



**InvenSense Inc.**

1745 Technology Drive, San Jose, CA 95110 U.S.A.  
Tel: +1 (408) 988-7339 Fax: +1 (408) 988-8104  
Website: [www.invensense.com](http://www.invensense.com)

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# **ITG-3701**

## **Product Specification**

### **Revision 1.0**

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# 1 Document Information

## 1.1 Revision History

Date	Revision	Description
12/13/2013	1.0	Initial Release

## 1.2 Purpose and Scope

This document is a preliminary product specification, providing a description, specifications, and design related information for the three axis ITG-3701™ gyroscopes. The device is housed in a small 3x3x0.75mm QFN package.

Specifications are subject to change without notice. Final specifications will be updated based upon characterization of production silicon. For references to register map and descriptions of individual registers, please refer to the ITG-3701 Register Map and Register Descriptions document.

## 1.3 Product Overview

The ITG-3701 is a single-chip, digital output, 3 Axis MEMS gyroscope IC which features a 512-byte FIFO. The FIFO can lower the traffic on the serial bus interface, and reduce power consumption by allowing the system processor to burst read sensor data and then go into a low-power mode.

The gyroscope includes a programmable full-scale range of ±500, ±1000, ±2000, and ±4000 degrees/sec, very low Rate noise at 0.02 dps/√Hz and extremely low power consumption at 3.3mA. Factory-calibrated initial sensitivity reduces production-line calibration requirements.

Other industry-leading features include on-chip 16-bit ADCs, programmable digital filters, a precision clock with 1% drift from -40°C to 85°C, an embedded temperature sensor, and programmable interrupts. The device features I<sup>2</sup>C and SPI serial interfaces, a VDD operating range of 1.71 to 3.6V, and a separate digital IO supply, VDDIO from 1.71V to 3.6V.

By leveraging its patented and volume-proven CMOS-MEMS fabrication platform, which integrates MEMS wafers with companion CMOS electronics through wafer-level bonding, InvenSense has driven the gyro package size down to a footprint and thickness of 3x3x0.75mm (16-pin QFN), to provide a very small yet high performance low cost package. The device provides high robustness by supporting 10,000g shock reliability.

## 1.4 Applications

- Health and sports monitoring
- Motion UI
- Handset gaming

## 2 Power management Features

The ITG-3701 MEMS gyroscope includes a wide range of features:

### 2.1 Sensors

- Monolithic angular rate sensor (gyros) integrated circuit
- Digital-output temperature sensor
- External sync signal connected to the FSYNC pin supports image, video and GPS synchronization
- Factory calibrated scale factor
- High cross-axis isolation via proprietary MEMS design
- 10,000g shock tolerant

### 2.2 Digital Output

- Fast Mode (400kHz) I<sup>2</sup>C serial interface
- 1 MHz SPI serial interface for full read/write capability
- 20 MHz SPI to read gyro sensor & temp sensor data.
- 16-bit ADCs for digitizing sensor outputs
- User-programmable full-scale-range of  $\pm 500^\circ/\text{sec}$ ,  $\pm 1000^\circ/\text{sec}$ ,  $\pm 2000^\circ/\text{sec}$  and  $\pm 4000^\circ/\text{sec}$

### 2.3 Data Processing

- The total data set obtained by the device includes gyroscope data, temperature data, and the one bit external sync signal connected to the FSYNC pin.
- FIFO allows burst read, reduces serial bus traffic and saves power on the system processor.
- FIFO can be accessed through both I<sup>2</sup>C and SPI interfaces.
- Programmable interrupt
- Programmable low-pass filters

### 2.4 Clocking

- On-chip timing generator clock frequency  $\pm 1\%$  drift over full temperature range

### 2.5 Power

- VDD supply voltage range of 1.71V to 3.6V
- Flexible VDDIO reference voltage allows for multiple I<sup>2</sup>C and SPI interface voltage levels
- Power consumption for three axes active: 3.3mA
- Sleep mode: 8 $\mu$ A
- Each axis can be individually powered down

### 2.6 Package

- 3x3x0.75mm footprint and maximum thickness 16-pin QFN plastic package
- MEMS structure hermetically sealed at wafer level
- RoHS and Green compliant

### 3 Electrical Characteristics

#### 3.1 Sensor Specifications

 Typical Operating Circuit of Section 4.2, VDD = 2.5V, VDDIO = 1.8V, T<sub>A</sub>=25°C.

Parameter	Conditions	Min	Typical	Max	Unit	Notes
<b>GYRO SENSITIVITY</b>						
Full-Scale Range	FS_SEL=0		±500		°/s	
	FS_SEL=1		±1000		°/s	
	FS_SEL=2		±2000		°/s	
	FS_SEL=3		±4000		°/s	
Sensitivity Scale Factor	FS_SEL=0		65.5		LSB/(°/s)	
	FS_SEL=1		32.8		LSB/(°/s)	
	FS_SEL=2		16.4		LSB/(°/s)	
	FS_SEL=3		8.2		LSB/(°/s)	
Gyro ADC Word Length			16		bits	
Sensitivity Scale Factor Tolerance	25°C		±3		%	
Sensitivity Scale Factor Variation Over Temperature	-10°C to +75°C		±4		%	
Nonlinearity	Best fit straight line; 25°C		±0.3		%	
Cross-Axis Sensitivity			±5		%	
<b>GYRO ZERO-RATE OUTPUT (ZRO)</b>						
Initial ZRO Tolerance	25°C		±15		°/s	
ZRO Variation Over Temperature	-10°C to +75°C		±15		°/s	
<b>GYRO NOISE PERFORMANCE</b>						
Total RMS Noise	FS_SEL=0 DLPFCFG=2 (1-100Hz)		0.2		°/s-rms	
Rate Noise Spectral Density	At 10Hz		0.02		°/s/√Hz	
<b>GYRO MECHANICAL</b>						
Mechanical Frequency		25	27	29	kHz	
<b>GYRO START-UP TIME</b>						
ZRO Settling	DLPCFG=0, to ±1°/s of Final					
	From Sleep Mode to ready		35		ms	
	From Power On to ready		50		ms	
<b>TEMPERATURE SENSOR</b>						
Range	Untrimmed		-10 to +75		°C	
Sensitivity			321.4		LSB/°C	
Room-Temperature Offset	21°C		0		LSB	
Linearity			±0.2		°C	
<b>TEMPERATURE RANGE</b>						
Specification Temperature Range		-10		+75	°C	

### 3.2 Electrical Specifications

 Typical Operating Circuit of Section 4.2, VDD = 2.5V, VDDIO = 1.8V, T<sub>A</sub> = 25°C.

Parameters	Conditions	Min	Typical	Max	Units	Notes
<b>VDD POWER SUPPLY</b>						
Operating Voltage Range		1.71		3.6	V	
Power-Supply Ramp Rate	Monotonic ramp. Ramp rate is 10% to 90% of the final value	1		100	ms	
Normal Operating Current	Three Axes Active		3.3		mA	
Sleep Mode Current			8		μA	
<b>VDDIO REFERENCE VOLTAGE</b> (must be regulated)						
Voltage Range		1.71		3.6	V	
Power-Supply Ramp Rate	Monotonic ramp. Ramp rate is 10% to 90% of the final value	0.1		100	ms	
Normal Operating Current	10pF load, 5MHz data rate. Does not include pull up resistor current draw as that is system dependent		300		μA	
<b>START-UP TIME FOR REGISTER READ/WRITE</b>						
	Ready to access registers		12		ms	
<b>I<sup>2</sup>C ADDRESS</b>						
	AD0 = 0		1101000			
	AD0 = 1		1101001			
<b>DIGITAL INPUTS (FSYNC, AD0, SCLK, SDI, /CS)</b>						
V <sub>IH</sub> , High Level Input Voltage		0.7*VDDIO			V	
V <sub>IL</sub> , Low Level Input Voltage				0.3*VDDIO	V	
C <sub>I</sub> , Input Capacitance			< 5		pF	
<b>DIGITAL OUTPUT (INT, SDO)</b>						
V <sub>OH</sub> , High Level Output Voltage	R <sub>LOAD</sub> =1MΩ	0.9*VDDIO			V	
V <sub>OL1</sub> , LOW-Level Output Voltage	R <sub>LOAD</sub> =1MΩ			0.1*VDDIO	V	
V <sub>OL,INT1</sub> , INT Low-Level Output Voltage	OPEN=1, 0.3mA sink current			0.1	V	
Output Leakage Current	OPEN=1		100		nA	
t <sub>INT</sub> , INT Pulse Width	LATCH_INT_EN=0		50		μs	

### 3.3 Electrical Specifications, continued

 Typical Operating Circuit of Section 4.2, VDD = 2.5V, VDDIO = 1.8V, T<sub>A</sub>=25°C.

