AN4771

Application note

MEMS motion sensor: L2G2IS ultra-compact two-axis gyroscope for optical image stabilization

Introduction

The L2G2IS is a two-axis MEMS gyroscope for image stabilization applications. It includes a sensing element and an IC interface capable of providing the measured angular rate to the application through an SPI digital interface.

The unique sensing element is manufactured using a dedicated micromachining process developed by STMicroelectronics to produce inertial sensors and actuators on silicon wafers.

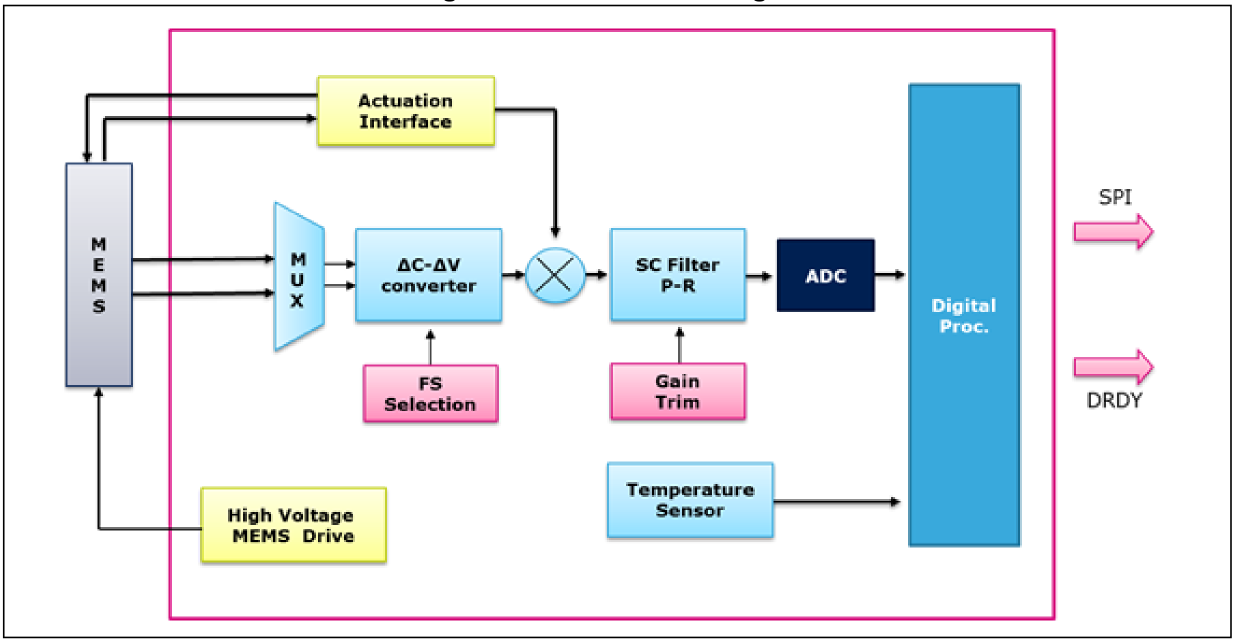
The IC interface is manufactured using a CMOS process that allows a high level of integration to design a dedicated circuit which is trimmed to better match the characteristics of the sensing element.

The L2G2IS is available in a plastic land grid array (LGA) package and can operate over a temperature range of -40 °C to +85 °C.

Contents

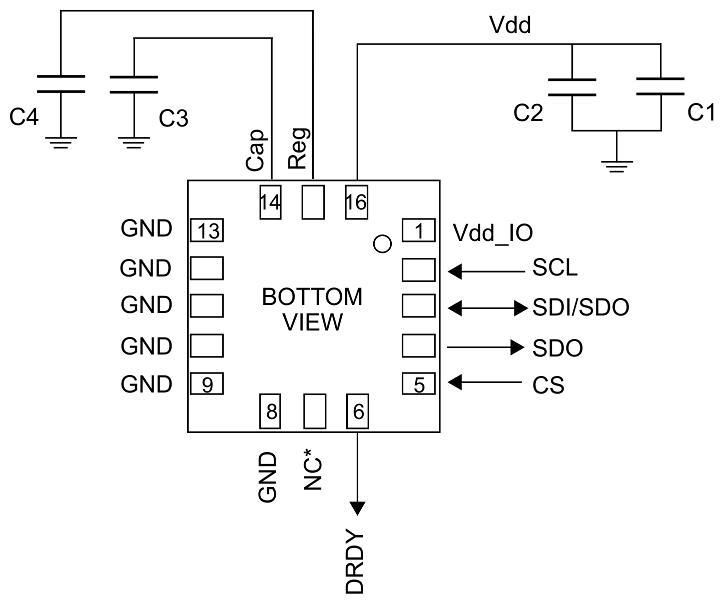
1 Readout chain

Figure 1. L2G2IS block diagram



2 Electrical connections and values for external components

Figure 2. L2G2IS electrical connections



*Leave pin electrically unconnected and soldered to PCB.

