W		
	2	ProtSoftR[2]	0	R/W		
	1	ProtSoftR[1]	0	R/W		
	0	ProtSoftR[0]	0	R/W		
0x1B	7	Reserved	0	R	Reserved	Reserved
	6	Reserved	0	R	Reserved	Reserved
	5	Reserved	0	R	Reserved	Reserved
	4	Reserved	0	R	Reserved	Reserved
	3	Reserved	0	R	Reserved	Reserved
	2	Reserved	0	R	Reserved	Reserved
	1	Reserved	0	R	Reserved	Reserved
	0	SoftReset	0	R/W	Software reset signal	0→1: Software reset execution

(Note 1) When changing the setting, set the initial value except for the change bit. If the bits are in the same register (same address), the settings can be changed at the same time.

(Note 2) Do not change the Reserved register and use the default value.

7.8. Output data format

In this register, the output format of the angular velocity will be selected from the 16-bit or 24-bit.

Table 7.11 Select output data format

Address	Bit	Register	Default	R/W	Function	Settings
0x1C	7	Reserved	0	R	Reserved	Reserved
	6	Reserved	0	R	Reserved	Reserved
	5	Reserved	0	R	Reserved	Reserved
	4	Reserved	0	R	Reserved	Reserved
	3	Reserved	0	R	Reserved	Reserved
	2	SelGyroOut	0	R/W	Select the output data format	0: 16-bit (Default) 1: 24-bit
	1	Reserved	0	R	Reserved	Reserved
	0	Reserved	0	R	Reserved	Reserved

7.9. MISO pin control

The MISO Pin control is the address "0x1D" in the Table 7.12. The MISO output is changed by writing the "SelMISO[1:0]". The pin condition is shown in Table 7.13.

Table 7.12 Control of the MISO pin

Address	Bit	Register	Default	Type	Function	Settings
0x1D	7	Reserved	0	R	Reserved	Reserved
	6	Reserved	0	R	Reserved	Reserved
	5	Reserved	0	R	Reserved	Reserved
	4	Reserved	0	R	Reserved	Reserved
	3	Reserved	0	R	Reserved	Reserved
	2	Reserved	0	R	Reserved	Reserved
	1	SelMISO[1]	1	R/W	MISO pin status select	(Note 1)
	0	SelMISO[0]	0	R/W		

Table 7.13 Condition of the MISO pin control

Mode	SelMISO[1]	SelMISO[0]	SS	MISO
SafeSPI	X	X	0	Output
	0	0	1	Output ”L” level
	0	1	1	Output ”H” level
	1	X	1	High-Z

(Note 1) Initial value is ”1” in the SelMISO[1] and it is ”0” in the SelMISO[0].
(Note 2) In case of the readings the pin outputs, in the other status it is High-Z.

7.10. Setting of the INT1 and INT2

This register can select the function in INT1 pin and INT2 pin. The control of INT1 pin and INT2 pin is shown in the Table 7.15.

Regarding to external trigger mode control, refer to Section 7.6.1, regarding to Saturation flag, refer to Section 8.2. DRY(Data ready) is a data updating flag.

Table 7.14 SelONT

Address	Bit	Register	Default	Type	Function	Settings
0x1E	7	Int2Trg	0	R/W	Extarnal trigger mode control in INT2	0: Disable 1: Enable
	6	Int2St	0	R/W	Saturation flag output control in INT2	
	5	Reserved	0	R/W	Reserved	
	4	Int2Dry	0	R/W	Data ready output control in INT2	
	3	Int1Trg	0	R/W	Extarnal trigger mode control in INT1	
	2	Int1St	0	R/W	Saturation flag output control in INT1	
	1	Reserved	0	R/W	Reserved	
	0	Int1Dry	0	R/W	Data ready output control in the INT1	

Table 7.15 Condition of the INT1 and INT2 pin control

Setting mode	Condition of the pin register		Pin status(INT1, INT2)		
	INT1 output setting	INT2 output setting	Default	After register setting	Sleep-In
No setting	Default	Default	High-Z	High-Z	High-Z
DRY output	Address:1E 0x01	Address:1E 0x10	High-Z	Output	Output L “Level”
Satuation flag output	Address:02 0x0D Address:1E 0x04	Address:02 0x0E Address:1E 0x40	High-Z	Output	High-Z
Trigger latch Input	Address:0B 0x40 Address:1E 0x08	Address:0B 0x40 Address:1E 0x80	High-Z	Input	High-Z

8. Diagnosis function
8.1. Error flags
The error flags assign 11 failure diagnosis results to the 16-bit format. The output data rate for the diagnosis is 1 kHz. Please refer to Table 8.1 for the correspondence between read bits and error flags.