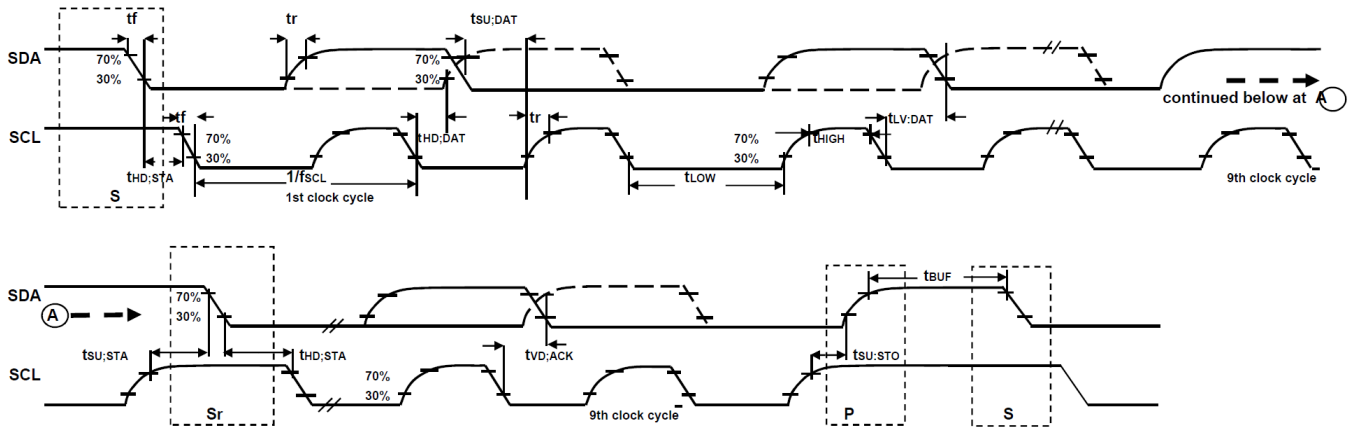
Parameters	Conditions	Min	Typical	Max	Units	Notes
<b>I<sup>2</sup>C I/O (SCL, SDA)</b>						
V <sub>IL</sub> , LOW Level Input Voltage			-0.5V to 0.3*VDDIO		V	
V <sub>IH</sub> , HIGH-Level Input Voltage			0.7*VDDIO to VDDIO + 0.5V		V	
V <sub>hys</sub> , Hysteresis			0.1*VDDIO		V	
V <sub>OL1</sub> , LOW-Level Output Voltage	3mA sink current		0 to 0.4		V	
I <sub>OL</sub> , LOW-Level Output Current	V <sub>OL</sub> = 0.4V		3		mA	
	V <sub>OL</sub> = 0.6V		6		mA	
Output Leakage Current			100		nA	
t <sub>of</sub> , Output Fall Time from V <sub>IHmax</sub> to V <sub>ILmax</sub>	C <sub>b</sub> bus capacitance in pf		20+0.1C <sub>b</sub> to 250		ns	
C <sub>I</sub> , Capacitance for Each I/O pin			< 10		pF	
<b>INTERNAL CLOCK SOURCE</b>						
	Fchoice=0,1,2 SMPLRT_DIV=0		32		kHz	
Sample Rate	Fchoice=3; DLPFCFG=0 or 7 SMPLRT_DIV=0		8		kHz	
	Fchoice=3; DLPFCFG=1,2,3,4,5,6; SMPLRT_DIV=0		1		kHz	
Clock Frequency Initial Tolerance	CLK_SEL=0, 6; 25°C	-2		+2	%	
	CLK_SEL=1,2,3,4,5; 25°C	-1		+1	%	
Frequency Variation over Temperature	CLK_SEL=0,6		-10 to +10		%	
	CLK_SEL=1,2,3,4,5		±1		%	
PLL Settling Time	CLK_SEL=1,2,3,4,5		4		ms	



### 3.4 I<sup>2</sup>C Timing Characterization

Typical Operating Circuit of Section 4.2, VDD = 2.5V, VDDIO = 1.8V, T<sub>A</sub>=25°C.

Parameters	Conditions	Min	Typical	Max	Units	Notes
<b>I<sup>2</sup>C TIMING</b>						
<b>I<sup>2</sup>C FAST-MODE</b>						2
f <sub>SCL</sub> , SCL Clock Frequency		0		400	kHz	
t <sub>HD:STA</sub> , (Repeated) START Condition Hold Time		0.6			μs	
t <sub>LOW</sub> , SCL Low Period		1.3			μs	
t <sub>HIGH</sub> , SCL High Period		0.6			μs	
t <sub>SU:STA</sub> , Repeated START Condition Setup Time		0.6			μs	
t <sub>HD:DAT</sub> , SDA Data Hold Time		0			μs	
t <sub>SU:DAT</sub> , SDA Data Setup Time		100			ns	
t <sub>r</sub> , SDA and SCL Rise Time	C <sub>b</sub> bus cap. from 10 to 400pF	20+0.1 C <sub>b</sub>		300	ns	
t <sub>f</sub> , SDA and SCL Fall Time	C <sub>b</sub> bus cap. from 10 to 400pF	20+0.1 C <sub>b</sub>		300	ns	
t <sub>SU:STO</sub> , STOP Condition Setup Time		0.6			μs	
t <sub>BUF</sub> , Bus Free Time Between STOP and START Condition		1.3			μs	
C <sub>b</sub> , Capacitive Load for each Bus Line			< 400		pF	
t <sub>VD:DAT</sub> , Data Valid Time				0.9	μs	
t <sub>VD:ACK</sub> , Data Valid Acknowledge Time				0.9	μs	



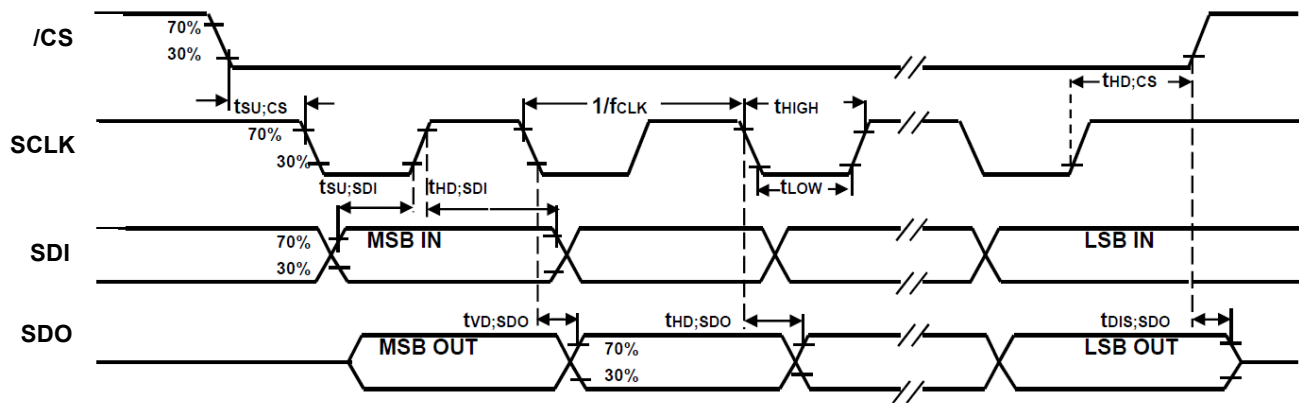
**I<sup>2</sup>C Bus Timing Diagram**

### 3.5 SPI Timing Characterization

Typical Operating Circuit of Section 4.2, VDD = 2.5V, VDDIO = 1.8V, T<sub>A</sub> = 25°C.

