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PS-IDG-0400B-00-06
Release Date: 04/13/10

IDG-400 Dual-Axis Gyro Product Specification

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1. Revision History

Revision Date	Revision	Description
4/04/08	01	Initial Release
5/01/08	02	Updated Diagram
8/28/08	03	Updated Spec Table
9/19/08	04	Updated PCB Pad Layout Diagram and Materials Declaration Datasheet
07/28/09	05	Updated noise specification, tape and reel specification, reflow specification and profile, and qualification test policy. Widened operating temperature range. Removed PCB pad layout diagram, removed environmental compliance section. Several formatting and textual changes.
04/13/10	06	Removed confidentiality mark



2. Purpose

The purpose of this document is to provide a detailed product description and design-related information regarding the IDG-400 dual-axis gyroscope.

3. Product Overview

The IDG-400 is a state-of-the-art dual-axis gyroscope designed specifically for complex motion sensing in 3D-input devices and gaming controllers. The IDG-400 gyroscope utilizes state-of-the-art MEMS fabrication with wafer-scale integration technology. This technology combines completed MEMS wafers and completed CMOS electronic wafers together using a patented and proprietary wafer-scale bonding process that simultaneously provides electrical connections and hermetically sealed enclosures. This unique and novel fabrication technique is the key enabling technology that allows for the design and manufacture of high performance, multi-axis, integrated MEMS gyroscopes in a very small and economical package. Integration at the wafer-level minimizes parasitic capacitances, allowing for improved signal-to-noise over a discrete solution.

4. Features

By integrating the control electronics with the sensor elements at the wafer level, the IDG-400 gyroscope supports a rich feature set including:

- Integrated X- and Y-axis gyros on a single chip
- 500°/s full scale range with 2.0mV/°/s sensitivity
- Integrated amplifiers and low-pass filters
- High vibration rejection over a wide frequency range
- High cross-axis isolation by proprietary MEMS design
- 3V single-supply operation
- Hermetically sealed for temp and humidity resistance
- 10,000 g shock tolerant
- Smallest dual axis gyro package at 4 x 5 x 1.2mm
- RoHS and Green Compliant

5. Functional Block Diagram

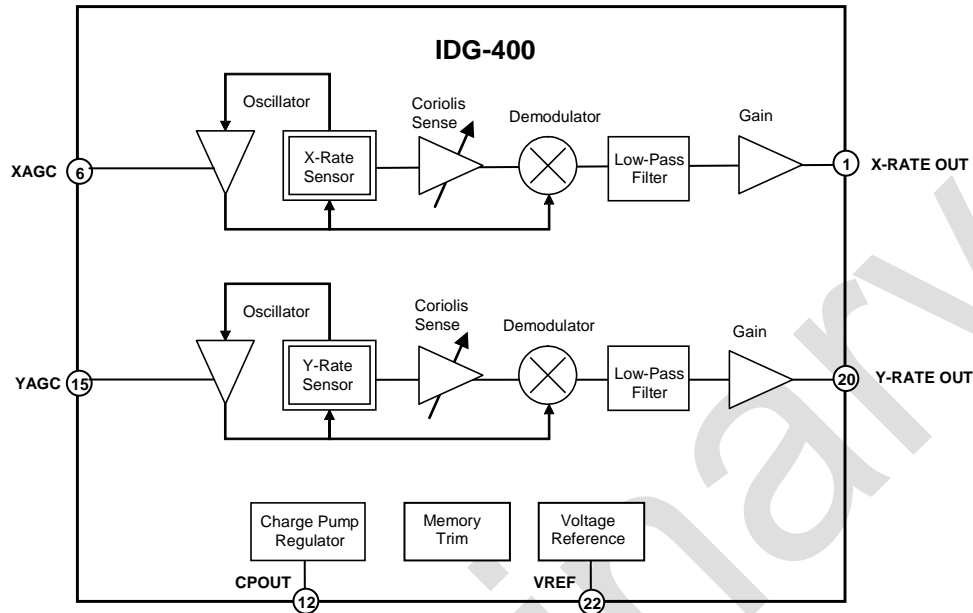


Figure 1

6. Functional Description

6.1 Overview

The IDG-400 gyroscope consists of two independent vibratory MEMS gyroscopes. One detects rotation about the X-axis; the other detects rotation about the Y-axis.

The gyroscope's proof-masses are electrostatically oscillated at resonance. An internal automatic gain control circuit precisely controls the oscillation of the proof masses. When the sensor is rotated about the X- or Y-axis, the Coriolis Effect causes a vibration that can be detected by a capacitive pickoff. The resulting signal is amplified, demodulated, and filtered to produce an analog voltage that is proportional to the angular rate.

6.2 Rate Sensors

The mechanical structures for detecting angular rate about the X- and Y-axes are fabricated using InvenSense's proprietary bulk silicon technology. The structures are covered and hermetically sealed at the wafer level. The cover shields the gyro from electromagnetic and radio frequency interferences (EMI/RFI). The dual-mass design inherently rejects any signal caused by linear acceleration. The X-gyro and the Y-gyro have different resonant frequencies to prevent undesired coupling.

6.3 Oscillator Circuit

The oscillator circuit generates electrostatic forces to vibrate the structure at resonance. The circuit detects the vibration by measuring the capacitance between the oscillating structure and a fixed electrode. The oscillator circuit switches in quadrature phase with the capacitance measurement in order to vibrate at resonance.