Table 8.1 Error flags description

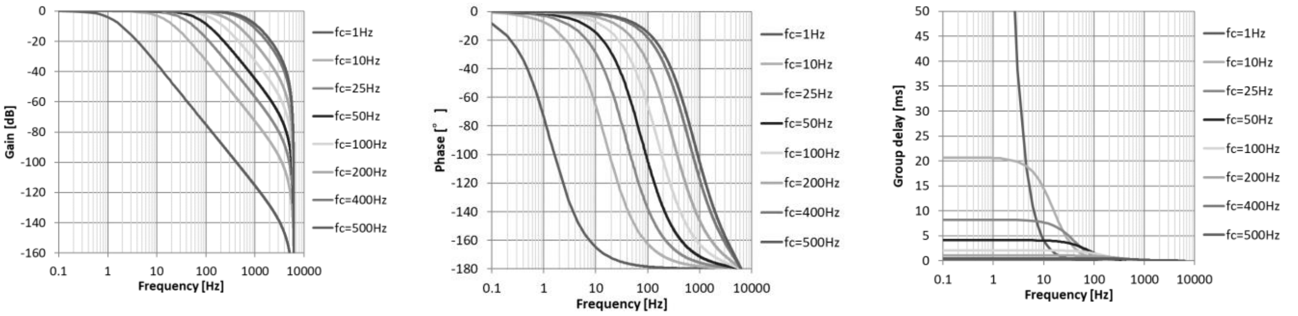
Error flag, EF[15:0]	Diagnosis blocks	Description
EF[0]	Gyro drive block1	0: Normal state 1: Errors related to gyro drive
EF[1]	Gyro drive block2	0: Normal state 1: Errors related to gyro drive
EF[3]	Gyro detection block	0: Normal state 1: Errors related to gyro detection
EF[4]	Temperature sensor block	0: Normal state 1: Errors related to temperature sensor
EF[5]	Power supply block1	0: Normal state 1: Errors related to power supply
EF[6]	Power supply block2	0: Normal state 1: Errors related to power supply
EF[7]	ADC block	0: Normal state 1: Errors related to ADC
EF[8]	Non-volatile memory & register block	0: Normal state 1: Errors related to memory & register
EF[13]	Logic DSP block1	0: Normal state 1: Errors related to Logic
EF[14]	Logic DSP block2	0: Normal state 1: Errors related to Logic
EF[15]	Internal clock block	0: Normal state 1: Errors related to internal clock

8.2. Saturation flag
This saturation flag is the monitor for the saturation of the input stage amplifier, and the flag outputs from INT1 or INT2 pin.

If the amplifier is saturated to excessive shock or vibration, it will output “H” level. While this flag is “H”, the gyro detection block EF[3] diagnosis is stop and the sensor output would be unreliable.

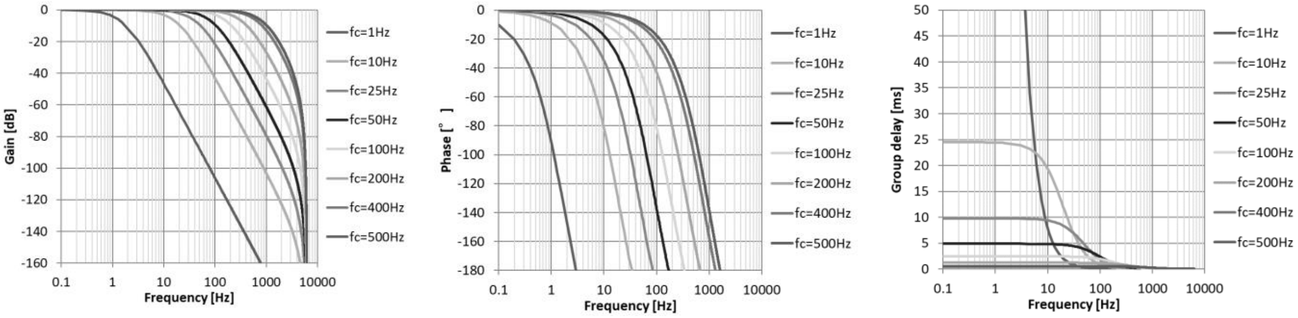
9. Filter characteristics
9.1. Digital filter
9.1.1. Low pass filter (LPF)

Figure 9.1 - Figure 9.3 shows the Bode diagram of the digital LPF. The digital LPF has selectable filter orders (2nd, 3rd and 4th order) and cutoff frequencies (1Hz to 500 Hz). Please refer to Section 7.3 for the setting method.