Parameters	Conditions	Min	Typical	Max	Units	Notes
<b>SPI TIMING (fSCLK = 1 MHz) R/W</b>						
f <sub>SCLK</sub> , SCLK Clock Frequency				1	MHz	
t <sub>LOW</sub> , SCLK Low Period		400			ns	
t <sub>HIGH</sub> , SCLK High Period		400			ns	
t <sub>SU,CS</sub> , CS Setup Time		8			ns	
t <sub>HD,CS</sub> , CS Hold Time		500			ns	
t <sub>SU,SDI</sub> , SDI Setup Time		11			ns	
t <sub>HD,SDI</sub> , SDI Hold Time		7			ns	
t <sub>VD,SDO</sub> , SDO Valid Time	C <sub>load</sub> = 20pF			100	ns	
t <sub>HD,SDO</sub> , SDO Hold Time		4			ns	
t <sub>DIS,SDO</sub> , SDO Output Disable Time				50	ns	
t <sub>BUF</sub> , CS high time between transactions				600	ns	

Parameters	Conditions	Min	Typical	Max	Units	Notes
<b>SPI TIMING (fSCLK = 20 MHz) Read<sup>3</sup></b>						
f <sub>SCLK</sub> , SCLK Clock Frequency				20	MHz	
t <sub>LOW</sub> , SCLK Low Period		-	25	-	ns	
t <sub>HIGH</sub> , SCLK High Period		-	25	-	ns	
t <sub>SU,CS</sub> , CS Setup Time		25			ns	
t <sub>HD,CS</sub> , CS Hold Time		25			ns	
t <sub>SU,SDI</sub> , SDI Setup Time		5			ns	
t <sub>HD,SDI</sub> , SDI Hold Time		6			ns	
t <sub>VD,SDO</sub> , SDO Valid Time	C <sub>load</sub> = 20pF			30	ns	
t <sub>HD,SDO</sub> , SDO Hold Time		4			ns	
t <sub>DIS,SDO</sub> , SDO Output Disable Time				25	ns	
t <sub>BUF</sub> , CS high time between transactions				600	ns	



**SPI Bus Timing Diagram**

### 3.6 Absolute Maximum Ratings

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

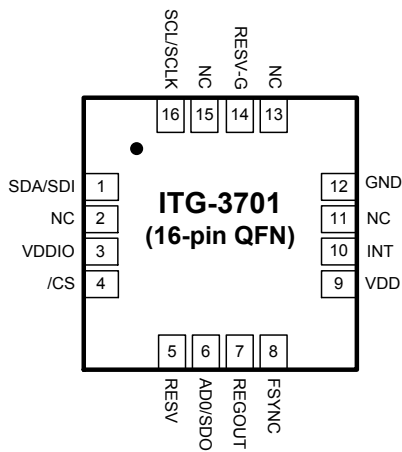
#### Absolute Maximum Ratings

Parameter	Rating
Supply Voltage, VDD	-0.5V to 4.0V
VDDIO Input Voltage Level	-0.5V to 4.0V
REGOUT	-0.5V to 2V
Input Voltage Level (AD0, FSYNC)	-0.5V to VDDIO
SCL, SDA, INT (SPI enable)	-0.5V to VDDIO
SCL, SDA, INT (SPI disable)	-0.5V to VDDIO
Acceleration (Any Axis, unpowered)	10,000g for 0.2ms
Operating Temperature Range	-40°C to +85°C
Storage Temperature Range	-40°C to +125°C
Electrostatic Discharge (ESD) Protection	2kV (HBM); 250V (MM)
Latch-up	JEDEC Class II (2), 125°C, ±100mA

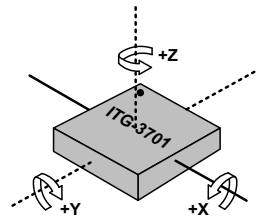
## 4 Applications Information

### 4.1 Pin Out and Signal Description

Pin Number 3x3x0.75mm	Pin Name	Pin Description
1	SDA/SDI	I <sup>2</sup> C serial data (SDA); SPI serial data input (SDI)
3	VDDIO	I/O supply voltage.
4	/CS	SPI chip select (0=SPI mode, 1= I <sup>2</sup> C mode)
5	RESV	Reserved. Do not connect.
6	AD0 / SDO	I <sup>2</sup> C Slave Address LSB (AD0); SPI serial data output (SDO)
7	REGOUT	Regulator filter capacitor connection
8	FSYNC	Frame synchronization digital input. Connect to GND if not used.
9	VDD	Power supply voltage
10	INT	Interrupt digital output (totem pole or open-drain)
12	GND	Power supply ground
14	RESV-G	Reserved. Connect to Ground.
16	SCL/SCLK	I <sup>2</sup> C serial clock (SCL); SPI serial clock (SCLK)
2, 11, 13, 15	NC	Not internally connected. May be used for PCB trace routing.

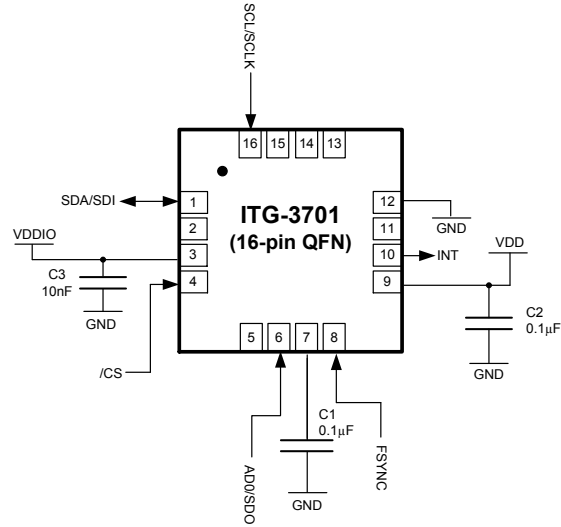


**QFN Package (Top View)**  
 16-pin, 3mm x 3mm x 0.75mm  
 Footprint and maximum thickness



**Orientation of Axes of Sensitivity and Polarity of Rotation**

## 4.2 Typical Operating Circuit



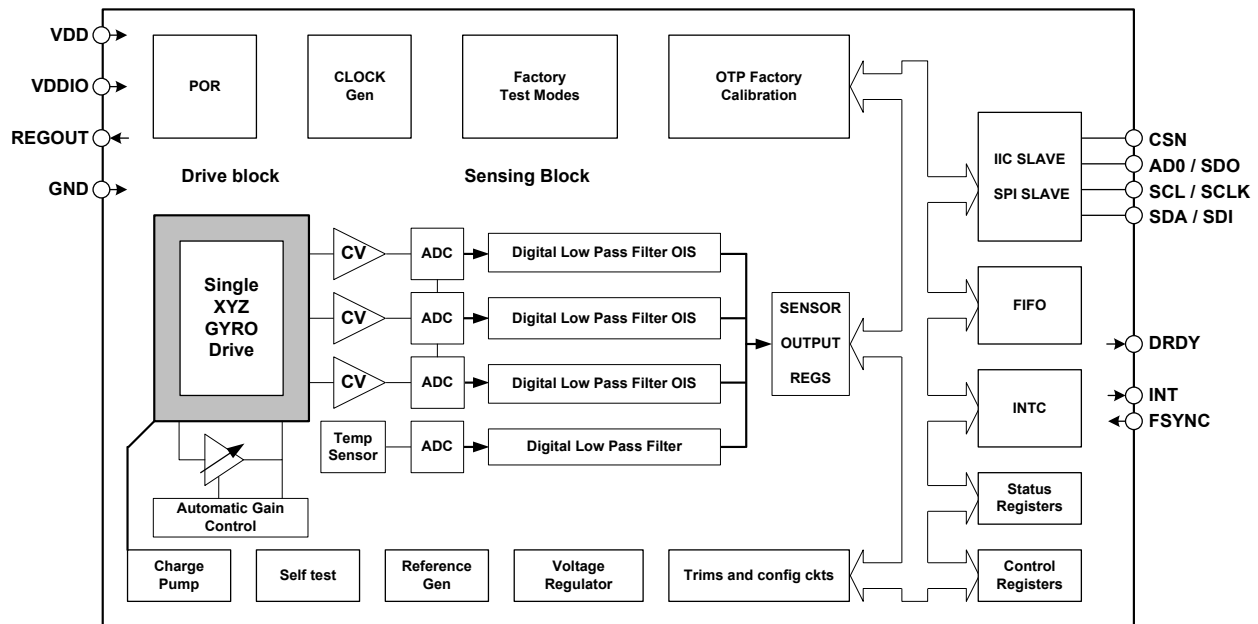
Typical Operating Circuit

## 4.3 Bill of Materials for External Components

Component	Label	Specification	Quantity
Regulator Filter Capacitor	C1	Ceramic, X7R, 0.1µF ±10%, 2V	1
VDD Bypass Capacitor	C2	Ceramic, X7R, 0.1µF ±10%, 4V	1
VDDIO Bypass Capacitor	C3	Ceramic, X7R, 10nF ±10%, 4V	1