6.4 Amplitude Control

The scale factor of the gyroscope depends on the amplitude of the mechanical motion and the trim setting of the internal programmable gain stages. The oscillation circuit precisely controls the amplitude to maintain



constant sensitivity over the temperature range. The capacitors ($0.22\mu\text{F} \pm 10\%$) connected to Pin 6 (XAGC) and Pin 15 (YAGC) are compensation capacitors for the amplitude control loops.

6.5 Coriolis Sense

Rotating the sensor about the X- or Y-axis results in a Coriolis force on the corresponding X- or Y-rate sensor. The Coriolis force causes the mechanical structure to vibrate in-plane. The resulting vibration is detected by measuring the capacitance change between the mechanical structure and fixed electrodes. This signal is converted to a voltage waveform by means of low-noise charge integrating amplifier and amplification stages.

6.6 Demodulator

The output of the Coriolis sense is an amplitude modulated waveform. The amplitude corresponds to the rotation rate, and the carrier frequency is the mechanical drive frequency. The synchronous demodulator converts the Coriolis sense waveform to the low-frequency, angular rate signal.

6.7 Low-Pass Filter

After the demodulation stage, there is a low-pass filter. This filter attenuates noise and high frequency artifacts before final amplification.

6.8 Charge Pump

The on-chip charge pump generates the voltage required to oscillate the mechanical structure.

6.9 Memory Trim

The on-chip memory is used to select the gyro's sensitivity, calibrate the sensitivity, null DC offsets and select the low-pass filter option

6.10 Scale Factor

The Rate-Out of the gyros is not ratiometric to the supply voltage. The scale factor is calibrated at the factory and is nominally independent of supply voltage.

6.11 Reference Voltage

The gyro includes a bandgap reference circuit. The output voltage is typically 1.23V and is nominally independent of temperature. The zero-rate signal is nominally equal to the reference value.

6.12 Analog Outputs

The IDG-400 gyro has independent X and Y-outputs (X-OUT and Y-OUT), each with a full scale range of $\pm 500^\circ/\text{sec}$ and a sensitivity of $2\text{mV}/^\circ/\text{sec}$.



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7. Specification

7.1 Specified Parameters

All parameters specified are @ VDD = 3.0 V and T_A = 25°C. External LPF @ 2kHz. All specifications apply to both axes.

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
SENSITIVITY					
Full-Scale Range	At X-OUT and Y-OUT		±500		°/s
Sensitivity	At X-OUT and Y-OUT		2.0		mV/°/s
Initial Calibration Tolerance	At X-OUT and Y-OUT		±6		%
Calibration Drift Over Specified Temperature	At X-OUT and Y-OUT		±10		%
Nonlinearity	At X-OUT and Y-OUT, Best Fit Straight Line		<1		% of FS
Cross-axis Sensitivity			±1		%
ZERO-RATE OUTPUT					
Static Output (Bias)	Factory Set		1.5		V
Initial Calibration Tolerance			±200		mV
Over Specified Temperature			±100		mV
Power Supply Sensitivity	@ 50Hz		10		°/sec/V
REFERENCE					
Voltage (VREF)	Factory set		1.23		V
Load Drive			1		mA
Capacitive Load Drive	Load directly connected to VREF		100		pF
Power Supply Rejection	VDD= 3.0V to 3.3V		1		mV/V
Reference Drift Over Specified Temperature			±5		mV
FREQUENCY RESPONSE					
High Frequency Cutoff	Internal LPF -90°		140		Hz
LPF Phase Delay	10Hz		-4.5		°
MECHANICAL FREQUENCIES					
X-Axis Resonant Frequency		20	24	28	kHz
Y-Axis Resonant Frequency		23	27	31	kHz
Frequency Separation	X and Y Gyroscopes		3		kHz
NOISE PERFORMANCE					
Total RMS Noise	Bandwidth 1Hz to 1kHz, At X-OUT and Y-OUT		0.8		mV rms
OUTPUT DRIVE CAPABILITY					
Output Voltage Swing	Load = 100kΩ to Vdd/2	0.05		Vdd-0.05	V
Capacitive Load Drive			100		pF
Output Impedance			100		Ω
POWER ON-TIME					
Zero-rate Output	Settling to ±3°/s		50	200	ms
POWER SUPPLY (VDD)					
Operating Voltage Range		2.7		3.3	V
Quiescent Supply Current			7		mA
Supply Current Change Over Specified Temperature			±2		mA
TEMPERATURE RANGE					
Specified Temperature Range		-20		+85	°C



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7.2 Recommended Operating Conditions

Parameter	Min	Typ	Max	Unit
Power Supply Voltage (VDD)	2.7	3.0	3.3	V
Power Supply Voltage (VDD) Rise Time (10% - 90%)			20	ms

7.3 Absolute Maximum Ratings

Stress above those listed as “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device under these conditions is not implied. Exposure to the absolute maximum rating conditions for extended periods may affect device reliability.