Table 1. External components

External component	Value	Purpose
C1	1 µF	Decoupling
C2	100 pF	Decoupling
C3(1)	10 nF (16 V class)	Charge pump
C4	100 nF (5 V class)	Internal regulator

1. This value must guarantee a minimum value of 1 nF under 12 V bias condition.

3 Registers

Table 2. Register address map

Register name	Address	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
WHO_AM_I	00h	1	1	0	1	1	0	0	1
TEMP_OUT_L	01h	Temp3	Temp2	Temp1	Temp0	0	0	0	0
TEMP_OUT_H	02h	Temp11	Temp10	Temp9	Temp8	Temp7	Temp6	Temp5	Temp4
OUT_X_L	03h	XD_7	XD_6	XD_5	XD_4	XD_3	XD_2	XD_1	XD_0
OUT_X_H	04h	XD_15	XD_14	XD_13	XD_12	XD_11	XD_10	XD_9	XD_8
OUT_Y_L	05h	YD_7	YD_6	YD_5	YD_4	YD_3	YD_2	YD_1	YD_0
OUT_Y_H	06h	YD_15	YD_14	YD_13	YD_12	YD_11	YD_10	YD_9	YD_8
STATUS_REG	09h	YXOR	XOR	YOR	0	YXDA	XDA	YDA	0
CTRL_REG1	0Bh	BOOT	P_DRDY	BLE	SIM	ODU	--	PW1	PW0
CTRL_REG2	0Ch	LPF_O	0	0	0	0	HPreset	SWreset	HPF
CTRL_REG3	0Dh	0	ST	0	PP_OD	0	0	DRDY_EN	LPF_D
ORIENT_CONFIG	10	0	0	Sign_x	Sign_y	0	0	0	Orient
OFF_X	11	OFFX7	OFFX6	OFFX5	OFFX4	OFFX3	OFFX2	OFFX1	OFFX0
OFF_Y	12	OFFY7	OFFY6	OFFY5	OFFY4	OFFY3	OFFY2	OFFY1	OFFY0
CTRL_REG4	1F	0	0	0	0	FS	0	0	HPF_BW

4 Operating modes

The L2G2IS features three operating modes, normal mode, sleep mode and power down which are described in the following paragraphs.

4.1 Sleep mode

When the device is set in a sleep mode, the reading chain is completely turned off, while the mass is kept in oscillation, resulting in a lower power consumption than in normal mode. In this condition the device turn-on time is significantly reduced, allowing simple external power cycling.

4.2 Power down

When the device is in power-down mode, almost all internal blocks of the device are switched off to minimize power consumption.The SPI interface is still active to allow communication with the device. The content of the configuration registers is preserved and output data registers are not updated, therefore keeping the last data sampled in memory before going into power-down mode.

4.3 Normal mode

When in normal mode, the angular rates are generated at 9.09 kHz data rate (ODR), while the temperature data are generated at 70 Hz.

To select the operating mode, PW[1:0] bits in CTRL_REG1 (0Bh) are used.

Table 3. Operating selection

PW1	PW0	Operating mode selection
0	0	Power-down
0	1	Power-down
1	0	Sleep mode
1	1	Normal mode

5 Startup sequence

Once the device is powered up, it automatically downloads the calibration coefficients from the embedded Flash to the internal registers. When the boot procedure is completed, i.e. after approximately 15 milliseconds, the device automatically enters power-down mode. To turn on the device and gather angular rate data, it is necessary to set the device in normal mode through the PW[1:0] bits in CTRL_REG1 (0Bh).

The following general-purpose sequence can be used to configure the device:

1. Write CTRL_REG4 -- HPF configuration (only if HPF is used)
2. Write CTRL_REG3* -- Digital LPF configuration
   *If L2G2IS shares the SPI bus with other devices then write bit 5 to 1
3. Write CTRL_REG2 -- Analog LPF configuration and HPF enable
4. Write CTRL_REG1 -- Set the gyro in normal mode
5. Write CTRL_REG2 -- HPF enable reset (only if HPF is used)

5.1 Understanding angular rate data

The measured angular rates are sent to the OUT_X_H (04h), OUT_X_L (03h), OUT_Y_H (06h) and OUT_Y_L (05h) registers. These registers contain, respectively, the most significant part and the least significant part of the angular rate signals acting on the X and Y axes.

The complete angular rate data for the X and Y channels are given by the concatenation OUT_X_H & OUT_X_L (OUT_Y_H & OUT_Y_L) and are expressed as a 2's complement number.

Angular rate data are represented as 16-bit numbers and are left-justified.

