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## Features

- Digital angular rate sensor with SPI interface
- Angular rate measurement around Z-axis (yaw)
- ±300°/sec input range
- Ultra low noise
- Excellent bias instability
- Low latency
- 24 bit angular rate output
- Embedded temperature sensor for on-chip or external temperature compensation
- Built-in Self-Test
- 5V single supply voltage
- Low operating current consumption: 25mA
- CLCC 30 package: 19.6 mm x 11.5 mm x 3.7 mm
- Weight : 2 grams
- REACH and RoHS compliant

## Applications

- Precision instrumentation
- Platform stabilization
- Guidance and control
- IMU, AHRS and navigation systems
- Avionics Flight Control and Back-up instruments
- Unmanned vehicles and Autonomous systems
- 3D mapping
- Marine electronics
- Oil and gas
- Robotics

## General Description

GYPRO® product line is a new generation of Micro-Electro-Mechanical Systems (MEMS) angular rate sensor specifically designed for demanding applications.

The MEMS transducer is manufactured using Tronics proprietary vacuum wafer-level packaging technology based on micro-machined thick single crystal silicon.

The integrated circuit (IC) provides a stable primary anti-phase vibration of the 'drive' proof masses, thanks to electrostatic comb drives. When the sensor is subjected to a rotation, the Coriolis force acts on the 'sense' proof masses and forces them into a secondary anti-phase movement perpendicular to the direction of drive vibration, which is itself counter-balanced by electrostatic forces. The sense closed loop operates as an electromechanical ΣΔ modulator providing a digital output. This output is finally demodulated using the drive reference signal.

The sensor is factory calibrated and compensated for temperature effects to provide high-accuracy digital output over a broad temperature range.

Raw data output can be also chosen to enable customer-made compensations.

## GYPRO® Product references

| | Description | Vibration range | Bandwidth | Data Rate | Latency |
|---|---|---|---|---|---|
| **GYPRO2300** | Standard configuration | 4 grms | 100Hz | 200Hz | 40 ms |
| **GYPRO2300LD** | Low delay configuration | 4 grms | >200Hz | 1700Hz | 2 ms |
| **GYPRO3300** | Improved vibration tolerance & Ultra low delay configuration | 8 grms | >200Hz | 1800Hz | 1 ms |

## Disclaimer

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## Contents

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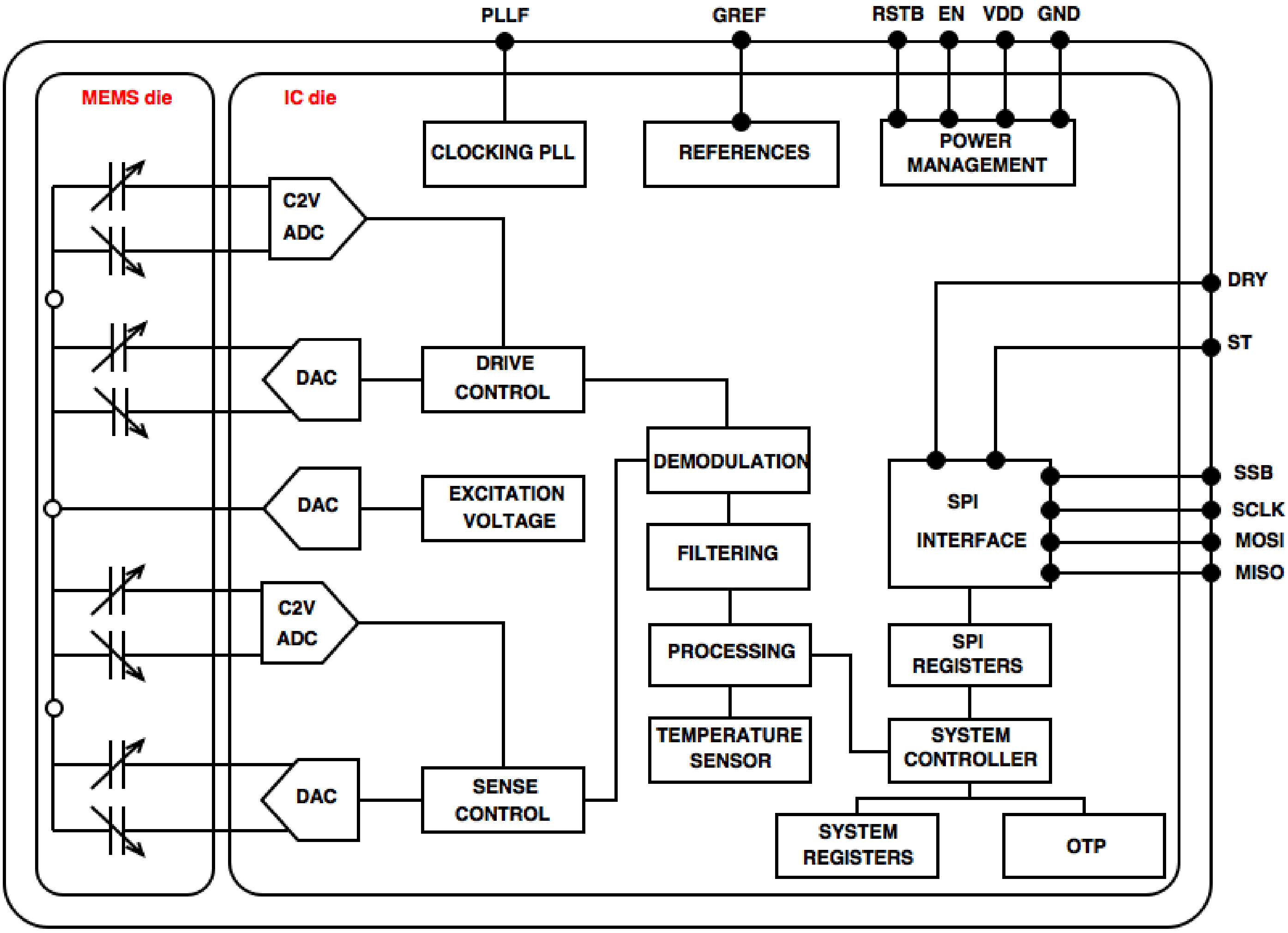
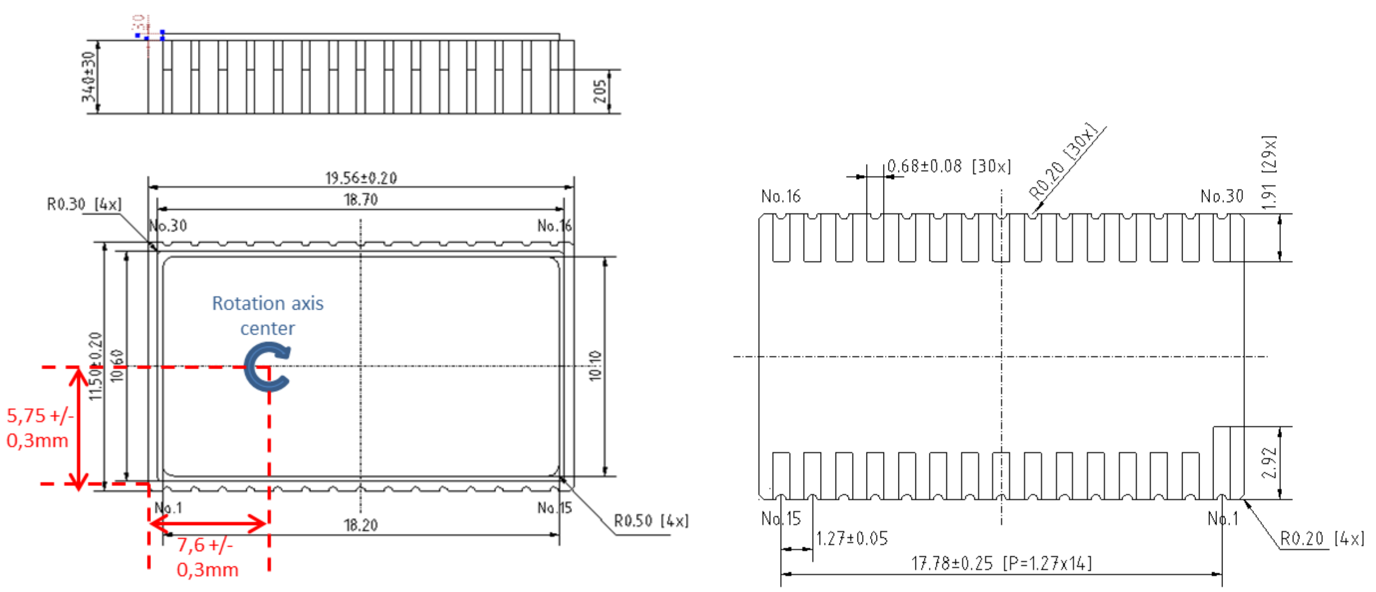
## Block diagram