Parameter	Rating
Supply Voltage	-0.3V to +3.6V
Acceleration (Any Axis, unpowered)	10,000g for 0.3ms
Operating Temperature Range	-40 to +105°C
Storage Temperature Range	-40 to +125°C

7.4 Reference Circuit

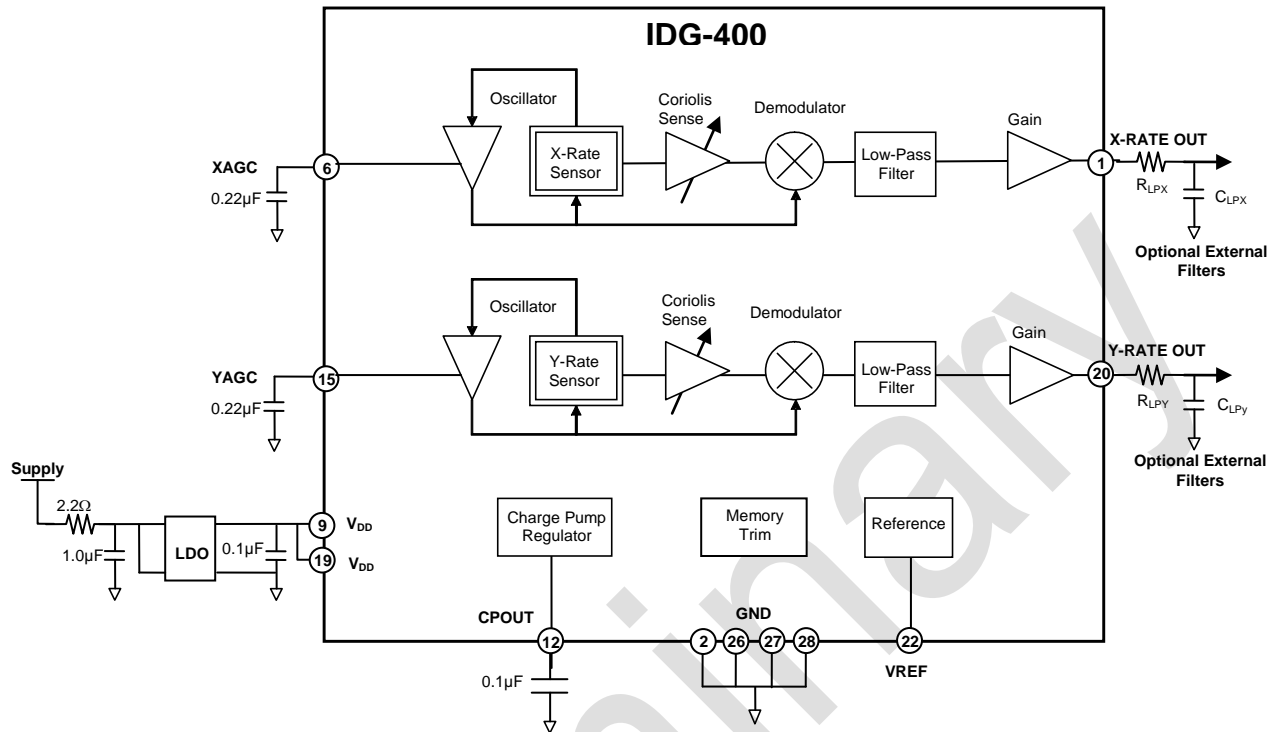


Figure 2

7.4.1 Bill of Material for External Components

Component	Specification
Low Pass Filter Capacitors	0.1µF ±20% / 10V
AGC Capacitors	0.22µF ±10% / 10V
VDD Bypass Capacitor	0.1µF ±20% / 10V
Charge Pump Capacitor	0.1µF ±20% / 25V
LDO Input Filter Capacitor	1.0µF / Ratings Dependent upon Supply Voltage
LDO Input Filter Resistor	2.2Ω ±1%
Low Pass Filter Resistors	750Ω ±1%
VDD Bypass Capacitor	0.1µF ±20% / 10V

8.2 Design Considerations

8.2.1 Power Supply Rejection Ratio

The gyro is most susceptible to power supply noise (ripple) at frequencies less than 100Hz. At less than 100Hz, the PSRR is determined by the overall internal gain of the gyroscope. Above 100Hz, the PSRR is determined by the characteristics of the on-chip low-pass filter. Above 1kHz, the PSRR is relatively constant except for two narrow frequency ranges corresponding to the resonant frequencies of the X and Y gyroscopes.

8.2.2 Power Supply Filtering

The power supply voltage (VDD) rise time (10% - 90%) must be less than 20ms at VDD (Pin 9, 19) for proper device operation.

The IDG-400 gyroscope should be isolated from system power supply noise by a combination of an RC filter that attenuates high frequency noise and a Low Drop Out power supply regulator (LDO) that attenuates low frequency noise. Figure 4 shows a typical configuration.

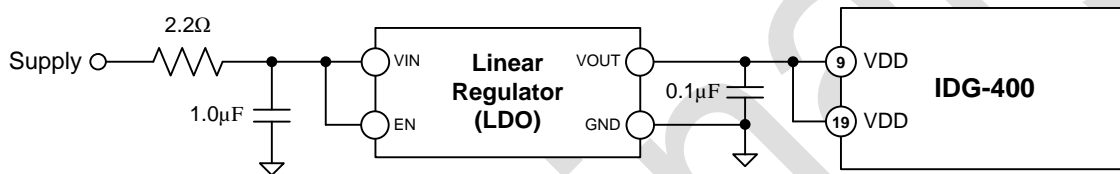


Figure 4

The low-pass RC filter should be chosen such that it provides significant attenuation of system noise at high frequencies. The LDO should be a low noise regulator ($<100\mu\text{V}/\text{rtHz}$) that exhibits good noise rejection at low frequencies.