## 5 Functional Overview

### 5.1 Block Diagram



### 5.2 Overview

The ITG-3701 is comprised of the following key blocks / functions:

- Three-axis MEMS rate gyroscope sensor with 16-bit ADCs and signal conditioning
- I<sup>2</sup>C and SPI serial communications interfaces
- Clocking
- Sensor Data Registers
- FIFO
- Interrupts
- Digital-Output Temperature Sensor
- Bias and LDO

### 5.3 Three-Axis MEMS Gyroscope with 16-bit ADCs and Signal Conditioning

The ITG-3701 consists of a single structure vibratory MEMS rate gyroscope, which detects rotation about the XY&Z axes, respectively. When the gyroscope is rotated about any of the sense axes, the Coriolis Effect causes a vibration that is detected by a capacitive pick off. The resulting signal is amplified, demodulated, and filtered to produce a voltage that is proportional to the angular rate. This voltage is digitized using individual on-chip 16-bit Analog-to-Digital Converters (ADCs) to sample each axis. The chip features a programmable full-scale range of the gyroscope sensors of  $\pm 500$ ,  $\pm 1000$ ,  $\pm 2000$ , and  $\pm 4000$  dps. User-selectable low-pass filters enable a wide range of cut-off frequencies. The ADC sample rate can be programmed to 32 kHz, 8 kHz, 1 kHz, 500 Hz, 333.3 Hz, 250 Hz, 200 Hz, 166.7 Hz, 142.9 Hz, or 125 Hz.

### 5.4 I<sup>2</sup>C and SPI Serial Communications Interface

The ITG-3701 has both I<sup>2</sup>C and SPI serial interfaces. The device always acts as a slave when communicating to the system processor. The logic level for communications to the master is set by the voltage on the VDDIO pin. The LSB of the I<sup>2</sup>C slave address is set by the AD0 pin. The I<sup>2</sup>C and SPI protocols are described in more detail in Section 6.

## 5.5 Internal Clock Generation

The ITG-3701 uses a flexible clocking scheme, allowing for a variety of internal clock sources for the internal synchronous circuitry. This synchronous circuitry includes the signal conditioning and ADCs, various control circuits, and registers.

Allowable internal sources for generating the internal clock are:

- An internal relaxation oscillator
- PLL (gyroscope based clock)

In order for the gyroscope to perform to spec, the PLL must be selected as the clock source. When the internal 20MHz oscillator is chosen as the clock source, the device can operate while having the gyroscope disabled. However, this is only recommended if the user wishes to use the internal temperature sensor in this mode.

## 5.6 Sensor Data Registers

The sensor data registers contain the latest gyro and temperature data. They are read-only registers, and are accessed via the Serial Interface. Data from these registers may be read anytime, however, the interrupt function may be used to determine when new data is available.

## 5.7 FIFO

The ITG-3701 contains a 512-byte FIFO register that is accessible via the both the I<sup>2</sup>C and SPI Serial Interfaces. The FIFO configuration register determines what data goes into it, with possible choices being gyro data, temperature readings and FSYNC input. A FIFO counter keeps track of how many bytes of valid data are contained in the FIFO. The FIFO register supports burst reads. The interrupt function may be used to determine when new data is available.

## 5.8 Interrupts

Interrupt functionality is configured via the Interrupt Configuration register. Items that are configurable include the INT pin configuration, the interrupt latching and clearing method, and triggers for the interrupt. Items that can trigger an interrupt are (1) Clock generator locked to new reference oscillator (used when switching clock sources), (2) new data is available to be read (from the FIFO and Data registers), and (3) FIFO overflow. The interrupt status can be read from the Interrupt Status register.

## 5.9 Digital-Output Temperature Sensor

An on-chip temperature sensor and ADC are used to measure the device's die temperature. The readings from the ADC can be read from the FIFO or the Sensor Data registers.

## 5.10 Bias and LDO

The bias and LDO section generates the internal supply and the reference voltages and currents required by the ITG-3701. Its two inputs are unregulated VDD of 1.71V to 3.6V and a VDDIO logic reference supply voltage of 1.71V to 3.6V. The LDO output is bypassed by a 0.1µF capacitor at REGOUT.

## 6 Digital Interface

### 6.1 I<sup>2</sup>C Serial Interface

The internal registers and memory of the ITG-3701 can be accessed using the I<sup>2</sup>C interface.

#### Serial Interface

Pin Number	Pin Name	Pin Description
3	VDDIO	Digital I/O supply voltage.
6	AD0 / SDO	I <sup>2</sup> C Slave Address LSB (AD0); SPI serial data output (SDO)
16	SCL / SCLK	I <sup>2</sup> C serial clock (SCL); SPI serial clock (SCLK)
1	SDA / SDI	I <sup>2</sup> C serial data (SDA); SPI serial data input (SDI)

#### 6.1.1 I<sup>2</sup>C Interface

I<sup>2</sup>C is a two-wire interface comprised of the signals serial data (SDA) and serial clock (SCL). In general, the lines are open-drain and bi-directional. In a generalized I<sup>2</sup>C interface implementation, attached devices can be a master or a slave. The master device puts the slave address on the bus, and the slave device with the matching address acknowledges the master.

The ITG-3701 always operates as a slave device when communicating to the system processor, which thus acts as the master. SDA and SCL lines typically need pull-up resistors to VDD. The maximum bus speed is 400 kHz.

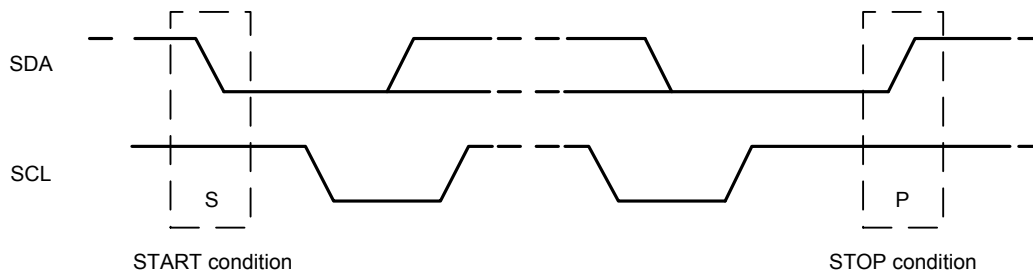
The slave address of the device is b110100X which is 7 bits long. The LSB bit of the 7 bit address is determined by the logic level on pin AD0. This allows the device to be connected to the same I<sup>2</sup>C bus. When used in this configuration, the address of the one of the devices should be b1101000 (pin AD0 is logic low) and the address of the other should be b1101001 (pin AD0 is logic high). The I<sup>2</sup>C address is stored in WHO\_AM\_I register.

#### I<sup>2</sup>C Communications Protocol

##### *START (S) and STOP (P) Conditions*

Communication on the I<sup>2</sup>C bus starts when the master puts the START condition (S) on the bus, which is defined as a HIGH-to-LOW transition of the SDA line while SCL line is HIGH (see figure below). The bus is considered to be busy until the master puts a STOP condition (P) on the bus, which is defined as a LOW to HIGH transition on the SDA line while SCL is HIGH (see figure below).