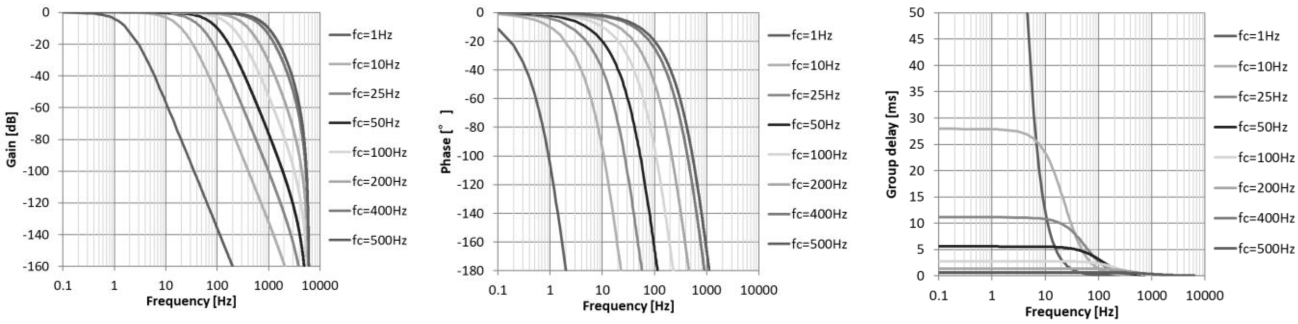
(a) Gain (b) Phase (c) Group delay

Figure 9.1 Bode plots of the selectable digital LPF(2nd)



(a) Gain (b) Phase (c) Group delay

Figure 9.2 Bode plots of the selectable digital LPF(3rd)

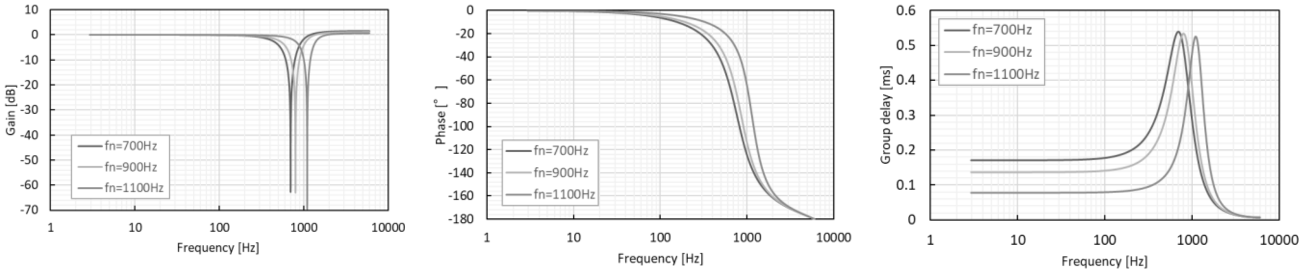


(a) Gain (b) Phase (c) Group delay

Figure 9.3 Bode plots of the selectable digital LPF(4th)

9.1.2. Notch filter (NF)

The notch filter is used to remove the detuned frequency component (see Section 13.3). As the center frequency f_n (700 Hz to 1100 Hz) of the filter is set at the factory individually, it cannot be changed. And it is possible to select whether enable or disable the notch filter. The characteristic of the notch filter is shown in Figure 9.4.



(a) Gain **(b) Phase** **(c) Group delay**

Figure 9.4 Bode plots of the notch filter (NF)