8.2.3 Amplitude Control

The scale factor of the gyroscope depends on the amplitude of the mechanical motion and the trim setting of the internal programmable gain stages. The oscillation circuit controls the amplitude to maintain constant sensitivity over the specified temperature range. The capacitors connected to Pin 6 (XAGC) and Pin 15 (YAGC) are compensation capacitors for the amplitude control loops.

8.2.4 Internal Low-Pass Filter

After the demodulation stage, there is a low-pass filter. This filter limits noise and high frequency artifacts from the demodulator before final amplification. The following graph shows the typical gain and phase response. The low-pass filter has been designed for a nominally flat gain up to the cutoff frequency while still achieving a low phase delay at 10Hz and 30Hz.

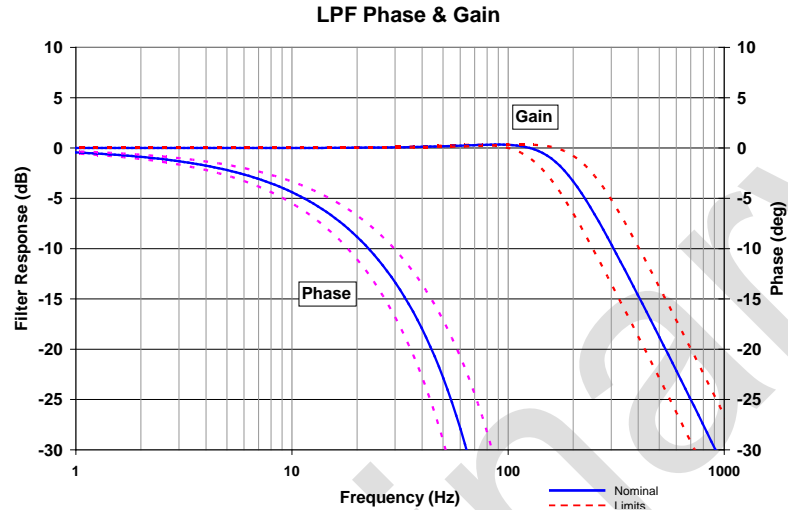


Figure 5

8.2.5 External Low-Pass Circuitry

To further attenuate high-frequency noise, an optional external low-pass filter may be used.

8.2.6 Gyro Outputs

The IDG-400 gyro has independent X and Y outputs, with scale factors and full-scale sensitivities as summarized below.

Axis	Gyro Output	Sensitivity (mV/°/s)	Full-Scale Range (±°/s)
X	X-OUT	2.0	500
Y	Y-OUT	2.0	500

The IDG-400 gyro outputs are independent of supply voltage (i.e. they are not ratiometric).

Gyro rotation rate is calculated as:

$$(Gyro\ Output\ Voltage - Gyro\ Zero-Rate\ Out) / Sensitivity$$

where the Zero-Rate Output (ZRO) is nominally VREF. There is a temperature dependence to ZRO, and an initial accuracy to ZRO.

8.2.7 High Impedance Nodes

XAGC (pin 6) and YAGC (pin 15) pins are high impedance (>1Mohm) nodes. Any coating, glue or epoxy on these pins or on the capacitors connected to these pins, will affect part performance and should be avoided.

8.2.8 Charge Pump

The on-chip charge pump requires a bypass capacitor for stable operation. This capacitor should be $0.1\mu\text{F}$ and rated for 25V.

8.2.9 Proper Interface Cleaning

Proper cleaning of PCB solder pads prior to assembly is recommended. PCB surface contaminants at XAGC (pin 6) or YAGC (pin 15) device interfaces may affect part performance.

8.2.10 Acoustic Noise Sensitivity

The IDG-400 gyroscope is insensitive to acoustic vibration except for a narrow frequency range near the gyro's resonant frequency. The typical bandwidth of the acoustic sensitivity is 200Hz. It is recommended that products using the IDG-400 gyroscope be designed such that the acoustic noise in the 20kHz to 31kHz range be attenuated by the product's enclosure.

8.2.11 Electrostatic Discharge Sensitivity

The IDG-400 gyroscope can be permanently damaged by an electrostatic discharge. ESD precautions for handling and storage are recommended.

9. Assembly

9.1 Orientation

The diagram below shows the orientation of the axes of sensitivity and the polarity of rotation.