5.2 Reading angular rate data

5.2.1 Asynchronous read: using the status register

The device is provided with a STATUS_REG (09h) which should be polled to check when a new set of data is available. The reading procedure should be as follows:

1. Read STATUS_REG
2. If STATUS_REG(3) = 0 then go to 1
3. If STATUS_REG(7) = 1 then some data have been overwritten
4. Read OUTX_L
5. Read OUTX_H
6. Read OUTY_L
7. Read OUTY_H
8. Go to 1

The check performed at step 3 allows understanding whether the reading rate is adequate compared to the data production rate. If one or more angular rate samples have been overwritten by new data, because of a reading rate that is too slow, the YXOR bit of STATUS_REG (09h) is set to 1.

The overrun bits are automatically cleared when all the data present inside the device have been read and new data have not been produced in the meantime.

5.2.2 Synchronous read: using the data-ready (DRDY) signal

The device may be configured to have one HW signal to determinate when a new set of measurement data is available for reading. This signal is equivalent to the XYDA bit in STATUS_REG (09h). The DRDY_EN bit in CTRL_REG3 (0Dh) has to be set to '1' to enable the data ready interrupt on the DRDY pin.

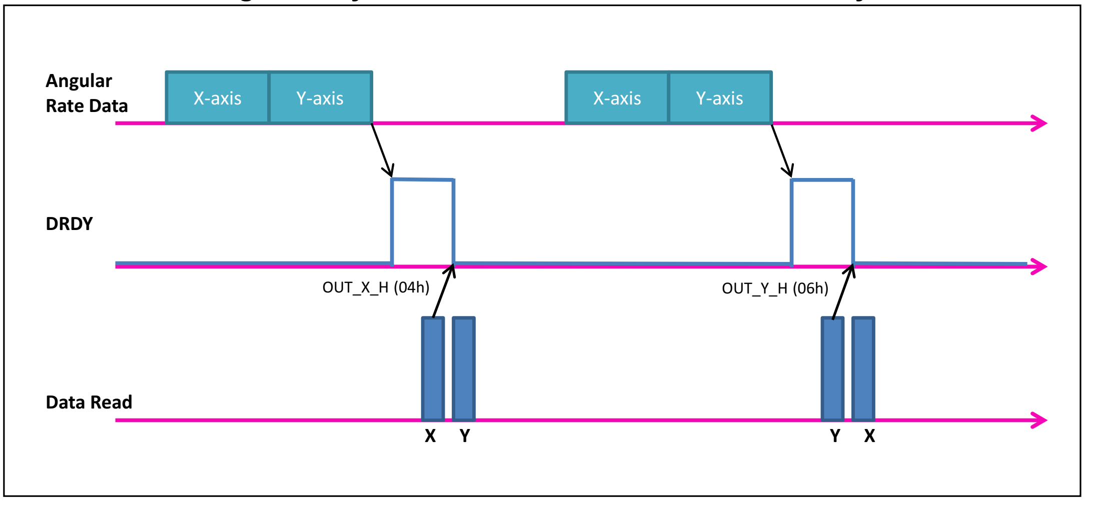
To properly perform a synchronous read, the angular rate data have to be read every time the DRDY pin goes high.

The DRDY signal can be latched (default condition) or pulsed if the P_DRDY bit in CTRL_REG1 (0Bh) is set to '1'.

When a latched condition is selected, the interrupt goes low when the high part of one of the output channels is read (OUT_X_H (04h) or OUT_Y_H (06h)) and returns high when new data is generated.

When a pulsed condition is selected, the interrupt behavior is independent from the read operations and remains high for 75 µsec every time new data is generated. The DRDY pin is set by default as push-pull output, but it can be configured as open-drain output by setting CTRL_REG3 (0Dh) (PP_OD) to ‘1’.

Figure 3. Synchronous read with latched data ready



5.3 Output data update (ODU)

By default the L2G2IS has the output data update (ODU) function enabled, preventing the update of the output registers until MSB and LSB have been read.

This feature avoids reading values (most significant and least significant parts of the angular rate data) related to different samples. In particular, when the ODU is activated, the data registers related to each channel always contain the most recent acceleration data produced by the device, but, if a read of a given pair (i.e. OUT_X_H and OUT_X_L, OUT_Y_H and OUT-Y_L) is initiated, the refresh for that pair is blocked until both MSB and LSB parts of the data are read.

The ODU only guarantees that OUT_X(Y)_L and OUT_X(Y)_H have been sampled at the same moment. For example, if the reading speed is too slow, it may be possible to read the angular rate data of the x-axis sampled at T1 while the y-axis data sampled at T2.

The ODU function can be set in CTRL_REG1 (0Bh).

5.4 Big-little endian selection

In the L2G2IS it is possible to swap the content of the lower and the upper part of the angular rate registers (i.e. OUT_X_H with OUT_X_L), to be compliant with both little-endian and big-endian data representations.