Additionally, the bus remains busy if a repeated START (Sr) is generated instead of a STOP condition.



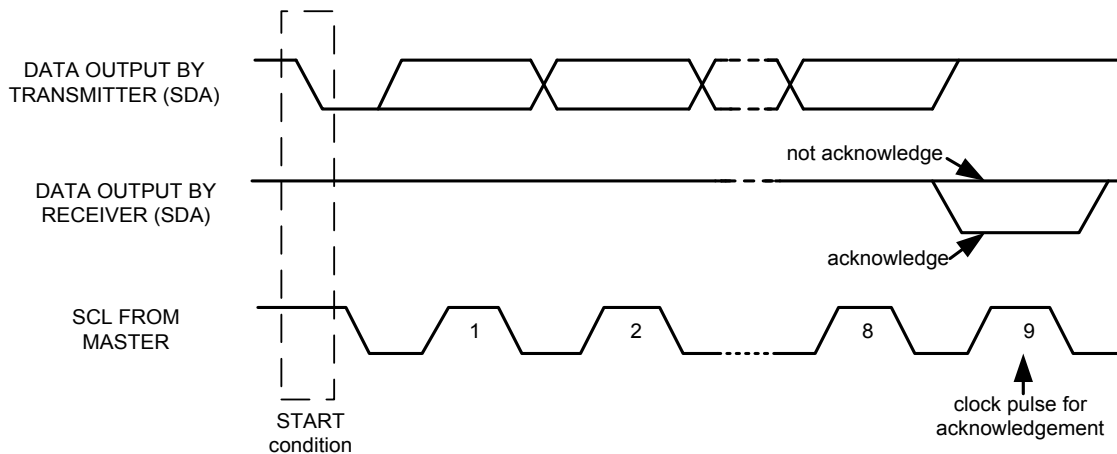
**START and STOP Conditions**



Data Format / Acknowledge

I<sup>2</sup>C data bytes are defined to be 8 bits long. There is no restriction to the number of bytes transmitted per data transfer. Each byte transferred must be followed by an acknowledge (ACK) signal. The clock for the acknowledge signal is generated by the master, while the receiver generates the actual acknowledge signal by pulling down SDA and holding it low during the HIGH portion of the acknowledge clock pulse.

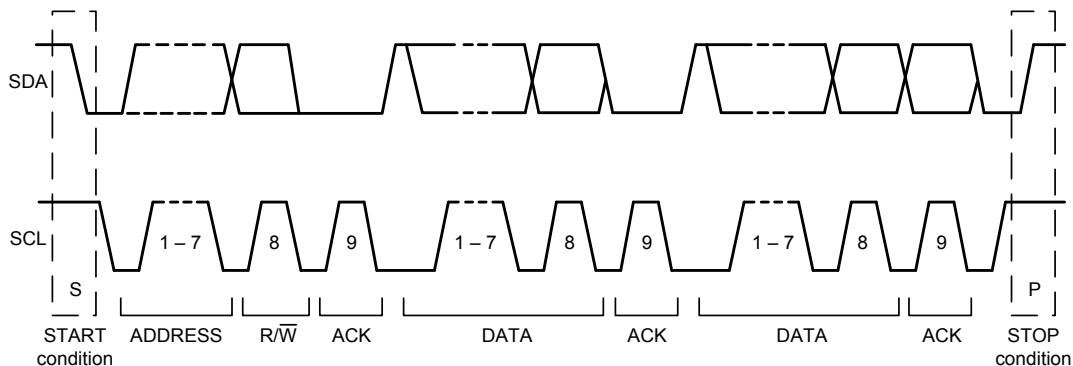
If a slave is busy and is unable to transmit or receive another byte of data until some other task has been performed, it can hold SCL LOW, thus forcing the master into a wait state. Normal data transfer resumes when the slave is ready, and releases the clock line (refer to the following figure).



**Acknowledge on the I<sup>2</sup>C Bus**

Communications

After beginning communications with the START condition (S), the master sends a 7-bit slave address followed by an 8<sup>th</sup> bit, the read/write bit. The read/write bit indicates whether the master is receiving data from or is writing to the slave device. Then, the master releases the SDA line and waits for the acknowledge signal (ACK) from the slave device. Each byte transferred must be followed by an acknowledge bit. To acknowledge, the slave device pulls the SDA line LOW and keeps it LOW for the high period of the SCL line. Data transmission is always terminated by the master with a STOP condition (P), thus freeing the communications line. However, the master can generate a repeated START condition (Sr), and address another slave without first generating a STOP condition (P). A LOW to HIGH transition on the SDA line while SCL is HIGH defines the stop condition. All SDA changes should take place when SCL is low, with the exception of start and stop conditions.



**Complete I<sup>2</sup>C Data Transfer**

To write the internal registers, the master transmits the start condition (S), followed by the I<sup>2</sup>C address and the write bit (0). At the 9<sup>th</sup> clock cycle (when the clock is high), the device acknowledges the transfer. Then the master puts the register address (RA) on the bus. After the device acknowledges the reception of the register address, the master puts the register data onto the bus. This is followed by the ACK signal, and data transfer may be concluded by the stop condition (P). To write multiple bytes after the last ACK signal, the master can continue outputting data rather than transmitting a stop signal. In this case, the device automatically increments the register address and loads the data to the appropriate register. The following figures show single and two-byte write sequences.

### Single-Byte Write Sequence

Master	S	AD+W		RA		DATA		P
Slave			ACK		ACK		ACK	

### Burst Write Sequence

Master	S	AD+W		RA		DATA		DATA		P
Slave			ACK		ACK		ACK		ACK	

To read the internal device registers, the master sends a start condition, followed by the I<sup>2</sup>C address and a write bit, and then the register address that is going to be read. Upon receiving the ACK signal from the device, the master transmits a start signal followed by the slave address and read bit. As a result, the device sends an ACK signal and the data. The communication ends with a not acknowledge (NACK) signal and a stop bit from master. The NACK condition is defined such that the SDA line remains high at the 9<sup>th</sup> clock cycle. The following figures show single and two-byte read sequences.

### Single-Byte Read Sequence

Master	S	AD+W		RA		S	AD+R			NACK	P
Slave			ACK		ACK			ACK	DATA		

### Burst Read Sequence

Master	S	AD+W		RA		S	AD+R			ACK		NACK	P
Slave			ACK		ACK			ACK	DATA		DATA		

## I<sup>2</sup>C Terms

Signal	Description
S	Start Condition: SDA goes from high to low while SCL is high
AD	Slave I <sup>2</sup> C address
W	Write bit (0)
R	Read bit (1)
ACK	Acknowledge: SDA line is low while the SCL line is high at the 9 <sup>th</sup> clock cycle
NACK	Not-Acknowledge: SDA line stays high at the 9 <sup>th</sup> clock cycle
RA	The internal register address
DATA	Transmit or received data
P	Stop condition: SDA going from low to high while SCL is high

## 6.1.2 SPI interface

SPI is a 4-wire synchronous serial interface that uses two control and two data lines. The ITG-3701 always operates as a Slave device during standard Master-Slave SPI operation. With respect to the Master, the Serial Clock output (SCLK), the Data Output (SDO) and the Data Input (SDI) are shared among the Slave devices. The Master generates an independent Chip Select (/CS) for each Slave device; /CS goes low at the start of transmission and goes back high at the end. The Serial Data Output (SDO) line, remains in a high-impedance (high-z) state when the device is not selected, so it does not interfere with any active devices.