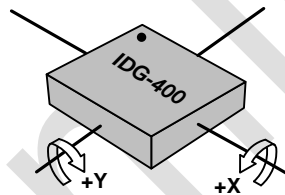


Figure 6

9.2 Package Dimensions

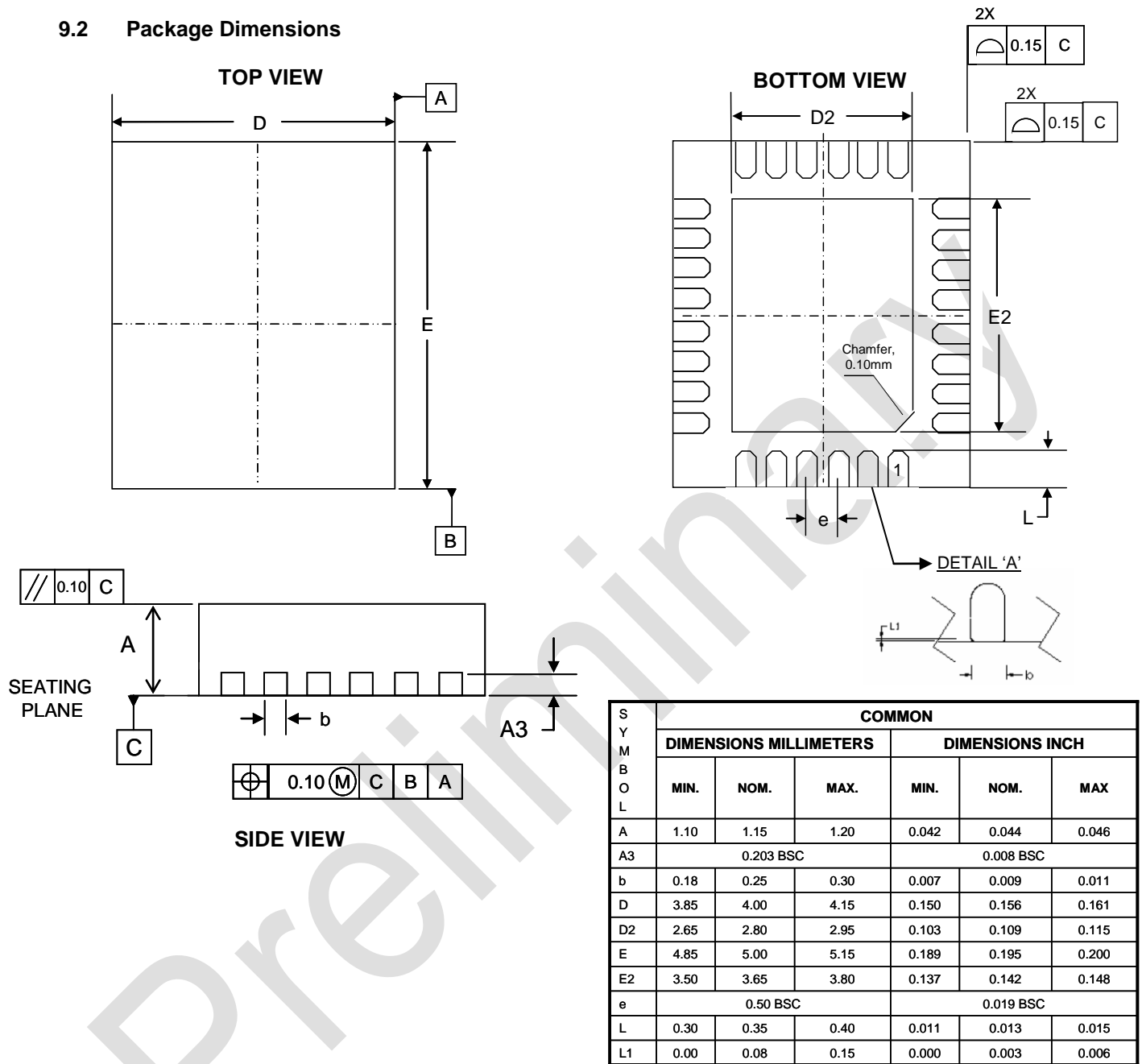
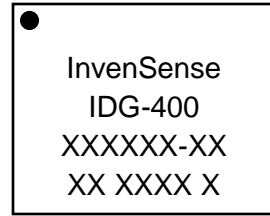


Figure 7

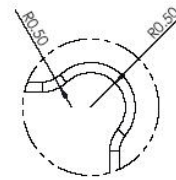
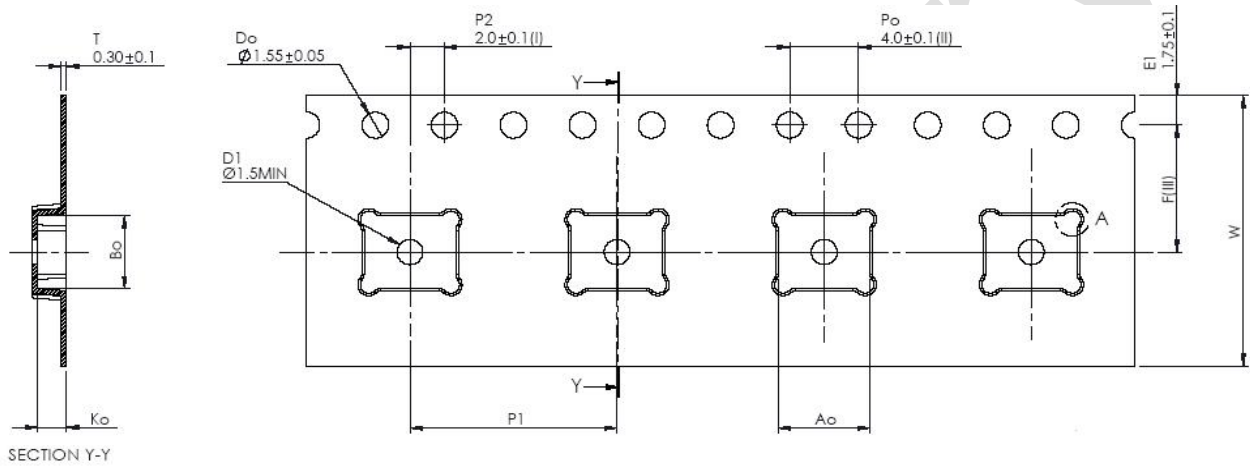
9.3 Package Marking Specification

- Line 1 = Company Name
- Line 2 = Part Number
- Line 3 = Lot Traceability Code
- Line 4 = Fabricator, Assembly, Date Code, Revision