"Little Endian" means that the low-order byte of the number is stored in memory at the lowest address, and the high-order byte at the highest address. (The little end comes first).

This mode corresponds to bit BLE in CTRL_REG1 (0Bh) set to 0 (default configuration).

On the contrary, "Big Endian" means that the high-order byte of the number is stored in memory at the lowest address, and the low-order byte at the highest address.

5.5 Orientation configuration

On the L2G2IS it is possible to change the sign and the orientation of the gyroscope axis through the ORIENT_CONFIG (10h) register. In particular the Sign_X and Sign_Y bits in the ORIENT_CONFIG (10h) register can be used to invert the sign of the X and Y-axis respectively.

The Orient bit in the ORIENT_CONFIG (10h) register allows changing the orientation of the X and Y-axis as given in the table below.

Table 4. Orientation configuration

Orient	OUT_X_L, OUT_X_H	OUT_Y_L, OUT_Y_H
0	X-axis	Y-axis
1	Y-axis	X-axis

6 Temperature sensor

The L2G2IS automatically measures the temperature and provides the data through the TEMP_OUT_L (01h), TEMP_OUT_H (02h) registers, at a data rate of 70 Hz.

The complete temperature data are given by the concatenation of TEMP_OUT_L (01h) and TEMP_OUT_H (02h), as two's complement data in 12-bit format, left-justified. The output of the temperature sensor is 0 at 25 °C.

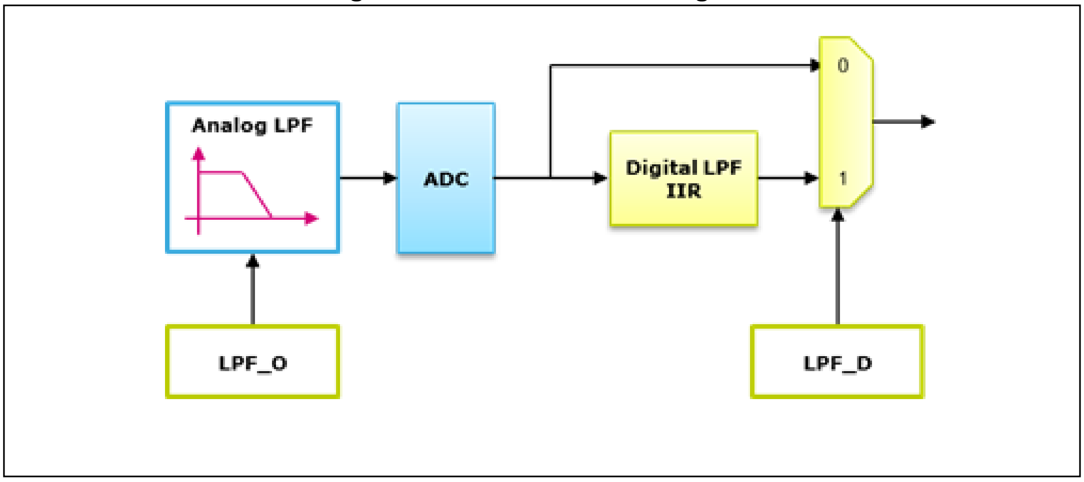
7 Filter chain

7.1 Low-pass filter chain

In the L2G2IS, the LPF chain is composed of an analog filter and a digital filter.

The LPF_O bit in CTRL_REG2 (0Ch) allows configuring the analog filter order to be a 1^{st} or a 2^{nd} order SC filter. The LPF_D bit in CTRL_REG3 (0Dh) enables the digital filter (IIR 1^{st} order).

Figure 4. LPF chain block diagram



The following table shows the filter cutoff frequency, based on LPF_O and LPF_D settings.

Table 5. Low-pass filter cutoff frequency selection

LPF_O CTRL_REG_2	LPF_D CTRL_REG3	Cutoff frequency	Phase delay @ 20 Hz
0	0	280 Hz	7 deg (default)
0	1	140 Hz	13.5 deg
1	0	350 Hz	5 deg
1	1	150 Hz	11.5 deg

7.2 High-pass filter chain

The L2G2IS integrates a 1st order digital high-pass filter and it can be enabled by setting the HPF bit in CTRL_REG2 (0Ch) to '1'.

Using the HPF_BW bit in CTRL_REG4 (1Fh), it is possible to select the high-pass filter cutoff frequency as indicated in *Table 6*.

If the HPF bit is set to '0', then the content of the HPF_BW bit is not considered.