## Overall Dimensions



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## 1. Specifications

| Parameter | Unit | Typ. | Max | Notes |
|---|---|---|---|---|
| **Measurement Ranges** | | | | |
| Input range* | °/s | ±300 | ±838 | |
| Temperature range * | °C | -40 to +85 | | |
| **Bias** | | | | |
| Bias instability | °/h | 0.8 | 3** | Lowest point of Allan variance curve at room temperature. |
| Bias in-run (short term) stability | °/h | 10 | 30** | Standard deviation of the 1 second filtered output over 1 hour at room temperature, after 30 min of stabilization. |
| Bias temperature variations (1σ), calibrated * | °/s | 0.02 | 0.05 | Standard deviation of the bias over the specified temperature range. |
| Bias run to run repeatability | °/h | 10 | | Standard deviation of 7 bias measurements at 30°C that occurs between seven runs of operation with 30 minutes power off between each run. |
| Vibration rectification coefficient | °/h/g² | 0.5 | | Bias rectification under vibration, overall level 7.3 g rms, test condition B, method 2026, MIL-STD-883F. |
| **Scale Factor** | | | | |
| Scale Factor * | LSB/°/s | 10 000 | | Nominal scale factor. |
| Scale Factor temperature variations (1σ), calibrated * | % | 0.04 | 0.15 | Standard deviation of the scale factor over the specified temperature range. |
| Scale Factor run to run repeatability | ppm | 25 | 100** | Standard deviation of 7 scale factor measurements at 30°C that occurs between seven runs of operation with 30 minutes power off between each run. |
| Scale factor non linearity* | ppm | 100 | 500 | Maximum deviation of the output from the expected value using a best fit straight line, at room temperature. |
| **Noise** | | | | |
| RMS Noise [1-100Hz] * | °/s | 0.04 | 0.05 | RMS noise level in the band [1-100Hz], obtained by integrating the power spectral density of the sensor output between 1 and 100Hz at zero rate and room temperature. |
| Angular random walk | °/√h | 0.15 | 0.3** | -1/2 slope of Allan variance curve at room temperature. |
| **Frequency response** | | | | |
| Bandwidth | Hz | >200Hz | | Defined as the frequency for which attenuation is equal to -3dB |
| Data Rate | Hz | 1700 to 1900 | | Refresh rate of the output data at room temperature. |
| Latency | ms | 1 | | Time interval between the implementation of a rate signal on the input and the availability of the corresponding data on the output. |
| Start-up Time | s | 0.5 | 1** | Time interval between application of power on and the availability of an output signal (at least 90% of the input rate), at room temperature. |

| Parameter | Unit | Typ. | Max | Notes |
|---|---|---|---|---|
| **Linear acceleration** | | | | |
| G sensitivity | °/h/g | 15 | 40** | Mean value on all axis of output variation under 1 g. |
| Recovery time | ms | 10 | | Time interval between an impact (half sine 50 g, 6 ms) and the presence of a usable output of the sensor. |
| **Axis alignment** | | | | |
| Rate axis misalignment | mrad | | 16 | Misalignment between the sensitive axis and the normal to the package bottom plane, by design. |
| **Environmental** | | | | |
| Storage temperature range | °C | -55 to +100 | | |
| Humidity at 45°C | % | <98 | | |
| Moisture Sensitivity Level (MSL) | -- | 1 | | Unlimited floor life out of the bag (hermetic package). |
| Shock (operating) | g \| ms | 50 \| 6 | | Half sine. |
| Shock (survival) | g \| ms | 2000 \| 0.3 | | |
| Vibrations (operating) | $g_{rms}$ | 7.3 | | test condition B, method 2026, MIL-STD-883F. |
| Vibrations (survival) | $g_{rms}$ | 20 | | |
| **Electrical** | | | | |
| Power Supply Voltage | V | 4.75 to 5.25 | | |
| Current consumption (normal mode) | mA | 25 | | |
| Current consumption (power down mode) | µA | <1 | <5 | Power down mode is activated by switching EN pin to GND. |
| Power supply rejection ratio | °/h/V | 40 | | |
| **Temperature sensor** | | | | |
| Scale Factor (raw data) | LSB/°C | 85 | | Temperature sensor is not factory-calibrated. |
| 25°C typical output (raw data) | LSB | 8000 | | Temperature sensor is not factory-calibrated. |
| Refresh rate | Hz | 6 | | |

**Table 1 Specifications**

* 100% tested in production.

** Unless otherwise specified, max values are ±3 sigma variation limits from validation test population.

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## 2. Maximum Ratings

Stresses higher than the maximum ratings listed below may cause permanent damage to the device, or affect its reliability. Functional operation is not guaranteed once stresses higher than the maximum ratings have been applied.

Exposure to maximum ratings conditions for extended periods may also affect device reliability.

| Parameter | Unit | Min | Max |
|---|---|---|---|
| Supply Voltage | V | -0.5 | +7 |
| Electrostatic Discharge (ESD) protection, any pin, Human Body Model | kV | -- | ±2 |
| Storage temperature range | °C | -55 | +100 |
| Shock survival | g | -- | 2000 |
| Vibrations survival, 20-2000Hz | $g_{rms}$ | -- | 20 |
| Ultrasonic cleaning | | Not allowed | |

**Table 2 Maximum ratings**

**Caution!**

The product may be damaged by ESD, which can cause performance degradation or device failure! We recommend handling the device only on a static safe work station. Precaution for the storage should also be taken.
The sensor MUST be powered-on *before* any SPI operation. Having the SPI pads at a high level while VDD is at 0V could damage the sensor, due to ESD protection diodes and buffers.