### SPI Operational Features

1. Data is delivered MSB first and LSB last
2. Data is latched on rising edge of SCLK
3. Data should be transitioned on the falling edge of SCLK
4. SCLK frequency is 1MHz max for SPI in full read/write capability mode. When the SPI frequency is set to 20MHz, its operation is limited to reading sensor registers only.
5. SPI read and write operations are completed in 16 or more clock cycles (two or more bytes). The first byte contains the SPI Address, and the following byte(s) contain(s) the SPI data. The first bit of the first byte contains the Read/Write bit and indicates the Read (1) or Write (0) operation. The following 7 bits contain the Register Address. In cases of multiple-byte Read/Writes, data is two or more bytes:

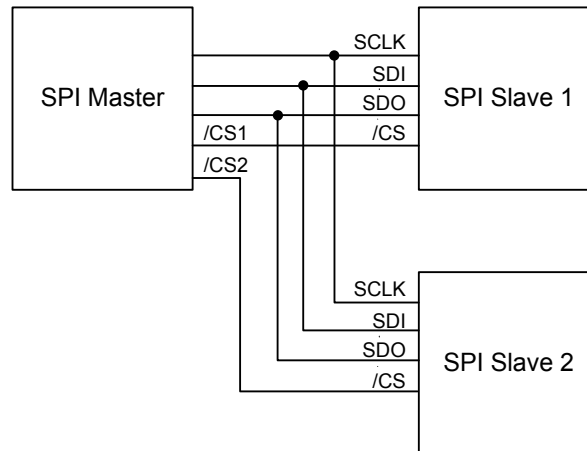
#### SPI Address format

MSB							LSB
R/W	A6	A5	A4	A3	A2	A1	A0

#### SPI Data format

MSB							LSB
D7	D6	D5	D4	D3	D2	D1	D0

6. Supports Single or Burst Read/Writes.

**Typical SPI Master / Slave Configuration**

Each SPI slave requires its own Chip Select (/CS) line. SDO, SDI and SCLK lines are shared. Only one /CS line is active (low) at a time ensuring that only one slave is selected at a time. The /CS lines of other slaves are held high which causes their respective SDO pins to be high-Z.

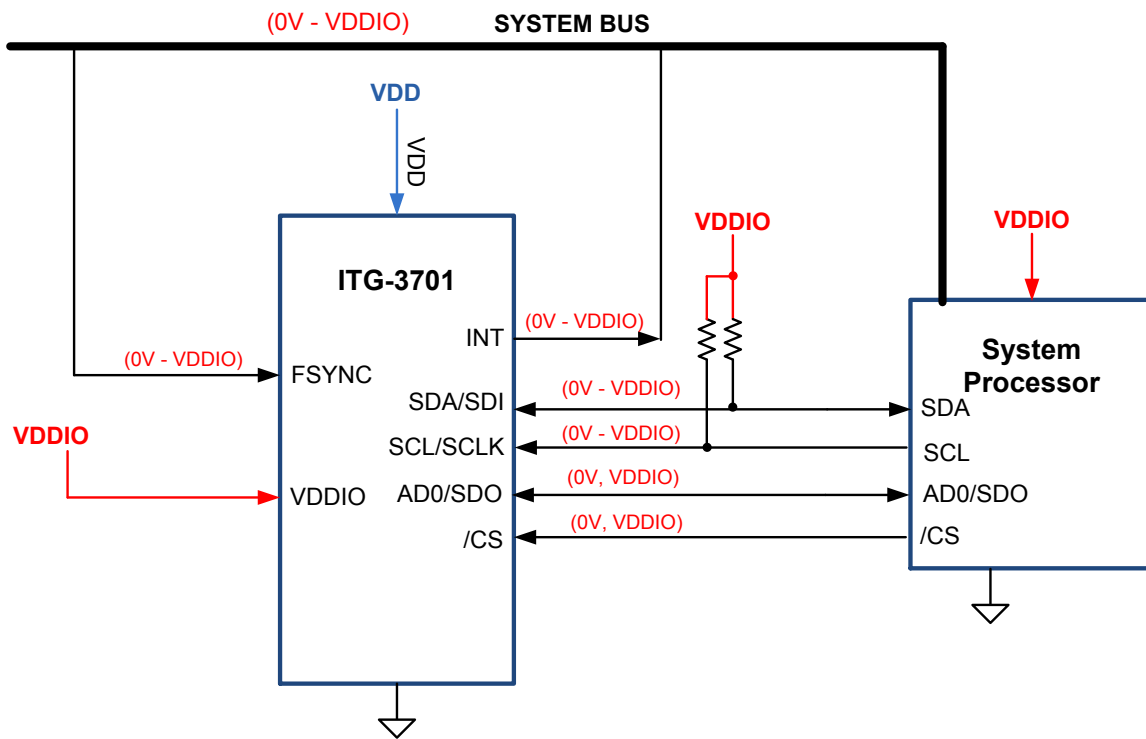
**7 Serial Interface Considerations**

**7.1 Supported Interfaces**

The ITG-3701 supports I<sup>2</sup>C and SPI communications.

**7.2 Logic Levels**

The I/O logic levels are set to VDDIO. VDDIO may be set to be equal to VDD or to another voltage, such that it is between 1.71 V and 3.6V at all times. Both I<sup>2</sup>C and SPI communication support VDDIO.

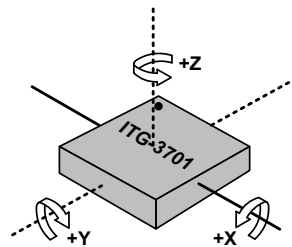


## 8 Assembly

This section provides general guidelines for assembling InvenSense Micro Electro-Mechanical Systems (MEMS) gyros packaged in Quad Flat No leads package (QFN) surface mount integrated circuits.

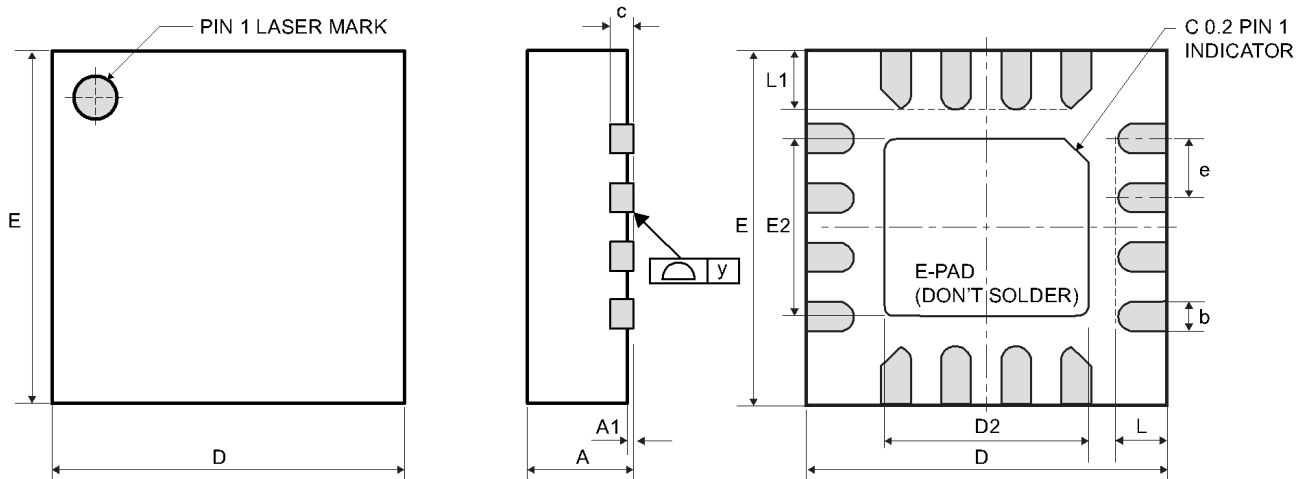
### 8.1 Orientation of Axes

The diagram below shows the orientation of the axes of sensitivity and the polarity of rotation. Note the pin 1 identifier in the figure.