Figure 5. HPF chain block diagram

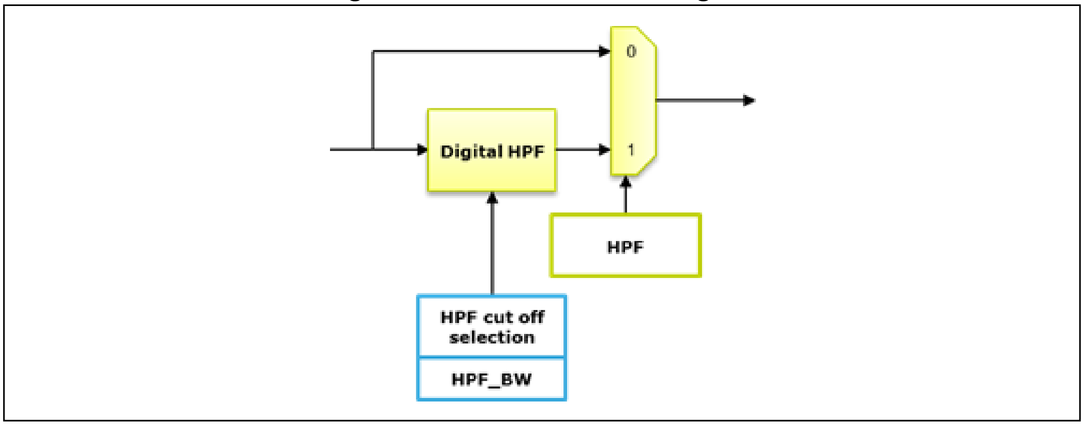
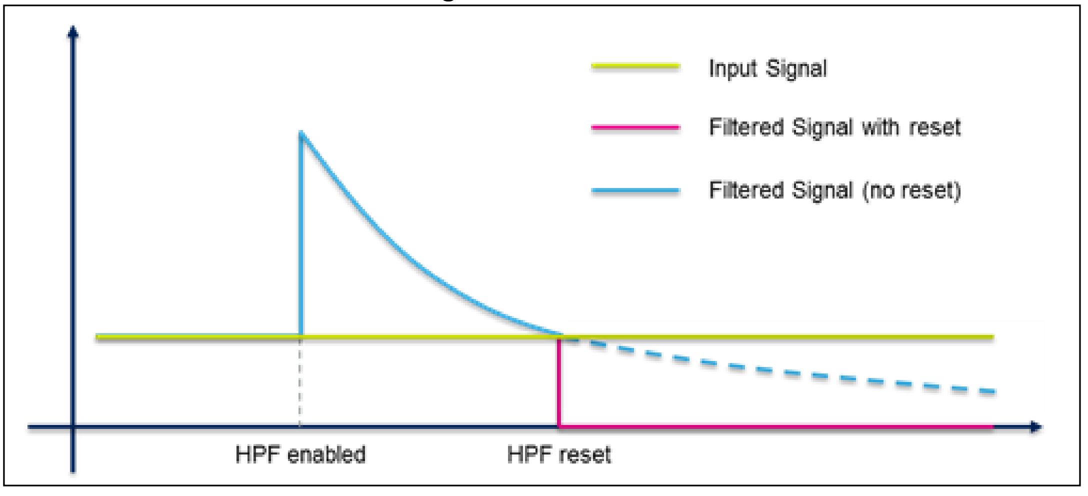


Table 6. High-pass filter cutoff frequency selection

HPF_BW in CTRL_REG4 (1Fh)	HPF cutoff frequency
0	0.02 Hz
1	0.09 Hz

The high-pass filter can be reset instantly by deleting the DC component of the angular rate. This reset can be performed by setting the HPreset bit in the CTRL_REG2 (0Ch) register to '1'.