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## 3. Typical performances

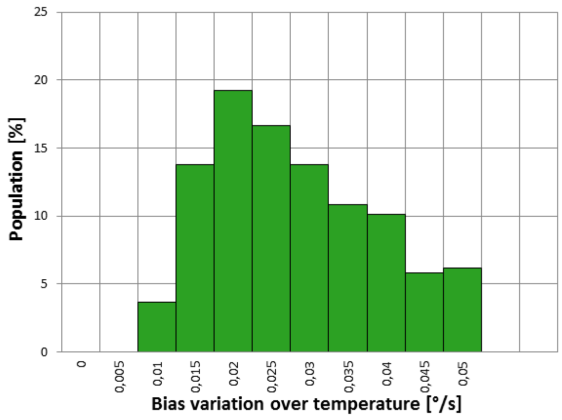


**Figure 1 Distribution of bias over temperature**

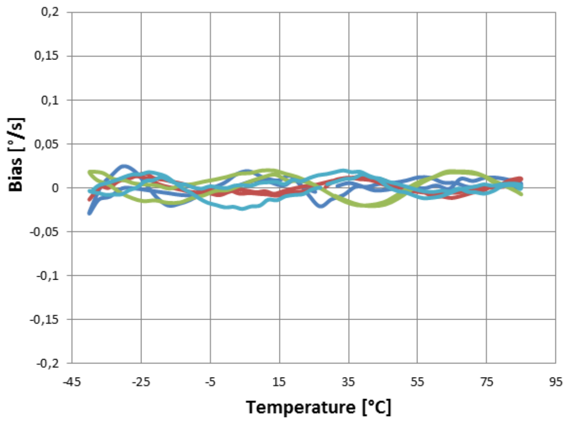


**Figure 4 Bias variation over temperature (4 samples)**

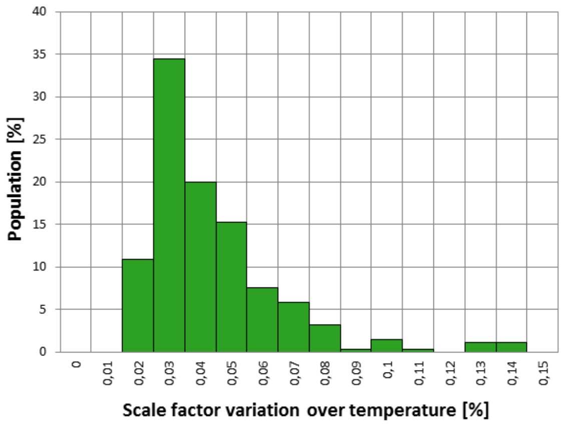


**Figure 2 Distribution of scale factor over temperature**

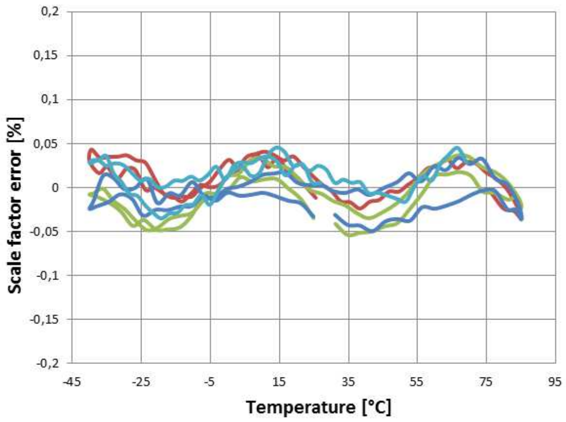


**Figure 5 Scale factor variation over temperature (4 samples)**

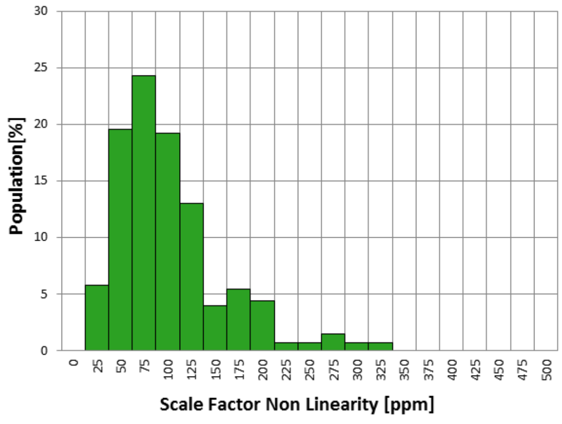


**Figure 3 Distribution of scale factor non linearity (RT)**

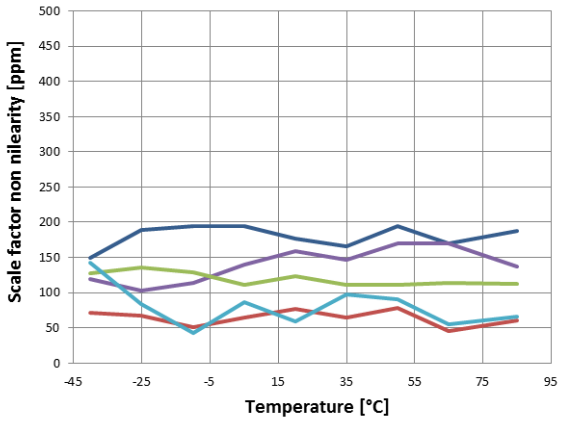


**Figure 6 Scale factor non linearity over temperature (5 samples)**

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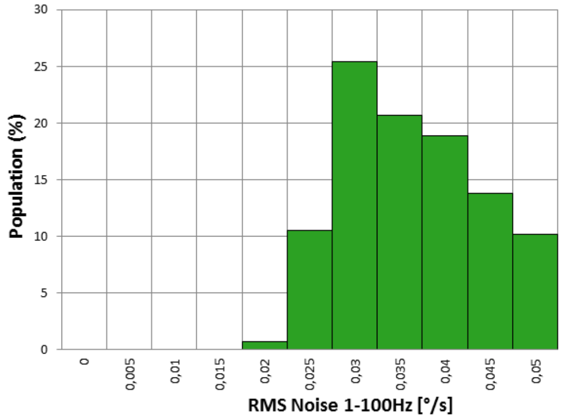


Figure 7 Distribution of RMS Noise (RT)

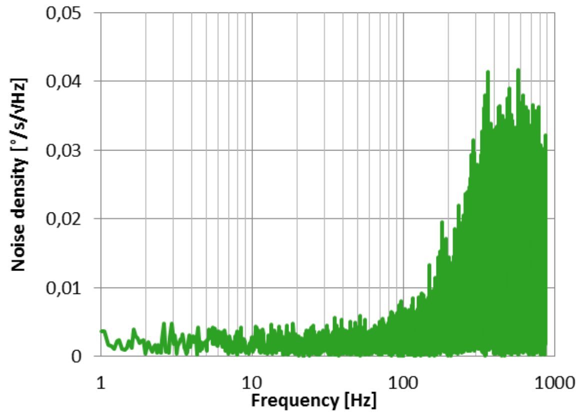


Figure 10 Noise density (RT)

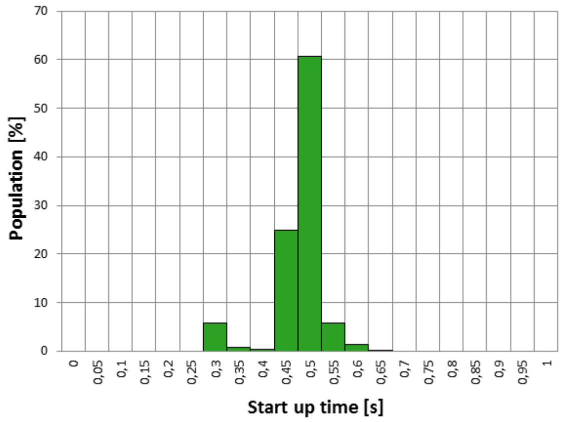


Figure 8 Distribution of Start-Up time (RT)

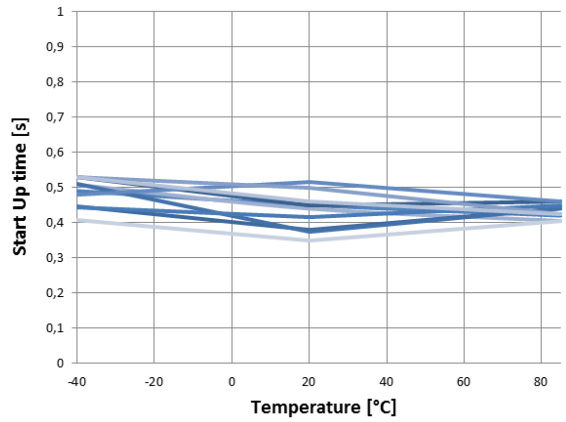


Figure 11 Start-up time variation over temperature

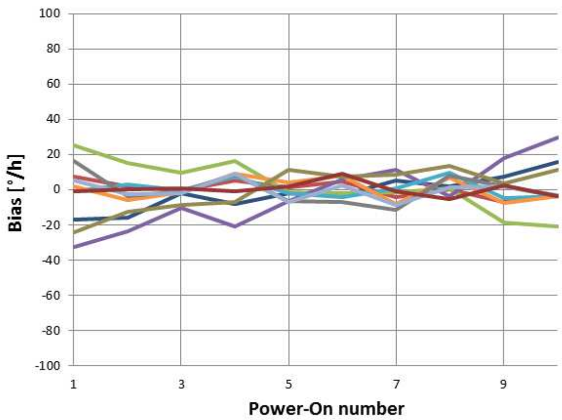


Figure 9 Run to run bias repeatability (30°C)