**Orientation of Axes of Sensitivity and Polarity of Rotation**

## 8.2 Package Dimensions



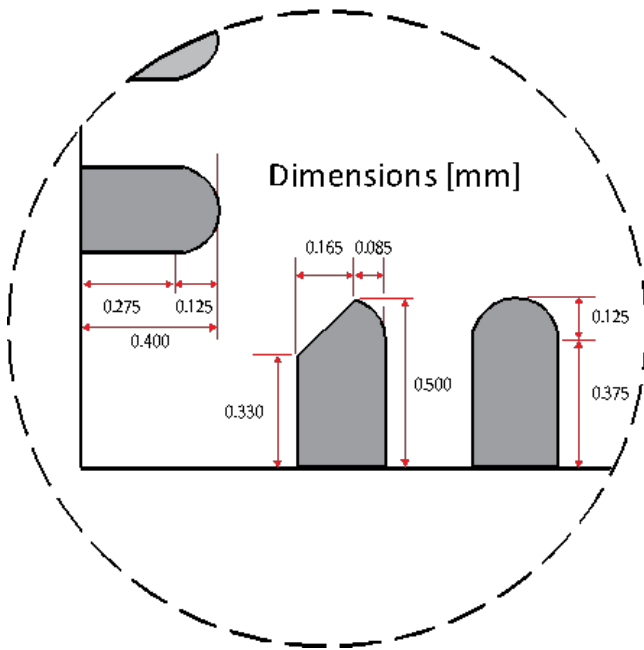
Dimensions in Millimeters			
Dimension	Min	Nom	Max
A	0.70	0.75	0.80
A1	0.00	0.02	0.05
b	0.18	0.25	0.30
c	---	0.15 ref	---
D	2.90	3.00	3.10
D2	1.65	1.70	1.75
E	2.90	3.00	3.10
E2	1.45	1.50	1.55
e	---	0.50	---
L	0.35	0.40	0.45
L1	0.45	0.50	0.55
y	0.000	---	0.075

## 8.3 PCB Design Guidelines

Do not solder the center Exposed Pad (E-pad). This is a solder keep-out area.

### Recommendations:

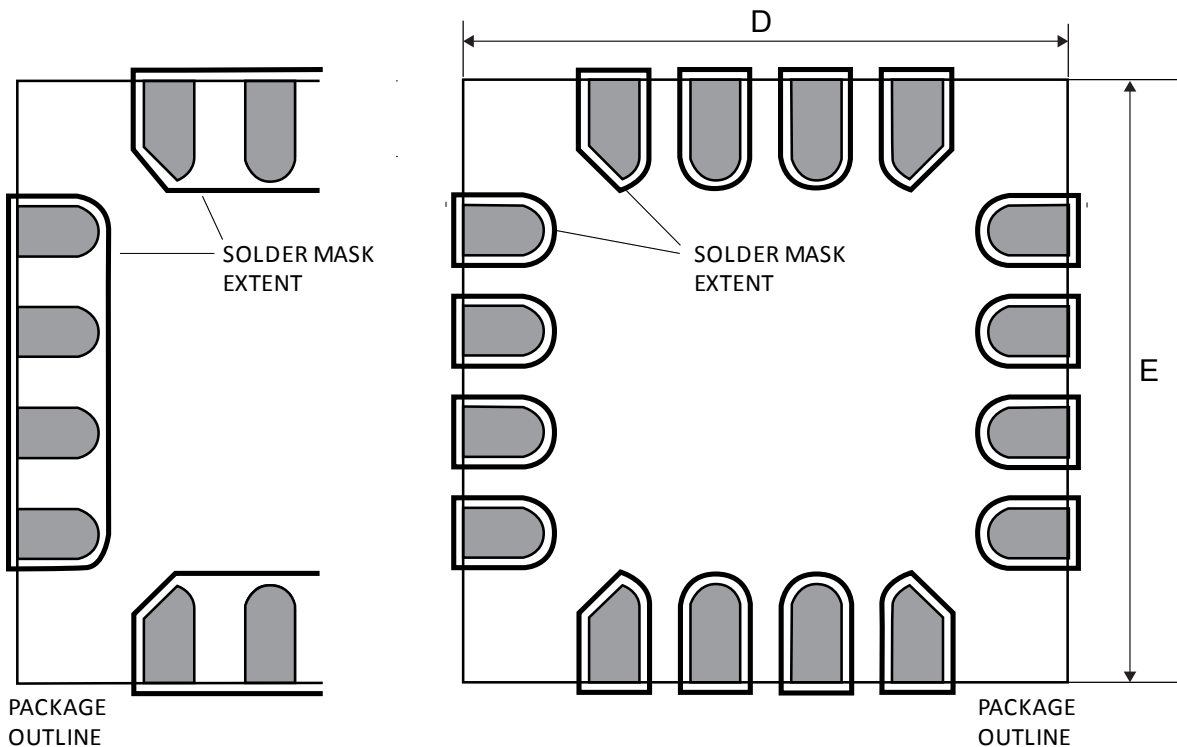
Size the PCB pad layout to match the QFN pad leads. Use the package dimensions shown in the Table above. The Dimensions Table is supplemented with the first figure that follows.



Design the PCB pad layout with Non Solder Mask Defined pads (NSMD). NSMD pads are recommended over Solder Mask Defined (SMD) pads. NSMD pads provide a tighter tolerance on copper etching, provide a larger copper pad area, and allow the solder to anchor to the edges of the copper pads to improve solder joint reliability. As a recommendation, set the solder mask aperture a minimum of 0.05 mm larger than the component solder pad per edge. Two alternative PCB layouts are shown below for reference.