Figure 6. HPF reset

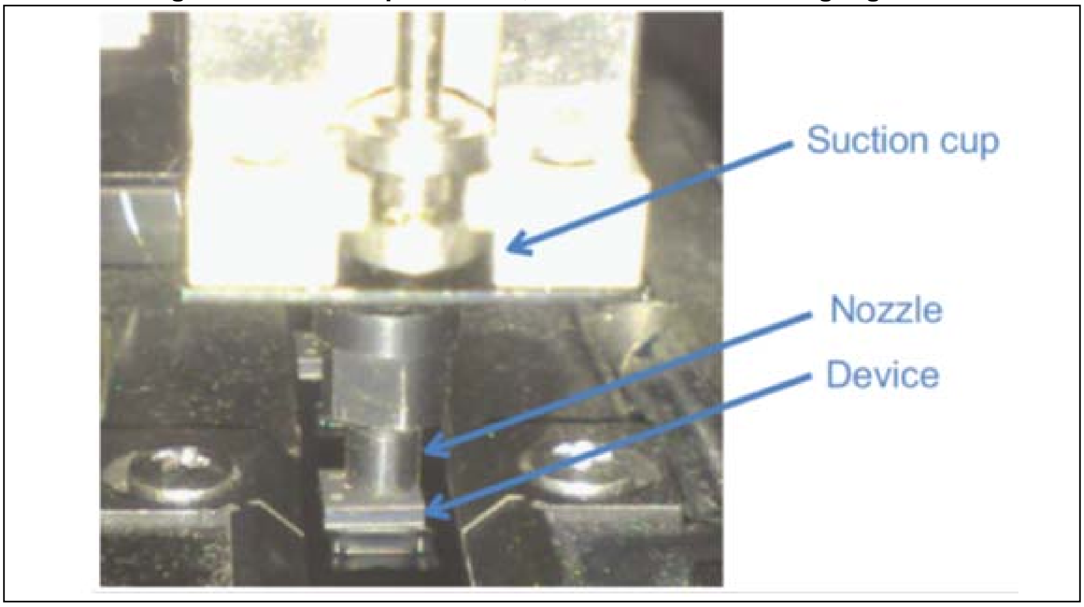


8 Pick-and-place settings for thin MEMS components

The use of pick-and-place equipment is frequent in several process steps of the printed circuit board assembly process. Pick-and-place machines are used for high-speed, high-precision placement of electronic components, like capacitors, resistors, or integrated circuits onto the PCB.

These systems normally use pneumatic suction cups, with a nozzle at the end to accurately pick up the device from a predetermined area.

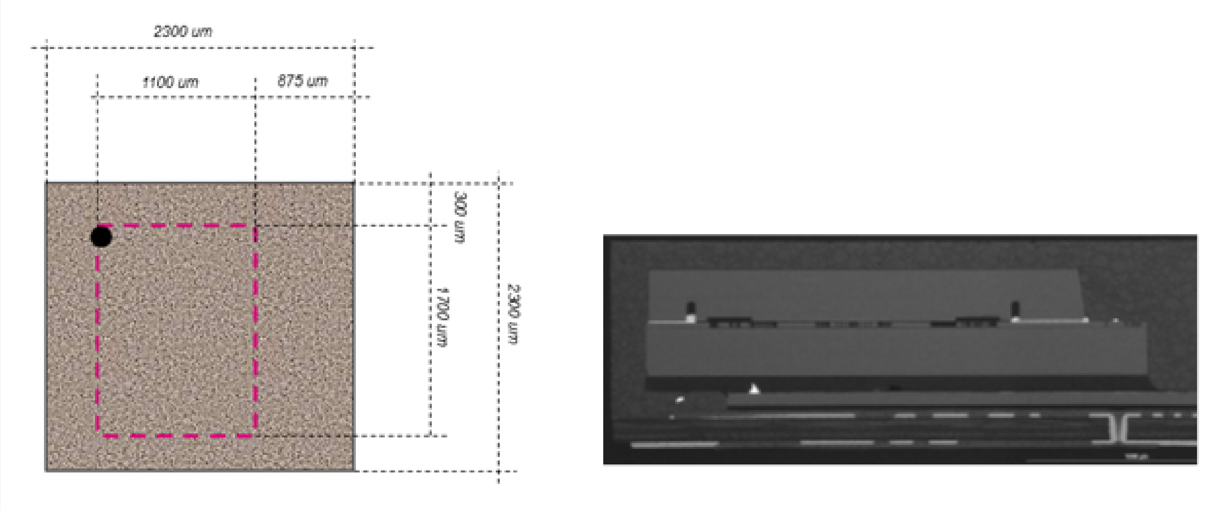
Figure 7. Pick-and-place head, with metallic nozzle highlighted



MEMS components are silicon integrated electro-mechanical systems that use a mechanical movable element to sense acceleration, angular velocity or other physical quantities.

In inertial sensors, the movable element is encapsulated in a closed cavity to protect the movable mass from the packaging process and external environment. ST’s ThELMA process produces this cavity at wafer level by means of wafer-to-wafer bonding of the sensor wafer with a protective silicon cap. Between the sensor wafer and the protective cap, an air gap is left to allow movement of the proof mass.

Figure 8. Cavity placement and size in the L2G2IS gyro for OIS applications



Overmolded packaging (LGA, BGA, DFN, etc.) establishes a direct mechanical connection between the device top and MEMS cavity. The increasing reduction in component size and thickness leads to close proximity of the MEMS cavity to the package boundaries, setting increasingly strict requirements on device handling in order to prevent damage to the MEMS cavity.

Pick-and-place equipment involve the most critical handling steps for the MEMS cavity, due to the direct contact of the picking nozzle with the device top.

In the case of thin components with wafer-level encapsulation, the pick-and-place settings must be rigorously controlled since the position of the nozzle, the force involved in the pick-and-place, and the mechanical parameters can damage the cap structure of the MEMS component.