Top View

9.4 Tape & Reel Specification

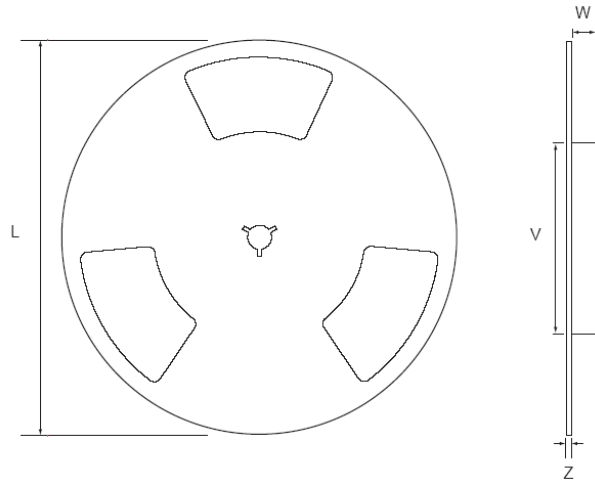


DETAIL 'A'

- (I) Measured from centerline of sprocket hole to centerline of pocket.
 - (II) Cumulative tolerance of 10 sprocket holes is ± 0.20 .
 - (III) Measured from centerline of sprocket holes to centerline of pocket.
 - (IV) Other material available.
- ALL DIMENSIONS IN MILLIMETERS UNLESS OTHERWISE STATED.

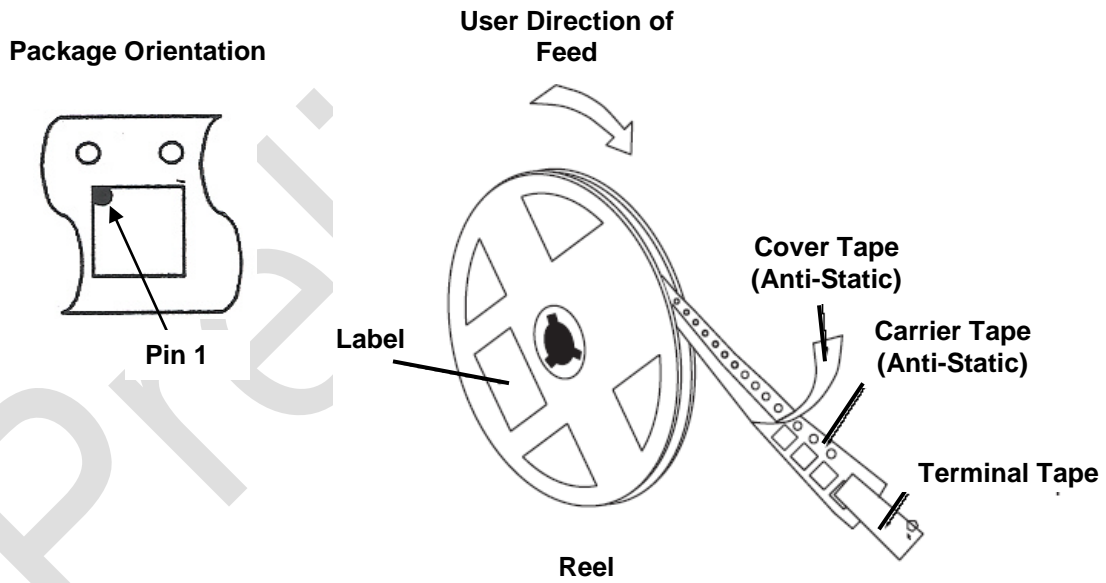
PKG SIZE	CARRIER TAPE (mm)							
	Tape Width (W)	Pocket Pitch (P1)	Ao	Bo	Ko	F	Leader Length (Min.)	Trailer Length (Min.)
4x5	16.00 ± 0.3	12.00 ± 0.1	5.30 ± 0.1	4.30 ± 0.1	1.65 ± 0.1	7.50 ± 0.1	300	300

Figure 8



PKG SIZE	REEL (mm)			
	L	V	W	Z
4x5	330	100	16.4	3.0

Figure 9



Quantity Per Reel	5000
Reels per Pizza Box	1
Pizza Boxes Per Carton (max)	3 full pizza boxes packed in the center of the carton, buffered by two empty pizza boxes (front and back).
Pieces/Carton (max)	15,000

Figure 10



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9.4.1 Label

InvenSense
 DEVICE (1P) : IDG-XXXXX
 LOT 1 (1T) : XXXXXX-X D/C (D) : XXXX
 LOT 2 (1T) : XXXXXX-X D/C (D) : XXXX
 Reel Date: XX/XX/XX

REEL QTY (Q) : XXXX
 QTY (Q) : XXXX
 QTY (Q) : XXXX
 QC STAMP



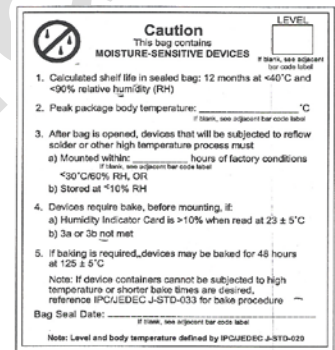
Location of Label

9.4.2 Packing



Moisture Barrier Bag With Labels

Anti-static Label
 Moisture-Sensitive Caution Label
 Tape & Reel Label



Moisture-Sensitive Caution Label



Reel in Pizza Box



Pizza Box with Tape & Reel Label

9.5 Trace Routing

Routing traces or vias under the gyro package such that they run under the exposed die pad is prohibited.