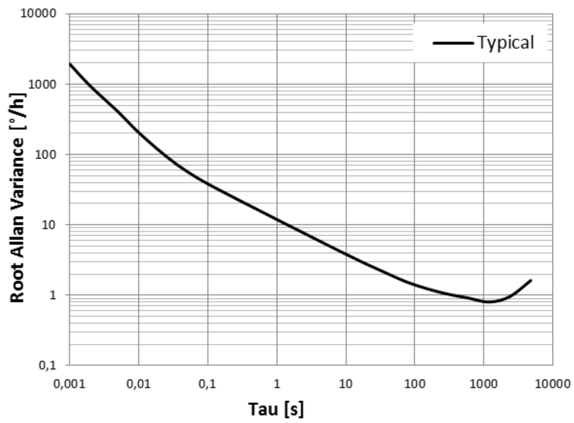


Figure 12 Allan variance

# 4. Interface

## 4.1. Pinout, sensitive axis identification

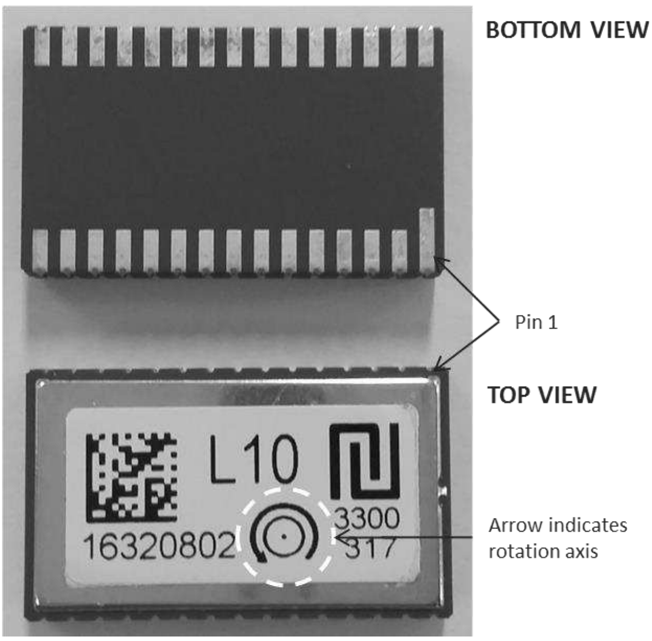


**Figure 13: How to locate Pin 1**

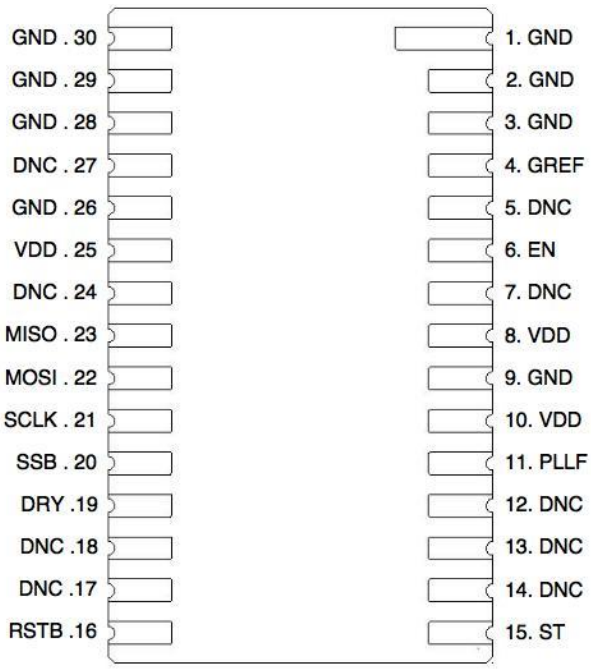


**Figure 14: GYPRO3300 Sensors Pinout (bottom view)**

## 4.2. Application circuit

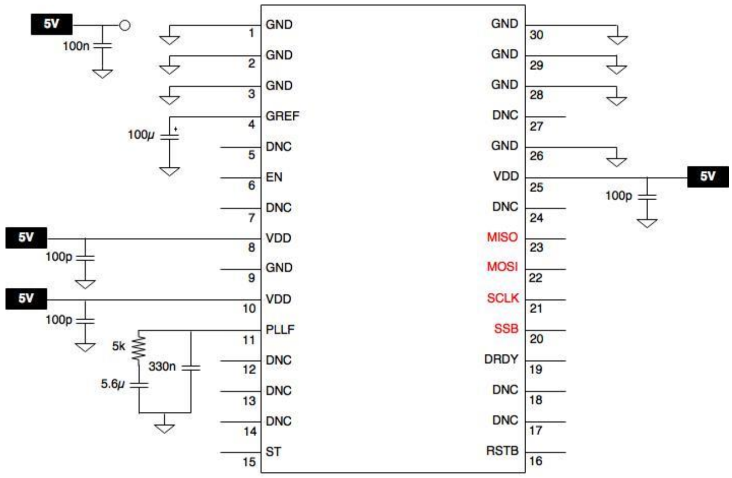


**Figure 15: Recommended Application Schematic (top view)**

Notes:

- All capacitances of Figure 15 should be placed as close as possible to their corresponding pins, except the 100nF capacitance between VDD and GND, which should be as close as possible to the board's supply input.
- The 100µF filtering capacitance between GREF and GND should have low Equivalent Series Resistance (ESR < 1Ω) and low leakage current (< 6µA).
- 5.6µF and 330nF filtering capacitance between PLLF and GND should have a low leakage current (<1µA).

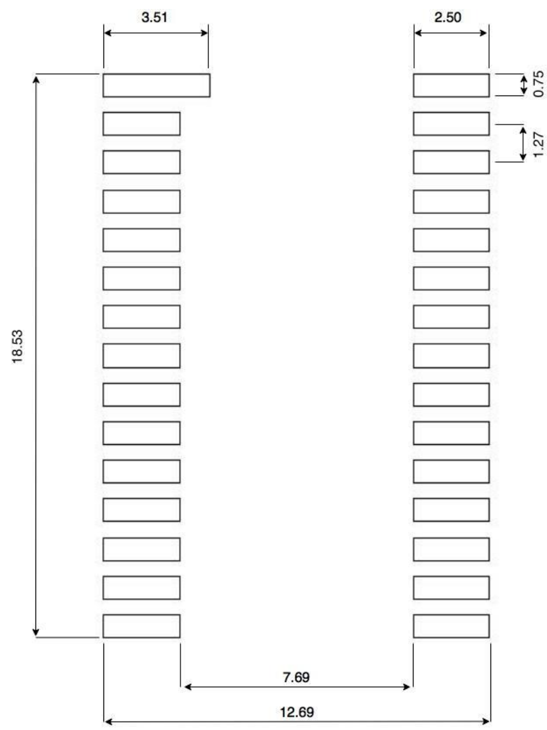


**Figure 16: Recommended Pad Layout in mm (top view)**

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## 4.3. Input/Output Pin Definitions

| Pin name | Pin number | Pin type | Pin direction | Pin levels | Function |
|---|---|---|---|---|---|
| **GND** | 1, 2, 3, 9, 26 , 28, 29, 30 | Supply | n/a | 0V | Power Ground |
| **VDD** | 8, 10, 25 | Supply | n/a | +5V | Power Supply |
| **GREF** | 4 | Analog | n/a | 4.4V | External decoupling pad. MUST be connected to the board's VSS through a 100µF external capacitor, in order to ensure low noise. |
| **EN** | 6 | Digital | Input | VDD with pull up of 100kΩ | Enable command. Active high. |
| **PLLF** | 11 | Analog | Output | 0.8V | External filtering pad. MUST be connected to a filtering stage, described in Figure 15. |
| **ST** | 15 | Digital | Output | VDD | Self-test status. Logic "1" when the sensor is OK. |
| **RSTB** | 16 | Digital | Input | VDD with pull-up of 100kΩ | Reset. Reloads the internal calibration data. Active low |
| **DRY** | 19 | Digital | Output | VDD | Data Ready flag. Generates a pulse when a new angular rate data is available. |
| **SSB** | 20 | Digital | Input | VDD | Slave Selection signal. Active low |
| **SCLK** | 21 | Digital | Input | VDD | SPI clock signal |
| **MOSI** | 22 | Digital | Input | VDD | Master Output Slave Input signal |
| **MISO** | 23 | Digital | Output | VDD | Master Input Slave Output signal |
| **DNC** | 5, 7, 12, 13, 14, 17, 18, 24, 27 | -- | -- | -- | Do Not electrically Connect. These pins provide additional mechanical fixing to the board and should be soldered to an unconnected pad. |

**Table 3: Pin Functions**

Note: The digital pads maximum ratings are GND-0.3V and VDD+0.3V.

## 5. Soldering Recommendations

Please note that the reflow profile to be used does not depend only on the sensor. The whole populated board characteristics shall be taken into account.

For a better reliability of the soldering, Tronics recommends using Copper-Invar-Copper or ceramic boards. These types of boards have a coefficient of thermal expansion (CTE) close to the CTE of GYPRO3300 package (6.8 ppm/°C).

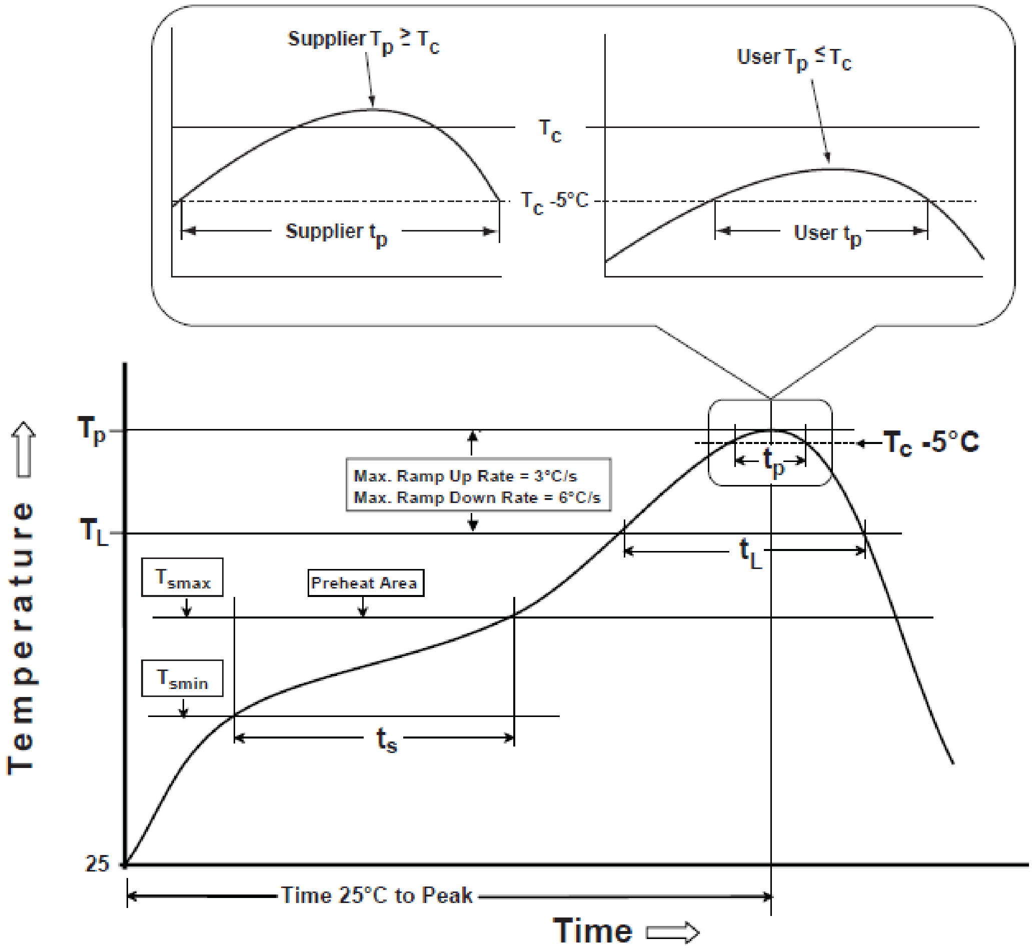


**Figure 17: Reflow Profile, according to IPC/JEDEC J-STD-020D.1**

| Profile Feature | Sn-Pb Eutectic Assembly | Pb-Free Assembly |
|---|---|---|
| **Time maintained above** | | |
| Temperature ($T_L$) | 183°C | 217°C |
| Time ($t_L$) | 60-150 sec | 60-150 sec |
| Peak Temperature ($T_p$) | 240°C (+/-5°C) | 260°C (+/-5°C) |
| Time within 5°C of Actual Peak Temperature ($t_p$) | 10-30 sec | 10-40 sec |

**Table 4: Reflow Profile Details, according to IPC/JEDEC J-STD-020D.1**

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# 6. Digital SPI interface

## 6.1. Electrical and Timing Characteristics

The device acts as a slave supporting only SPI "mode 0" (clock polarity CPOL=0, clock phase CPHA=0).