10. Connection circuit example

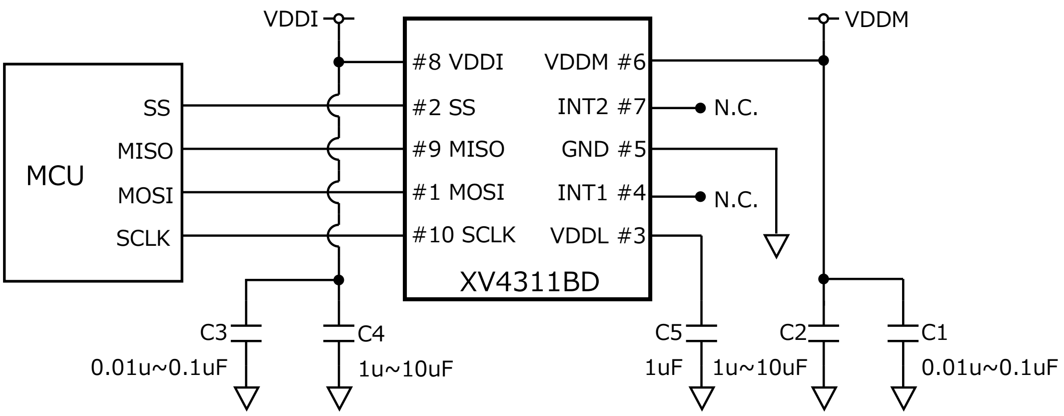


Figure 10.1 Connection example1 (Default: INT1, INT2 no setting)

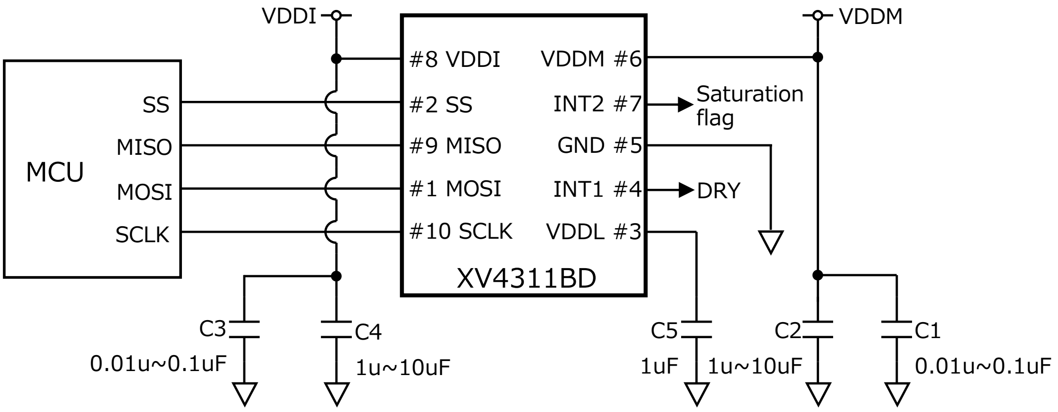


Figure 10.2 Connection example2 (DRY output, Saturation flag output)

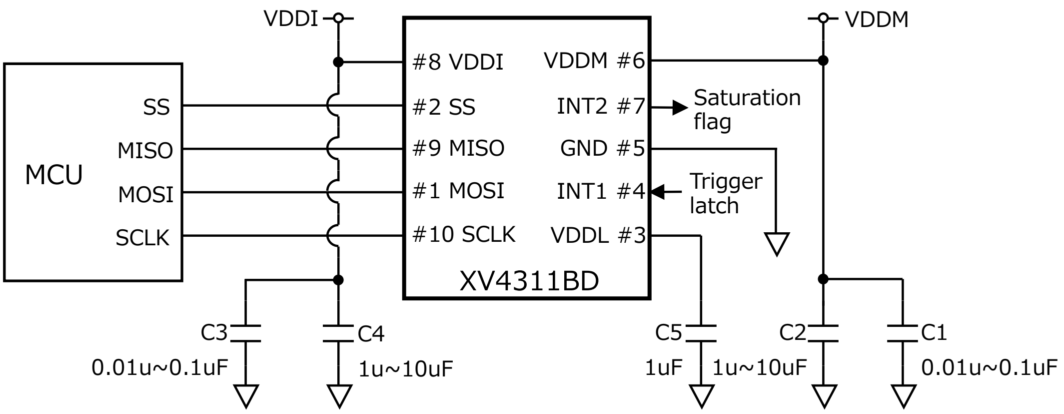


Figure 10.3 Connection example3 (Trigger latch input, Saturation flag output)

(Note) When using the INT1 and INT2 functions, please use the pull-up or pull-down resistors to connect the MCU as necessary.

11. Others

11.1. Electro-Static discharge (ESD)

Reliability test complies with AEC-Q100 Grade 2 Rev.J.

Model	Min.	Standard & Condition
HBM	2000 V	JESD22-A114, V_{DDM}, V_{DDI} and GND reference, 3 times
CDM	500 V	ANSI/ESD S5.3.1-2009, Charged Device Model (CDM), Component Level

11.2. Soldering profile

Soldering heat resistance has been confirmed under heat treatment conditions (JEDEC J-STD-020D.1) in an air reflow furnace.