For large size devices (i.e. when the pick-and-place nozzle size is small in comparison with full device size), a reference pick area can be defined, excluding the cavity region from the target pick region. For small size devices (i.e. when the pick-and-place nozzle size becomes comparable with full device size), it is impractical to define an exclusion area, therefore special care must be exercised when selecting pick-and-place nozzle material, size and settings.

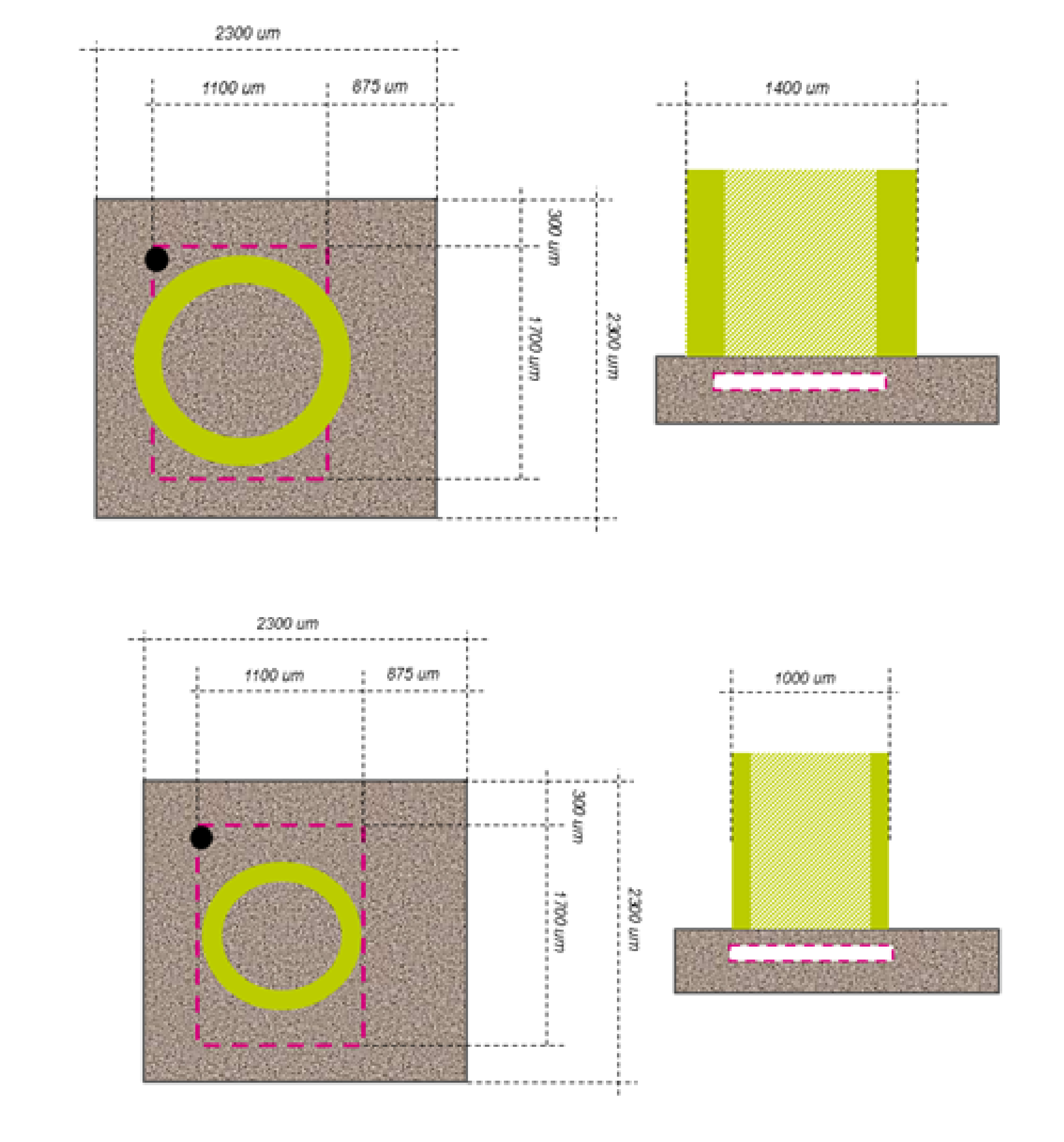
Material

Soft materials are preferred in the selection of nozzles. Rubber nozzles can be safely used without constraints for the pick area and nozzle design. Metallic nozzles, usually preferred for long-term use and higher precision, can be used if care is exercised with all other settings.

Size

Nozzle size impacts the distribution of the pick force on the device top side. For small MEMS components, a large nozzle has to be preferred over a small nozzle. Large nozzles reduce the risk of transferring all the force in the cavity region of the MEMS die.