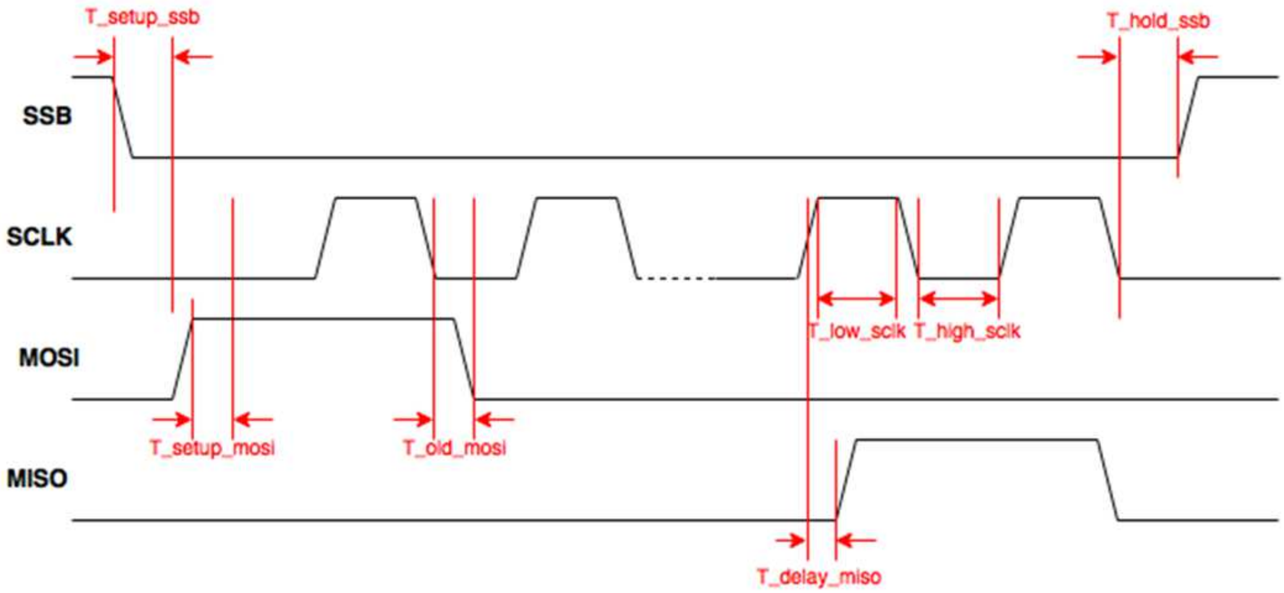


**Figure 18: SPI timing diagram**

| Symbol | Parameter | Condition | Unit | Min | Typ | Max |
|---|---|---|---|---|---|---|
| **Electrical characteristics** | | | | | | |
| VIL | Low level input voltage | | VDD | 0 | | 0.1 |
| VIH | High level input voltage | | VDD | 0.8 | | 1 |
| VOL | Low level output voltage | ioL=0mA (Capacitive Load) | V | | GND | |
| VOH | High level output voltage | ioH=0mA (Capacitive Load) | V | | VDD | |
| Rpull_up | Pull-up resistor | Internal pull-up resistance to VDD | kΩ | | 100 | |
| Rpull_down | Pull-down resistor | Internal pull-down resistance to GND | kΩ | | - | |
| **Timing parameters** | | | | | | |
| Fspi | SPI clock input frequency | Maximal load 25pF on MOSI or MISO | MHz | | 0.2 | 8 |
| T_low_sclk | SCLK low pulse | | ns | 62.5 | | |
| T_high-sclk | SCLK high pulse | | ns | 62.5 | | |
| T_setup_din | MOSI setup time | | ns | 10 | | |
| T_hold_din | MOSI hold time | | ns | 5 | | |
| T_delay_dout | MISO output delay | Load 25pF | ns | | | 40 |
| T_setup_csb | SS setup time | | Tsclk | 1 | | |
| T_hold_csb | SS hold time | | Tsclk | 1 | | |

**Table 5: SPI timing parameters**

The MISO pin is kept in high impedance when the SSB level is high, which allows sharing the SPI bus with other components.

**IMPORTANT NOTE: It is forbidden to keep SPI pads at a high level while VDD is at 0V due to ESD protection diodes and buffers.**

## 6.2. SPI frames description

The SPI frames used for the communication through the SPI Register are composed of an instruction followed by arguments. The SPI instruction is composed of 1 byte, and the arguments are composed of 2, 4 or 8 bytes, depending on the cases, as can be seen in Table 6 below.


**Figure 19: SPI Message Structure**

| Instruction | Argument | Meaning |
|---|---|---|
| 0x50 | 0x00000000 (n=4) | Read Angular Rate |
| 0x54 | 0x0000 (n=2) | Read Temperature |
| 0x58 | 0x00000000 (n=4) | Advanced commands. See Section 6.5 for more details. |
| 0x78 | 0xXXXXXXXX (n=8) | |
| 0x7C | 0xXXXX (n=2) | |

**Table 6: Authorized SPI commands**

## 6.3. Angular rate readings

From the 32-bits (4 bytes) frame obtained after the "Read Angular Rate" instruction, the 24-bits word of angular rate data (RATE) must be extracted as shown below in Figure 20.

DRY and ST are respectively the "data ready" and "self-test" bits, also directly available on Pins 19 and 16 of the sensor.

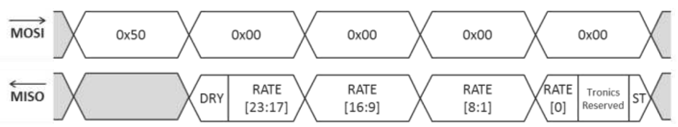


**Figure 20: Angular rate reading frames and data organization**

### 6.3.1. Angular rate (RATE) output

The 24-bit gyro output is coded in two's complement (Table 7).

- If the temperature compensation is not enabled (GOUT_SEL=0), then the user should perform scale factor measurements.
- If the temperature compensation of the angular rate output is enabled (default case), dividing the 24-bit value by a factor **10 000** results in the angular rate in °/s, as shown in Table 7.

| | | | |
|---|---|---|---|
| -838.8608 | °/s | ⇔ | 1000 0000 0000 0000 0000 0000 |
| … | | | |
| -300.0000 | °/s | ⇔ | 1101 0010 0011 1001 0100 0000 |
| … | | | |
| -0.0002 | °/s | ⇔ | 1111 1111 1111 1111 1111 1110 |
| -0.0001 | °/s | ⇔ | 1111 1111 1111 1111 1111 1111 |
| 0.0000 | °/s | ⇔ | 0000 0000 0000 0000 0000 0000 |
| +0.0001 | °/s | ⇔ | 0000 0000 0000 0000 0000 0001 |
| +0.0002 | °/s | ⇔ | 0000 0000 0000 0000 0000 0010 |
| … | | | |
| +300.0000 | °/s | ⇔ | 0010 1101 1100 0110 1100 0000 |
| … | | | |
| +838.8607 | °/s | ⇔ | 0111 1111 1111 1111 1111 1111 |

**Table 7: Conversion table for calibrated angular rate output**

### 6.3.2. Data Ready (DRY) bit

The Data Ready bit is a flag which is raised when a new angular rate data is available. The flag stays raised until the new data is read.

Similarly to the Data Ready pin, the Data Ready bit signal can be used as an interrupt signal to optimize the delays between newly available data and their readings.

### 6.3.3. Self-Test (ST) bit

The ST bit raises a flag (1 logic) at the same frequency as the angular rate output data rate indicating whether the sensor is properly operating (i.e. whether the drive loop control provides stable drive oscillations amplitude).

The self-test procedure is running in parallel to the main functions of the sensor.

The ST data is also available on the pin 15. This pin is set to VDD when the sensor is working properly.

## 6.4. Temperature readings

The temperature data is an unsigned integer, 14-bits word (TEMP). It must be extracted from the 2 bytes of read data, as shown below in Figure 21.

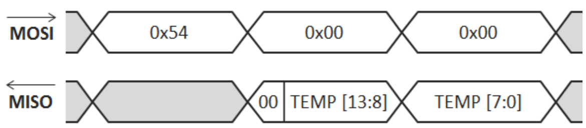


**Figure 21: Temperature reading frames and data organization**

By default the temperature sensor is *not* factory-calibrated (TOUTSEL=0).