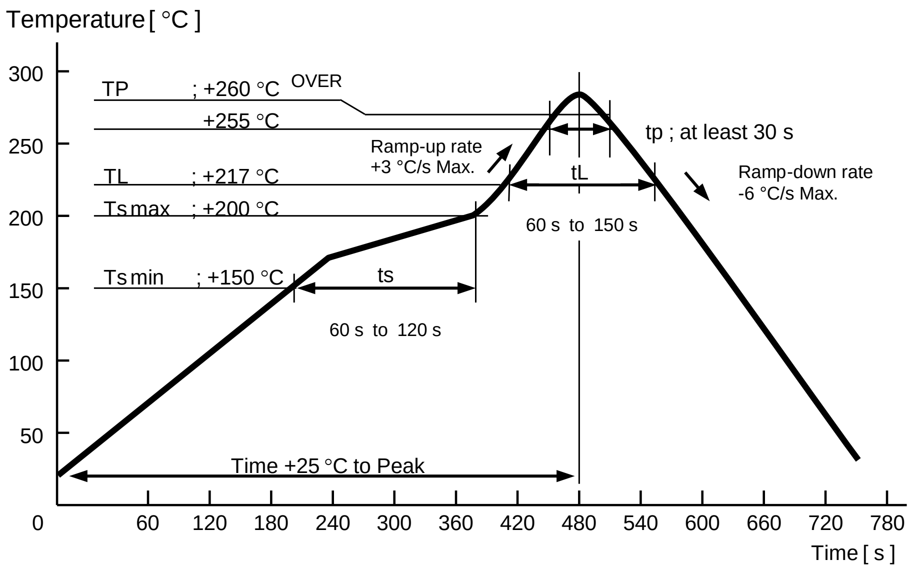


Figure 11.1 Reflow temperature profile

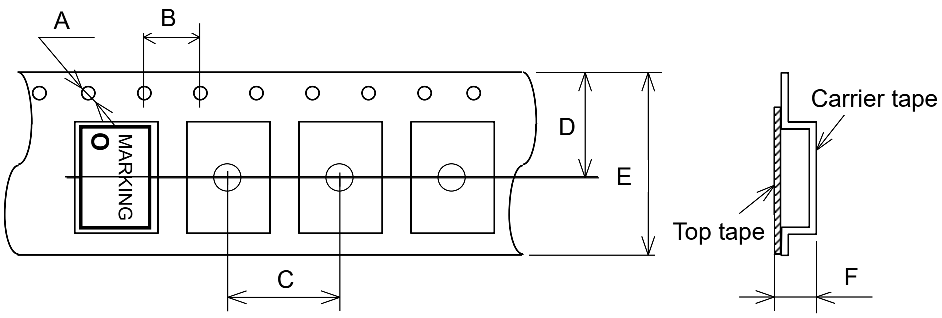
12. Taping information
12.1. Taping specification quantity
The standard quantity in a reel is 2000 pcs.

12.2. Taping
Subject to EIA-481, IEC 60286, JIS C0806.

Table 12.1 Tape and reel materials

Item	Material
Carrier tape	Black conductive PS (polystyrene)
Top tape	Antistatic PET (polyethylene terephthalate)
Reel	Black conductive PS