Figure 9. Pick and place nozzle positioning with respect to cavity size in the L2G2IS device (large nozzle size (preferred) vs. small nozzle size)



Force:

Static force applied by the pick-and-place nozzle on the device top is a function of nozzle design and maximum picker overdrive. The picker overdrive parameter can usually be calibrated by the end user to optimize the picking capability of the machine. The maximum static force should be minimized in order to prevent excessive load on the device top and possible damage to the MEMS cavity.

Picker velocity:

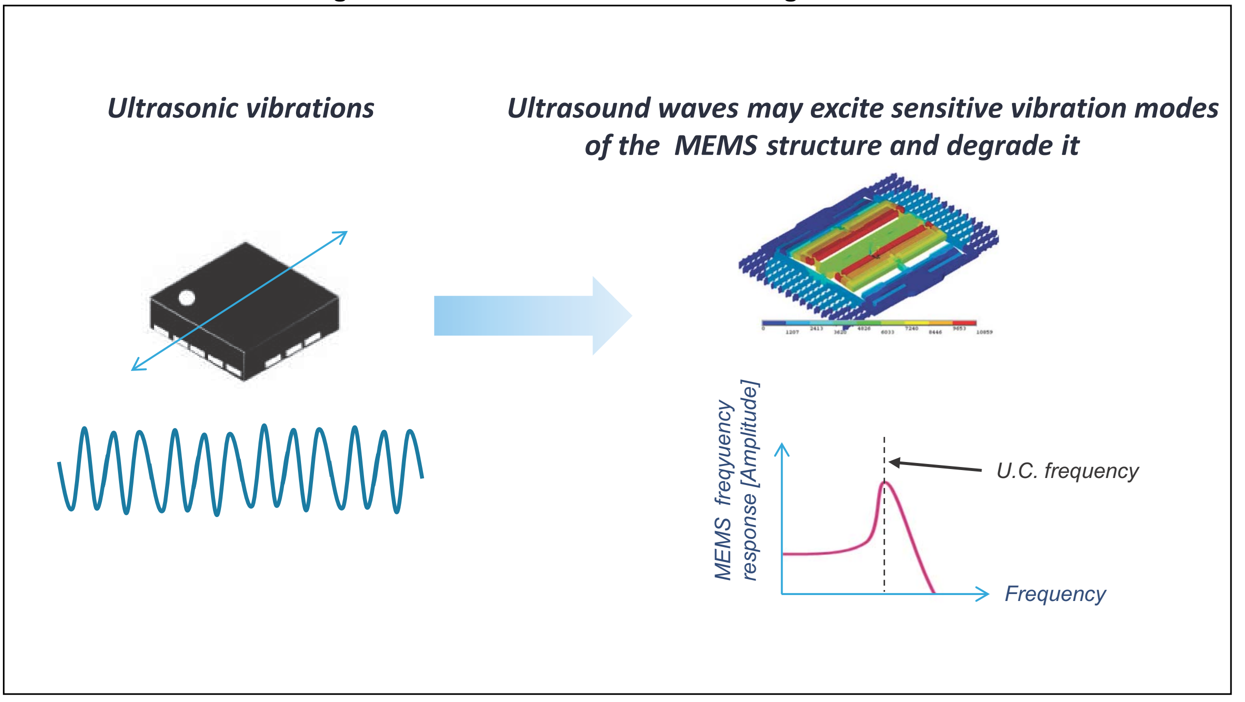
The pick-and-place nozzle should not be decelerated by impact on the device top, but rather have an independent deceleration mechanism that results in quasi-static application of the required force to pick up the device.

9 Ultrasonic cleaning

The ultrasonic cleaning process transfers energy at the cleaning frequency to the MEMS structure. This energy causes vibration of the movable masses within the MEMS structure at the ultrasonic cleaning frequency.

Special attention shall be paid to not transfer energy with a cleaning frequency close to the resonant frequencies of these movable masses within the MEMS structure.

Figure 10. Effect of ultrasonic cleaning on MEMS



The L2G2IS has a safe area for ultrasonic cleaning in the range of 40 ±4 kHz which is the recommended starting point to set up the ultrasonic cleaning process.

The main factors concerning ultrasonic cleaning are:

- Power
- Exposure time
- Tank volume

These factors can affect the frequency value set for ultrasonic cleaning.

For technical support of ultrasonic cleaning trials, please contact the local ST sales office.

10 Revision history

Table 7. Document revision history

Date	Revision	Changes
13-Oct-2015	1	Initial release.
25-Nov-2015	2	Added *Section 9: Ultrasonic cleaning*
17-Feb-2016	3	Updated *Figure 2: L2G2IS electrical connections* Updated *Section 4.2: Power down* Updated *Section 5.2.2: Synchronous read: using the data-ready (DRDY) signal* and *Figure 3: Synchronous read*
24-Feb-2016	4	Updated *Section 5.2.2: Synchronous read: using the data-ready (DRDY) signal* and *Figure 3: Synchronous read with latched data ready*