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## 6.5. Advanced use of SPI registers

SPI registers can also be used to access the System register or the MTP (Multi-Time-Programmable memory).

### 6.5.1. R/W access to the System Registers

**IMPORTANT NOTE:** Modifications to the system registers are **reversible**. Modified registers will *not* be restored after a RESET. There is no limitation to the number of times the system registers can be modified.

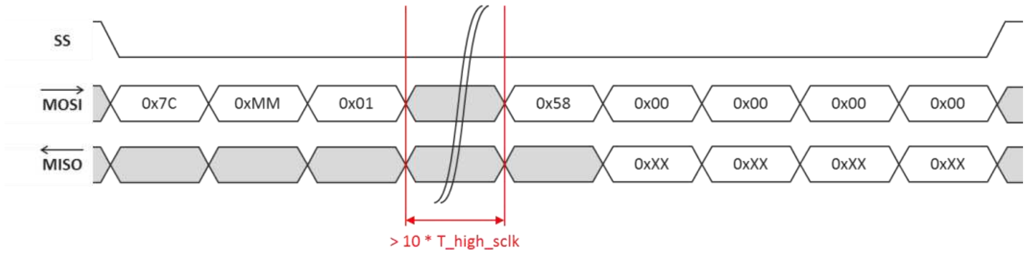


**Figure 22: Sequence of instructions to READ address 0xMM of the system registers**

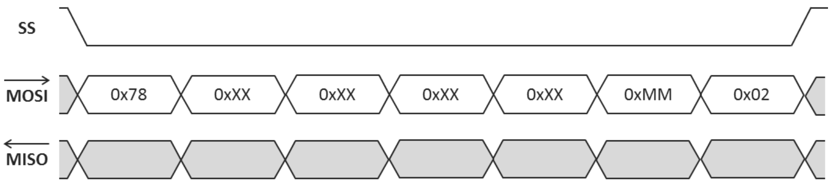


**Figure 23: Sequence of instructions to WRITE '0xXXXXXXXX' to address '0xMM' of the system registers**

### 6.5.2. R/W access to the MTP

**IMPORTANT NOTE:** Modifications to the MTP are **non-reversible.** Modified parameters will be restored, even after a RESET, and previous values of the MTP cannot be accessed anymore. The maximum number of times the MTP can be written depends on the address:

- 5 times for the angular rate calibration coefficients (see Section 7 for more details)
- Only 1 time for all the other coefficients, including the temperature sensor calibration coefficients.

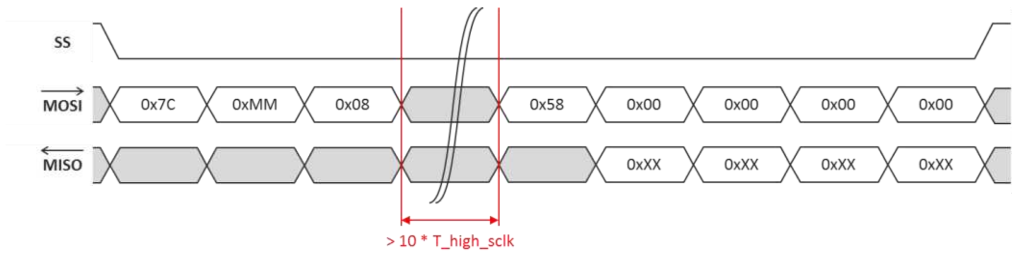


**Figure 24 : Sequence of instructions to READ address 0xMM of the MTP**

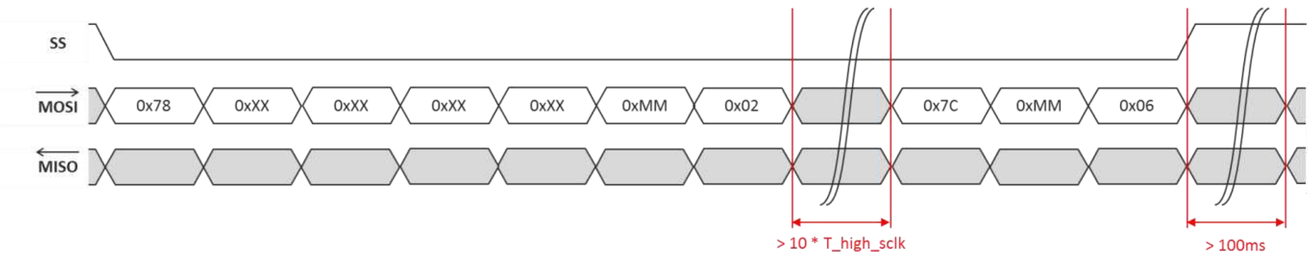


**Figure 25: Sequence of instructions to WRITE data '0xXXXXXXXX' to address '0xMM' of the MTP**

### 6.5.3. Useful Sensor Parameters

The instructions given in Sections 6.5.1 and 6.5.2 can be used to read and/or to modify the sensor's useful parameters given in Table 8 below.

| Parameter | Address M (System Register & MTP) | Bits | Encoding | Meaning |
|---|---|---|---|---|
| **Sensor Identification** | | | | |
| UID | 0x03 | [31:0] | Tronics reserved | Sensor 'Unique Identification' number |
| **Temperature output compensation** | | | | |
| TOUT_SEL | 0x04 | 3 * | 0 **<br>1 | Disable the calibrated temperature output<br>Enable the calibrated temperature output |
| O | 0x04 | [31:18] * | 0x0000 **<br>See section 8 | Offset calibration of temperature sensor |
| G | 0x04 | [17:4] * | 0x0800 **<br>See section 8 | Gain calibration of temperature sensor |
| **Angular rate output compensation** | | | | |
| GOUT_SEL | 0x3D | 31 * | 0<br>1 ** | Disable the calibrated angular rate output<br>Enable the calibrated angular rate output |
| MTPSLOTNB | 0x3D | [12:8] * | 0b00000<br>0b00001 **<br>0b00011<br>0b00111<br>0b01111<br>0b11111 | Unprogrammed part<br>Programmed once, 4 slots remaining<br>Programmed twice, 3 slots remaining<br>Programmed 3 times, 2 slots remaining<br>Programmed 4 times, 1 slot remaining<br>Programmed 5 times, no slot remaining |
| SF4 | 0x48 | [18:0] * | See Table 9 | Scale Factor 4th order coefficient (calibrated angular rate) |
| SF3 | 0x46 | [19:0] * | See Table 9 | Scale Factor 3rd order coefficient (calibrated angular rate) |
| SF2 | 0x44 | [20:0] * | See Table 9 | Scale Factor 2nd order coefficient (calibrated angular rate) |
| SF1 | 0x42 | [29:0] * | See Table 9 | Scale Factor 1st order coefficient (calibrated angular rate) |
| SF0 | 0x3F | [30:0] * | See Table 9 | Scale Factor constant coefficient (calibrated angular rate) |
| B4 | 0x47 | [18:0] * | See Table 9 | Bias 4th order coefficient (calibrated angular rate) |
| B3 | 0x45 | [19:0] * | See Table 9 | Bias 3rd order coefficient (calibrated angular rate) |
| B2 | 0x43 | [19:0] * | See Table 9 | Bias 2nd order coefficient (calibrated angular rate) |
| B1 | 0x41 | [29:0] * | See Table 9 | Bias 1st order coefficient (calibrated angular rate) |
| B0 | 0x3E | [23:0] * | See Table 9 | Bias constant coefficient (calibrated angular rate) |
| TMID | 0x40 | [19:0] * | See Table 9 | Mid-temperature calibration point |

**Table 8: Useful parameters information**

Notes:

* The other bits at those addresses shall remain unchanged. Please make sure that you write them without modification!
** Default Value

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# 7. Angular rate calibration procedure

## 7.1. Algorithm overview

After filtering, the raw angular rate sensor output is temperature compensated based on the on-chip temperature sensor output and the stored temperature compensation parameters.

### 7.1.1. Angular rate output calibration model

The formula below models the link between raw and compensated angular rate outputs:

$$\mathrm{RATE}[°/s] = \frac{\mathrm{RATE_{COMP}}[\mathrm{LSB}]}{\mathrm{SF_{setting}}[\mathrm{LSB}/°/s]} = \frac{\mathrm{RATE_{RAW}}[\mathrm{LSB}] - \mathbf{BIAS}[\mathrm{LSB}]}{\mathbf{SF}[\mathrm{LSB}/°/s]}$$

where:

- RATE is the angular rate output converted in °/s;
- $\mathrm{RATE_{COMP}}$ is the calibrated angular rate output;
- $\mathrm{SF_{setting}}$ is the constant conversion factor from LSB to °/s for the calibrated angular rate output. Default value for this parameter is $\mathrm{SF_{setting}}$ = 10 000;
- $\mathrm{RATE_{RAW}}$ is the raw data angular rate output;
- **BIAS** is a polynomial ($4^{th}$ degree) temperature-varying coefficient to model the sensor's bias temperature variations;
- **SF** is a polynomial ($4^{th}$ degree) temperature-varying coefficient to model the sensor's Scale Factor temperature variations.