9.6 Soldering Exposed Die Pad

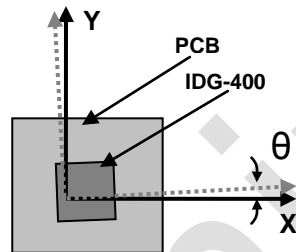
The exposed die pad is internally connected to VSS. The exposed die pad should not be soldered to the PCB since soldering to it contributes to performance changes due to package thermo-mechanical stress.

9.7 Component Placement

Testing indicates that there are no specific design considerations other than generally accepted industry design practices for component placement near the IDG-400 gyroscope to prevent noise coupling, and thermo-mechanical stress.

9.8 PCB Mounting and Cross-Axis Sensitivity

Orientation error of the gyroscope mounted to the printed circuit board can cause cross-axis sensitivity in which one gyro responds to rotation about the other axis, for example, the Y-axis gyroscope responding to rotation about the X-axis. The orientation mounting error is illustrated in Figure 12.



Packaged Gyro Axis (-----) Relative to PCB Axes (—) with Orientation Error θ .

Figure 11

The table below shows the cross-axis sensitivity as a percentage of the specified gyroscope's sensitivity for a given orientation error.

Orientation Error	Cross-Axis Sensitivity
Theta (θ)	$\sin\theta$
0°	0%
0.5°	0.87%
1°	1.75%

The specification for cross-axis sensitivity in Section 7.1 includes the effect of the die orientation error with respect to the package.

9.9 AGC Nodes

The gyro pins marked XAGC and YAGC are high impedance nodes that are sensitive to current leakage, which can impact gyroscope performance. Care should be taken to ensure that these nodes are not contaminated by residue such as flux and are clean.

9.10 MEMS Handling Instructions

MEMS (Micro Electro-Mechanical Systems) are a time-proven, robust technology used in hundredstens of millions of consumer, automotive and industrial products. MEMS devices consist of microscopic moving mechanical structures. They differ from conventional IC products even though they can be found in similar packages. Therefore, MEMS devices require different handling precautions than conventional ICs prior to mounting onto printed circuit boards (PCBs).



InvenSense's dual-axis gyroscopes utilize MEMS technology which consists of microscopic moving silicon structures to sense rotations and have a shock tolerance of 10,000g. InvenSense packages its gyroscopes as it deems proper for protection against normal handling and shipping. It recommends the following handling precautions to prevent potential damage.

1. Individual or trays of gyroscopes should not be dropped on hard surfaces. Components in trays if dropped could be subjected to g -forces in excess of 10,000g.
2. Printed circuit boards with mounted gyroscopes should not be separated by manually snapping apart. This could create g -forces in excess of 10,000g.

9.11 Gyroscope Surface Mount Guidelines

Any material used in the surface mount assembly process of the MEMS gyroscope should be free of restricted RoHS elements or compounds. Pb-free solders should be used for assembly.

In order to assure gyroscope performance, several industry standard guidelines need to be considered for surface mounting. These guidelines are for both printed circuit board (PCB) design and surface mount assembly and are available from packaging and assembly houses.

When using MEMS gyroscope components in plastic packages, package stress due to PCB mounting and assembly could affect the output offset and its value over a wide range of temperatures. This is caused by the mismatch between the Coefficient Temperature Expansion (CTE) of the package material and the PCB. Care must be taken to avoid package stress due to mounting.

9.12 Reflow Specification

The approved solder reflow curve shown in the figure below conforms to IPC/JEDEC J-STD-020C (reflow) with a maximum peak temperature ($255 \pm 5/0^\circ\text{C}$). This is specified for component-supplier reliability qualification testing using lead-free solder. All temperatures refer to the topside of the QFN package, as measured on the package body surface. Customer solder-reflow processes should use the solder manufacturer's recommendations, making sure to never exceed the constraints listed in the table and figure below, as these represent the maximum tolerable ratings for the device. For optimum results, production solder reflow processes should use lower temperatures, reduced exposure times to high temperatures, and lower ramp-up and ramp-down rates than those listed below.