12.3. Taping dimension



Unit: mm

Symbol	A	B	C	D	E	F
Value	φ1.5	4.0	8.0	7.25	12.0	2.1

Figure 12.1 Tape dimension

12.4. Reel dimension

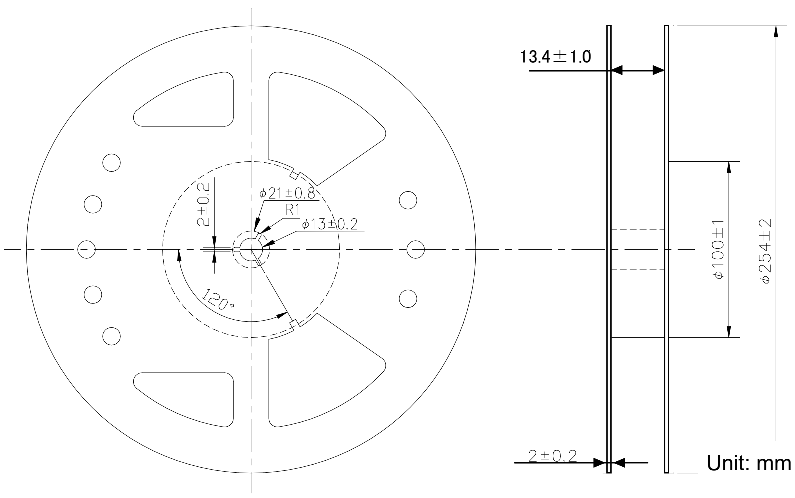


Figure 12.2 Reel dimension

13. Terminology and definitions

13.1. Cross axis sensitivity

The value obtained by dividing the X-axis or Y-axis sensitivity by the Z-axis sensitivity is called Cross axis sensitivity. The X, Y, and Z axis directions are as shown in Figure 13.1.

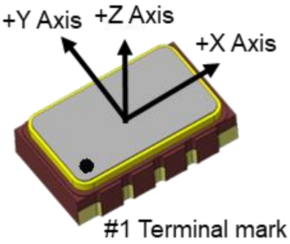


Figure 13.1 Each axis detection

13.2. Drive frequency

The drive frequency is the resonance frequency (drive mode) of the sensor element continuously vibrated to gain the Coriolis force.

13.3. Detuning frequency

The detuning frequency is the natural frequency used for the mechanical-electrical transduction of the Coriolis force. It is the difference from the drive frequency.

14. Handling precautions

★ THIS PRODUCT IS A PRECISION COMPONENT THAT INCLUDES A CRYSTAL DEVICE.
PLEASE PAY ATTENTION TO THE FOLLOWING POINTS WITH HANDLING. ★

1. This crystal product is designed in consideration of shock resistance. However, it may be destroyed depending on the condition of dropping and impact. Please do not use the product, in case it falls accidentally, or it is applied excessive shock, as it cannot be guaranteed after these.
   Do not use after applying impact higher than the acceleration shown below.
   1) Peak acceleration: ±22050 m/s^2 (2250G) or less
   2) Acceleration components above 2kHz*: ±294 m/s^2 (30G) or less
   * Power spectrum in FFT analysis under conditions of 10us (100kSps) and Hanning window function.
2. When the products are mounted, for example, vacuum-chucking, mechanical chucking, mounting on the circuit board and assembling to the vehicle, the excessive shock may make the characteristics of this product change or deteriorate. So please set up the condition so that the shock becomes as small as possible. Please be sure to test FFT analysis above described in your site before using and confirm that there is no influence on the characteristics. And confirm similarly when the condition is changed. And be careful not to collide the products with the machinery or with other circuit board when/after mounting.
3. Anti-static protection circuit is contained in this product. However, when the excessive static electricity is charged, IC may break. So please use conductive ones for packing and carrying containers. And use the soldering iron and the measurement instrument that don’t have high-voltage leakage and take anti-static measures such as grounding when handling.
4. If you apply ultrasonic oscillation (ex. Ultrasonic washing, Printed circuit board cutting) to our product, the sensor element may cause resonant destruction under some use conditions. Since we can not specify your use conditions, we do not pay guarantees the operation of our product after you apply ultrasonic oscillation. If you have no choice but to apply it, please be sure to examine and set up the conditions beforehand.
5. Please reflow up to 3 times. If you make a soldering mistake, please correct it using a soldering iron. In this case, please keep the temperature of the iron tip below +350 °C and within 3 seconds.
6. We recommend our soldering pattern size when you make the circuit board.
7. Please refrain from using the sensors under the condition such as condensation that causes a short circuit.
8. This product drives a sensor element to detect angular velocity. If an external signal with frequency components near the drive frequency or high-order harmonics is applied to the sensor, it may cause fluctuations in the sensor's angular velocity output. Your company is requested to thoroughly check the power supply decoupling measures and serial interface communication frequency settings.
9. This sensor is designed not to be interfered easily even if you operate several sensors closely. However, in some cases, the sensors may be interfered by vibration of circuit board or common impedance of power supply. Please check them before use at your side.
10. The gyro element detuned frequency is 900 Hz (Typ.). Please make your board design to avoid putting the resonance frequency of the board in the detuned frequency. Please also put our part on fixed area of board which is less influence from vibration.
11. To avoid malfunctions caused by induction of other signal lines, please design the circuit pattern so that other signal lines are not located near / above the sensor and the output signal line does not cross the other signal lines.
12. Please check and take measures against the vibration, shock and noise. If you do not mind disclosing your board design information, we can provide our advice for your design.