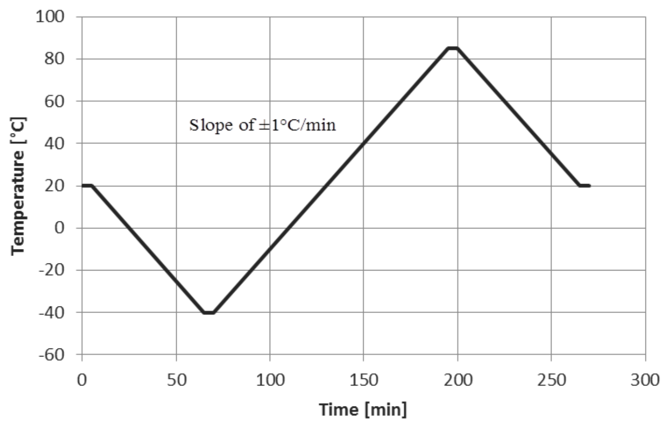


**Figure 26: Recommended Temperature profile for calibration**

### 7.1.2. Recommended procedure

1. Set GOUT_SEL to 0 in the System Registers (disable the calibration)
2. Place the sensor on a rate table in a thermal chamber and implement temperature profile according to Figure 26[1]
3. Perform continuous acquisition of the angular rate output with the following pattern:
   - Rest position (0°/s input) to evaluate the BIAS parameter
   - + 300°/s input then -300°/s input to evaluate the SF parameter[2]
4. Calculate the coefficients of BIAS and SF polynomials:

$$\mathrm{BIAS} = \sum_{i=0}^{4} \mathrm{b}_i(\mathrm{T_{RAW}} - \mathrm{T_{MID}})^i$$

$$SF = \sum_{i=0}^{4} \mathrm{sf}_i(\mathrm{T_{RAW}} - \mathrm{T_{MID}})^i$$

where

- $\mathrm{T_{RAW}}$ is the raw output of the temperature sensor **multiplied by 64**;
- $\mathrm{T_{MID}}$ is the mid-value of $\mathrm{T_{RAW}}$;
- $b_0$ to $b_4$ are the 5 coefficients of BIAS polynomial;
- $sf_0$ to $sf_4$ are the 5 coefficients of SF polynomial.

5. Convert $\mathrm{T_{MID}}$, $b_i$ and $sf_i$ parameters to their binary values according to Table 9 below:

| Parameter | Value (decimal) | Format |
|---|---|---|
| SF4 | $sf_4 . 2^{92} / SF_{setting}$ | signed 2's comp |
| SF3 | $s3_2 . 2^{72} / SF_{setting}$ | signed 2's comp |
| SF2 | $sf_2 . 2^{55} / SF_{setting}$ | signed 2's comp |
| SF1 | $sf_1 . 2^{46} / SF_{setting}$ | signed 2's comp |
| SF0 | $sf_0 . 2^{27} / SF_{setting}$ | signed 2's comp |
| B4 | $b_4 . 2^{73}$ | signed 2's comp |
| B3 | $b_3 . 2^{53}$ | signed 2's comp |
| B2 | $b_2 . 2^{32}$ | signed 2's comp |
| B1 | $b_1 . 2^{20}$ | signed 2's comp |
| B0 | $b_0$ | signed 2's comp |
| TMID | $T_{MID}$ | unsigned |

**Table 9: Angular rate calibration parameters**

[1] Temperature profile can be adapted to be in line with customer applications.
[2] Rate applied can be adapted to be in line with customer applications.

## 7.2. Programming of the new coefficients

**IMPORTANT NOTE:** The following steps are **non-reversible**. The previous values of the coefficients will not be accessible anymore. The temperature compensation coefficients can be re-programmed up to 4 additional times on the IC.

The programming procedure consists in three major steps:

- Checking the available MTP slot status
- Programming the coefficients
- Updating the available MTP slot status

An overview of the procedure is given in Figure 27.

### 7.2.1. Checking the MTP slot status

The first step is to check the number of remaining MTP slots (MTPSLOTNB), in other words, checking how many times the chip has been programmed before.

The detailed information of MTPSLOTNB register content is given in Table 8. The sequence of instructions to read the register is given in Figure 24.

The MTP slot number (MTPSLOTNB) re-programming iteration is given in the following table:

| Iteration | Correspondence | MTP number | |
|---|---|---|---|
| | | Value | Binary |
| 0 | Unprogrammed part | 0 | 00000 |
| 1 | Programmed once | 1* | 00001 |
| 2 | Programmed twice | 3 | 00011 |
| 3 | … | 7 | 00111 |
| 4 | | 15 | 01111 |
| 5 | Cannot be further programmed | 31 | 11111 |

**Table 10 MTPSLOTNB iterations**

* Default value

### 7.2.2. Programming the coefficients

This step describes the procedure for programming the calculated coefficients (temperature compensation of angular rate output). The programming procedure is:

1. Write SF4 in the system register
2. Program SF4 in the MTP
3. Write SF3 in the system register
4. Program SF3 in the MTP
5. Write SF2 in the system register
6. Program SF2 in the MTP
7. Write SF1 in the system register
8. Program SF1 in the MTP
9. Write SF0 in the system register
10. Program SF0 in the MTP
11. Write B4 in the system register
12. Program B4 in the MTP
13. Write B3 in the system register
14. Program B3 in the MTP
15. Write B2 in the system register
16. Program B2 in the MTP
17. Write B1 in the system register
18. Program B1 in the MTP
19. Write B0 in the system register
20. Program B0 in the MTP
21. Write TMID in the system register
22. Program TMID

The detailed SPI commands are given in section 6.5. The detailed information about each coefficient is given in Table 8.

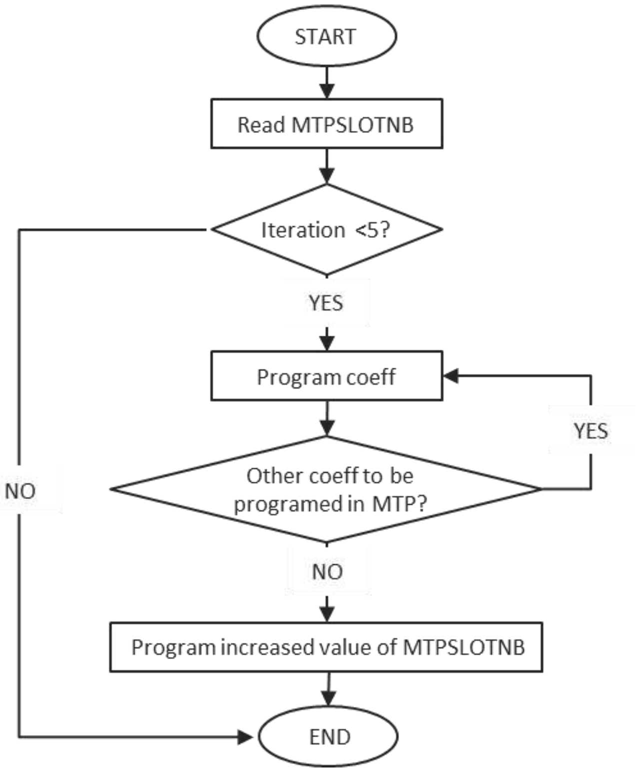


**Figure 27 Procedure to program new calibration parameters**

### 7.2.3. Updating MTP slot status

This section describes the procedure for programming the updated status of the MTP slots.

**If this step is not performed properly, the new compensation coefficients will not be effective.**

1. Read the MTPSLOTNB as described in section 6.5.2
2. Increment MTPSLOTNB according Table 10.
3. Write the updated MTPSLOTNB in the system register.
4. Program the updated MTPSLOTNB in the MTP.
5. After a reset, the new coefficients will be available.

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## 7.3. Switch to uncompensated data output

To optimize the thermal compensation of the angular rate output, it is possible to disable the on-chip compensation and use the uncompensated (raw) output to perform an external thermal compensation.

**IMPORTANT NOTE:** This step is **non-reversible**. The previous values of the coefficients will not be accessible anymore.

To switch the angular rate output to uncompensated data, the procedure is exactly the same as describe in section 7.2, but the coefficients given in Table 9 must be replaced by the coefficients given below in Table 11.

| Parameter | Value (hexadecimal) |
|---|---|
| SF4 | 0x0 |
| SF3 | 0x0 |
| SF2 | 0x0 |
| SF1 | 0x0 |
| SF0 | 0x0800 0000 |
| B4 | 0x0 |
| B3 | 0x0 |
| B2 | 0x0 |
| B1 | 0x0 |
| B0 | 0x0 |
| TMID | 0x0 |

**Table 11 Angular rate compensation coefficients to obtain raw data**

# 8. Temperature Sensor Calibration Procedure

The temperature output of GYPRO3300 sensors is *not* factory-calibrated, since only the relative temperature output is needed to perform temperature compensation of the angular rate output. However, it is possible to perform a first-order polynomial calibration of the temperature sensor, in order to output the absolute temperature information.