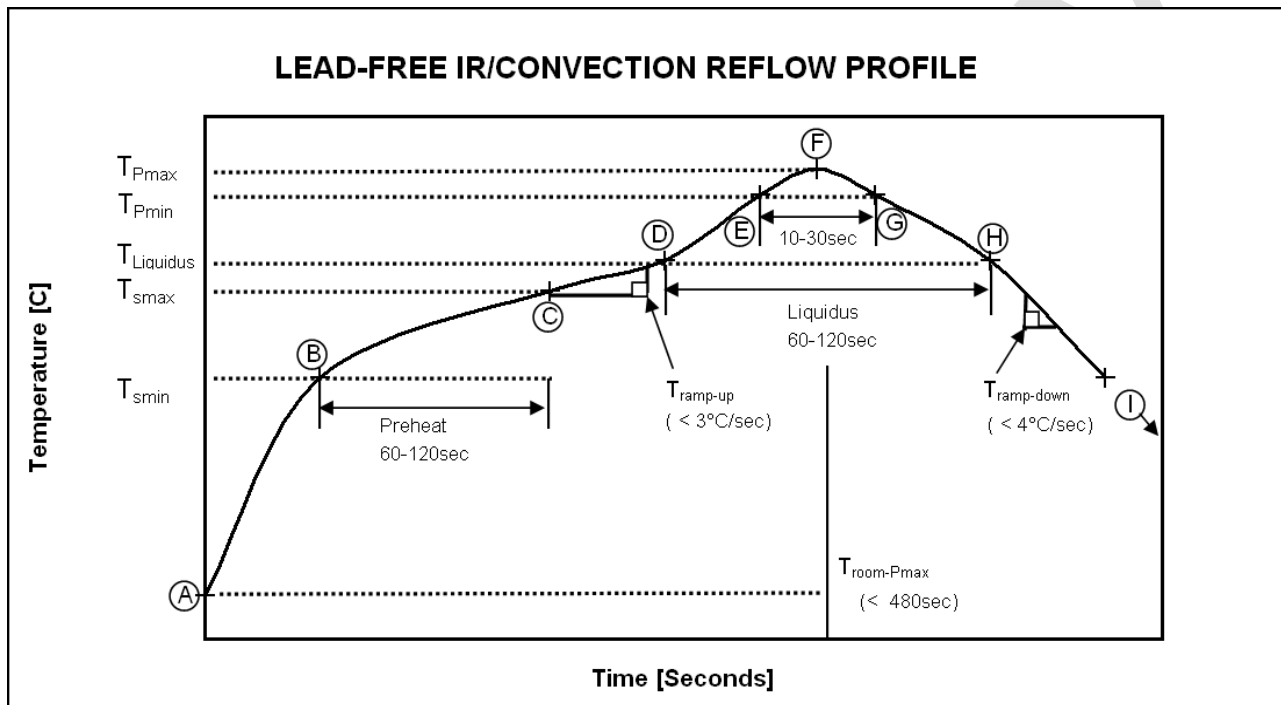


Figure 12. Approved IR/Convection Solder Reflow Curve



Temperature Set Points for IR / Convection Reflow Corresponding to Figure Above

Step	Setting	CONSTRAINTS		
		Temp (°C)	Time (sec)	Rate (°C/sec)
A	Troom	25		
B	TSmin	150		
C	TSmax	200	60 < tBC < 120	
D	TLiquidus	217		r(TLiquidus-TPmax) < 3
E	TPmin [< TPmax-5°C, 250°C]	255		r(TLiquidus-TPmax) < 3
F	TPmax [< TPmax, 260°C]	260	tAF < 480	r(TLiquidus-TPmax) < 3
G	TPmin [< TPmax-5°C, 250°C]	255	tEG < 30	r(TPmax-TLiquidus) < 4
H	TLiquidus	217	60 < tDH < 120	
I	Troom	25		

9.13 Storage Specifications

The storage specification of the IDG-400 gyroscope conforms to Moisture Sensitivity Level (MSL) 3, as defined by IPC/JEDEC J-STD-020D.01.

Storage Specifications for IDG-400

Calculated shelf-life in moisture-sealed bag	12 months -- Storage conditions: <40°C and <90% RH
After opening moisture-sealed bag	168 hours -- Storage conditions: ambient ≤30°C at 60% RH



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10. Reliability

10.1 Qualification Test Policy

InvenSense's products complete a Qualification Test Plan before being released to production. The Qualification Test Plan follows the JEDEC 47D Standards, "Stress-Test-Driven Qualification of Integrated Circuits," with the individual tests described below.

10.2 Qualification Test Plan

Accelerated Life Tests

Test	Method/Condition	Lot Quantity	Samples / Lot	Accept / Reject Criteria
High Temperature Operating Life (HTOL/LFR)	JEDEC JESD22-A108C, 3.63V biased, $T_j > 125^\circ\text{C}$ [read-points 168, 500, 1000 hours]	3	77	(1/2)
Steady-State Temperature Humidity Unbiased Life ⁽¹⁾	JEDEC JESD22-A101C, 85°C/85%RH [read-points 168, 500, 1000 hours]	3	77	(1/2)
High Temperature Storage Life	JEDEC JESD22-A103C, Cond. A, 125°C Non-Bias Bake [read-points 168, 500, 1000 hours]	3	77	(1/2)

Device Component Level Tests

Test	Method/Condition	Lot Quantity	Samples / Lot	Accept / Reject Criteria
ESD-HBM	JEDEC JESD22-A114F, Class 2 (2KV)	1	15	(0/1)
ESD-MM	JEDEC JESD22-A115-A, Class B (200V)	1	12	(0/1)
Latch Up	JEDEC JESD78B Class 1 (25°C), Level 1 (+/- 100mA)	1	6	(0/1)
Mechanical Shock	JEDEC JESD22-B104C, Mil-Std-883, method 2002, Cond. D, 10,000g's, 0.3ms, $\pm X, Y, Z$ – 6 directions, 5 times/direction	3	5	(0/1)
Vibration	JEDEC JESD22-B103B, Variable Frequency (random), Cond. B, 5-500Hz, X,Y,Z – 4 times/direction	3	5	(0/1)
Temperature Cycling ⁽¹⁾	JEDEC JESD22-A104D Condition N, -40°C to +85°C, Soak Mode 2, 100 cycles	3	77	(1/2)

Tests are preceded by MSL3 Preconditioning in accordance with JEDEC JESD22-A113F



**IDG-400 Dual-Axis Gyroscope
Product Specification**

PS-IDG-0400B-00-06
Release Date: 04/13/10

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