This section shows how to get and store temperature calibration parameters for the temperature output.

## 8.1. Temperature sensor calibration model

The formula below models the link between raw and calibrated temperature output:

$$T[°C] = \frac{T_{COMP}[LSB]}{GAIN_{setting}[LSB/°C]} = \frac{\mathbf{GAIN} \,.\, T_{RAW}[LSB] - \mathbf{OFFSET}[LSB]}{GAIN_{setting}[LSB/°C]}$$

where:

- T is the output temperature converted in °C;
- $T_{COMP}$ is the calibrated temperature output;
- $GAIN_{setting}$ is the constant conversion factor from LSB to °C for the calibrated temperature output. This gain is set to 20LSB/°C to provide an output resolution of 0,1°C;
- $T_{RAW}$ is the raw data temperature output;
- **OFFSET** is a constant coefficient to tune the offset;
- **GAIN** is a constant coefficient to tune gain.

The **OFFSET** and **GAIN** parameters will be computed and written in the ASIC as per the following calibration procedure.

## 8.2. Recommended Procedure

1. Check that TOUT_SEL = 0. If not, set it to 0 in the System Registers.
2. Measure the temperature output with at least 2 temperature points $T_1$ and $T_2$.
3. Calculate the GAIN and OFFSET coefficients according to formula above

$$GAIN = GAIN_{setting} \cdot \frac{T1_{ABS}[°C] - T2_{ABS}[°C]}{T1_{RAW}[LSB] - T2_{RAW}[LSB]}$$

$$OFFSET = GAIN_{setting} \,.\, T1_{ABS}[°C] - GAIN \,.\, T1_{RAW}[LSB]$$

where:

- $T1_{ABS}$ is the absolute temperature of $T_1$ in °C;
- $T2_{ABS}$ is the absolute temperature of $T_2$ in °C;
- $T1_{RAW}$ is the raw output temperature of $T_1$ in LSB;
- $T2_{RAW}$ is the raw output temperature of $T_2$ in LSB;

4. Convert GAIN and OFFSET to their binary values according to Table 12 below:

| Parameter | Value (decimal) | Format |
|---|---|---|
| G | GAIN . $2^{11}$ | Unsigned |
| O | OFFSET | Unsigned |

**Table 12: Temperature calibration parameters**

5. [Optional step: Write GAIN and OFFSET into the System Registers and repeat step 2. to check the accuracy of the new calibration.]
6. Write GAIN and OFFSET into the MTP according to instructions of Section 6.5.2. Meanwhile, set TOUT_SEL to 1 during this step, so that the new calibration parameters are effective after a RESET.

# 9. Device Identification

GYPRO3300 tracking information is accessible on the label, as shown in the next figure.

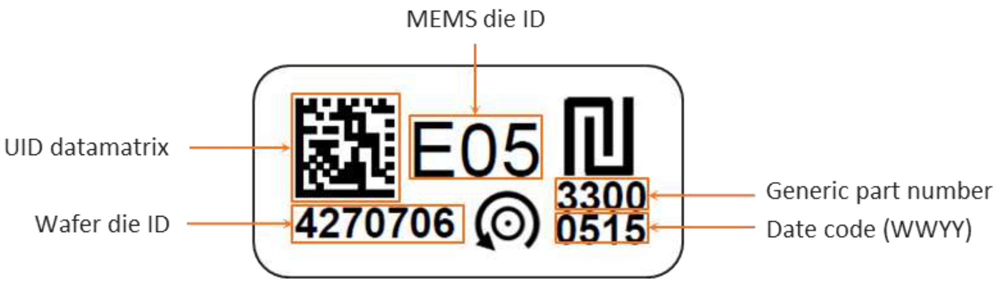


**Figure 28: GYPRO3300 label.**

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## 10. Internal construction and Theory of Operation

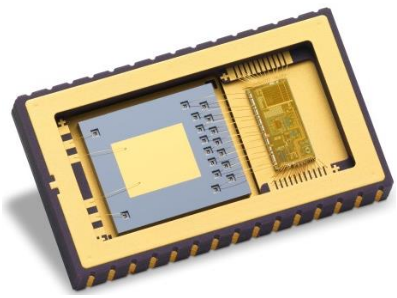

**Figure 29 : Inner view of the package, showing the MEMS and IC**

GYPRO series is using the dominant architecture for high performance MEMS gyro, namely the "Tunning fork or dual mass" design.

In details, each sensor consists in a MEMS transducer and an integrated circuit (IC) packaged in a 30-pins Ceramic Leadless Chip Carrier Package.

The sensing element (MEMS die), which is located on the left part of the Figure 29, is manufactured using Tronics' wafer-level packaging technology based on micro-machined thick single crystal silicon. The MEMS consists of two coupled sub-structures subjected to linear anti-phase vibrations. The structures are vacuumed at the wafer-level providing high Q-factor in the drive mode. The drive system is decoupled from the sense system in order to reduce feedback from sense motion to drive electrodes. The drive anti phase vibration is sustained by electrostatic comb drives. The sense anti phase vibration resulting from Coriolis forces is counter balanced by electrostatic forces. Differential detection and actuation are used for both drive and sense systems and for each sub-structure, keeping two identical structures for efficient common mode rejection.

The integrated circuit (IC), which is located on the right part of the Figure 29, is designed to interface the MEMS sensing element. It includes ultra-low noise capacitive to voltage converters (C2V) followed by high resolution voltage digitization (ADC) for both drive and sense paths. Excitation voltage required for capacitance sensing circuits is generated on the common electrode node. 1-bit force feedbacks (DAC) are used for both drive and sense system actuation.

The choice for the implemented close-loop architecture based on a Sigma-Delta principle is particularly well adapted as it brings the following key advantages:

1) Sigma-Delta is well suited for low-frequency signals. Noise shaping principle rejects quantization noise in high frequency bands.

2) Simplicity of hardware implementation. Oversampling concept allows significant design relaxation of the analog detection chain signal resolution. Additionally the voltage reference used for actuation force feedback is also of simple implementation as it is a 1-bit D/A converter, thus simplifying its design.

3) Linearization of the electrostatic forces thanks to the Sigma-delta principle (through force averaging) furthermore reduces non-linearity overall and more importantly its even-order terms, which result in rectification error.

4) Sigma-Delta signal output is inherently a digital signal, thus suppressing the need for costly high resolution A/D converter.

The digital part implements digital drive and sense loops, demodulates, decimates and processes the gyro output based on the on-chip temperature sensor output. The system controller manages the interface between the SPI registers, the system register and the non-volatile memory (OTP). The non-volatile memory provides the gyro settings, in particular the coefficients for angular rate sensor temperature compensation. On power up, the gyro settings are transferred from the OTP to the system registers and output data are available in the SPI registers. The angular rate sensor output and the temperature sensor output are available in the SPI registers. The SPI registers are available through the SPI interface (SSB, SCLK, MOSI, MISO). The self-test and the data ready are available respectively on the external pins ST and DRDY.

The "References" block generates the required biasing currents and voltages for all blocks as well as the low-noise reference voltage for critical blocks.

The "Power Management" block manages the power supply of the sensor from a single 5V supply between the VDD and GND pins. It includes a power on reset as well as an external reset pin (RSTB) to start or restart operation using default configuration. An enable pin (EN) with power-down capability is also available.

The sensor is powered with a single 5V DC power supply through pins VDD and GND. Although the sensor contains three separate VDD pins, the sensor is supplied by a single 5V voltage source. It is recommended to supply the three VDD pins in a star connection with appropriate decoupling capacitors. Regarding the sensor grounds, all the GND pins are internally shorted. The GND pins redundancy is used for multiple bonds in order to reduce the total ground inductance. It is therefore recommended to connect all the GND pins to the ground.

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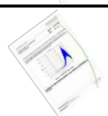
## 11. Available Tools and Resources

The following tools and resources are available the GYPRO® product page of our **website** or upon request.

| Item | Description |
|---|---|
| **Documentation & technical notes** | |
|  | **GYPRO® Product line -** Flyer |
|  | **GYPRO® product –** Technical note<br>External filtering for Gypro2300LD and Gypro3300 |
|  | **GYPRO® product** – Technical note<br>GYPRO MTBF Methodology |
| **Mechanical tools** | |
|  | **GYPRO3300 – 3D model** |
| **Evaluation kit** | |
|  | **GYPRO3300-EVB2** – Evaluation board<br>Evaluation board for GYPRO3300, compatible with Arduino M0 |
|  | **GYPRO® Evaluation Board** – User manual |
|  | **GYPRO® Evaluation Kit** – Quick start guide |
|  | **GYPRO® Evaluation Tool** – Software user manual |
|  | **GYPRO® Evaluation Tool** – Tutorial<br>Installation and programming of the Evaluation kit |
|  | **GYPRO® Evaluation Tool** – Tutorial<br>Software |
|  | **GYPRO® Evaluation Tool** – Software |
|  | **GYPRO® Evaluation Tool** – Arduino Firmware |