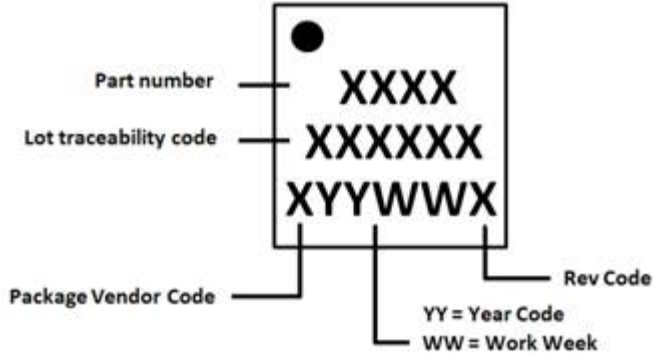
**Blocked Areas – Solder Mask**

**Individually Outlined Pads – Solder Mask**





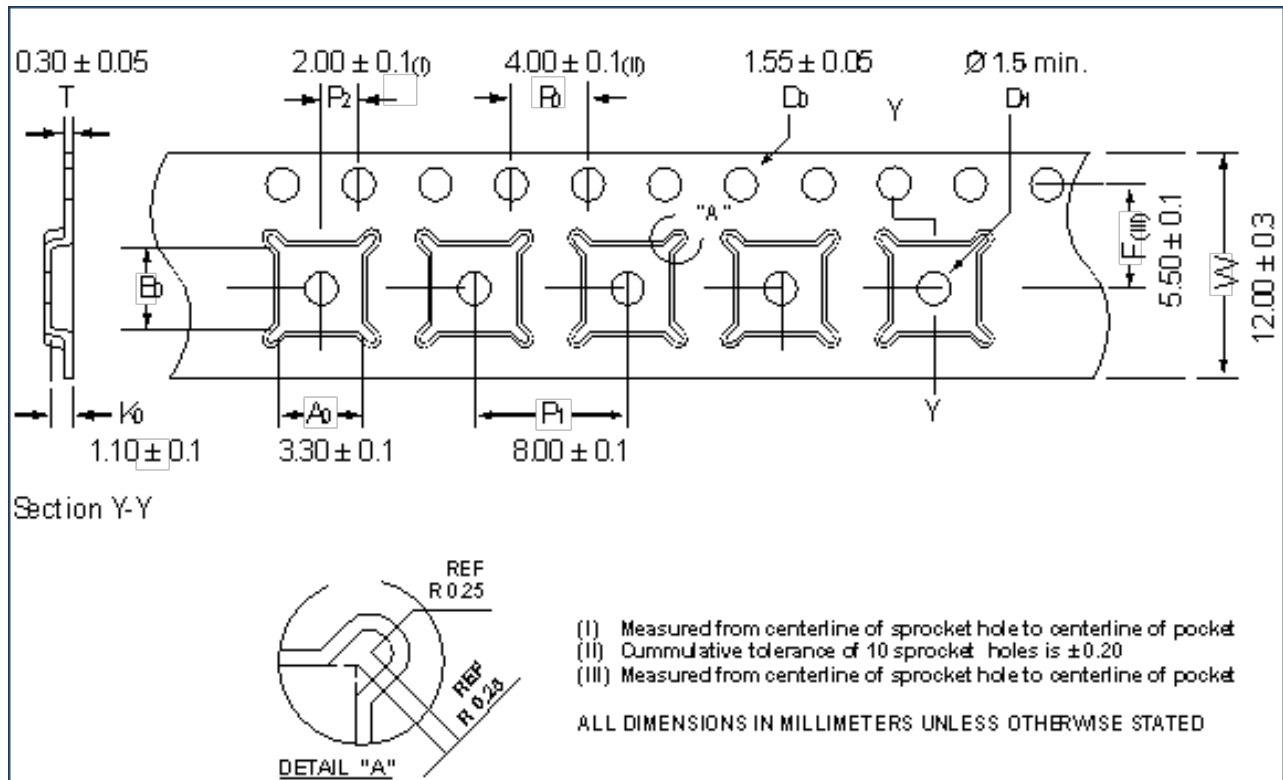
**8.4 Product Marking Specification**

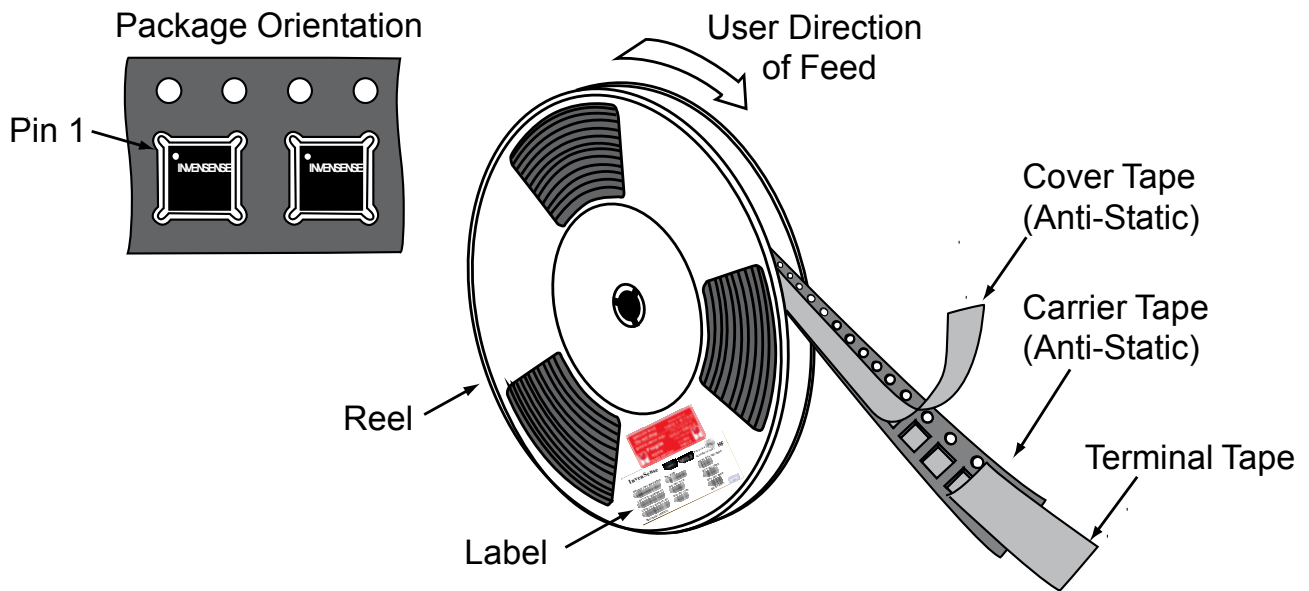
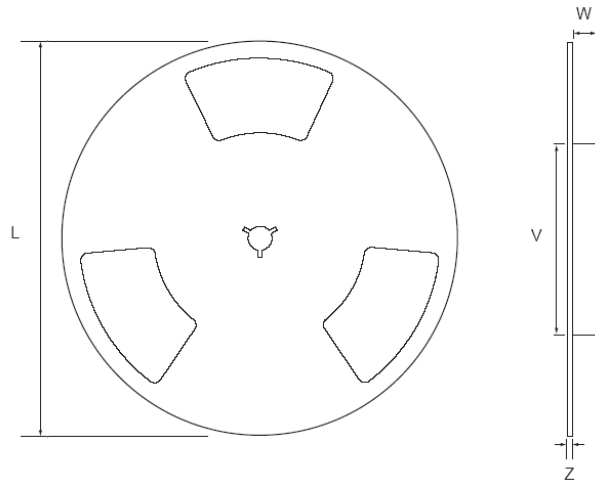


Part number Identification:

Product	Top Mark
ITG-3701	IT37

**8.5 Tape & Reel Specification**





**Tape and Reel Specification**

**Reel Specifications**

Quantity Per Reel	5,000
Reels per Pizza Box	1
Pizza Boxes Per Carton (max)	5
Pcs/Carton (max)	25,000

Note: empty pizza boxes are included to ensure that pizza boxes don't shift.

## **8.6 Assembly Precautions**

### **8.6.1 Gyroscope Surface Mount Guidelines**

InvenSense MEMS Gyros sense rate of rotation. In addition, gyroscope sense mechanical stress coming from the printed circuit board (PCB). This PCB stress can be minimized by adhering to certain design rules: When using MEMS gyroscope components in plastic packages, PCB mounting and assembly can cause package stress. This package stress in turn can affect the output offset and its value over a wide range of temperatures. This stress is caused by the mismatch between the Coefficient of Linear Thermal Expansion (CTE) of the package material and the PCB. Care must be taken to avoid package stress due to mounting. Traces connected to pads should be as symmetric as possible. Maximizing symmetry and balance for pad connection will help component self alignment and will lead to better control of solder paste reduction after reflow.

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.

### **8.6.2 Exposed Die Pad Precautions**

The ITG-3701 have very low active and standby current consumption. There is no electrical connection between the exposed die pad and the internal CMOS circuits. The exposed die pad is not required for heat-sinking, and should not be soldered to the PCB. Underfill is also not recommended. Soldering or adding underfill to the e-pad can induce performance changes due to package thermo-mechanical stress.

### **8.6.3 Trace Routing**

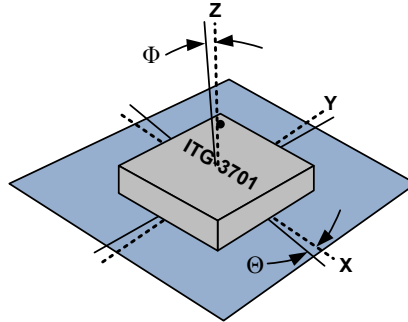
Routing traces or vias under the gyro package such that they run under the exposed die pad is prohibited. Routed active signals may harmonically couple with the gyro MEMS devices, compromising gyro response. The gyro drive frequency is ~27 KHz. To avoid harmonic coupling don't route active signals in non-shielded signal planes directly below, or above the gyro package. Note: For best performance, design a ground plane under the e-pad to reduce PCB signal noise from the board on which the gyro device is mounted. If the gyro device is stacked under another PCB board, design a ground plane directly above the gyro device to shield active signals from the PCB board mounted above.

### **8.6.4 Component Placement**

Do not place large insertion components such as keyboard or similar buttons, connectors, or shielding boxes at a distance of less than 6 mm from the MEMS gyro. Maintain generally accepted industry design practices for component placement near ITG-3701 to prevent noise coupling and thermo-mechanical stress.

### **8.6.5 PCB Mounting and Cross-Axis Sensitivity**

Orientation errors of the gyroscope as mounted to the printed circuit board can cause cross-axis sensitivity in which one gyro sense axis responds to rotation or acceleration about an orthogonal axis. For example, the X-gyro sense axis may respond to rotation about the Y or Z axes. The orientation mounting errors are illustrated in the figure on the next page.



**Package Gyro Axis ( - - - ) Relative to PCB Axis ( ——— ) with Orientation Errors ( $\Theta$  and  $\Phi$ )**

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

**Cross-Axis Sensitivity vs. Orientation Error**

Orientation Error ( $\theta$ or $\Phi$ )	Cross-Axis Sensitivity ( $\sin\theta$ or $\sin\Phi$ )
$0^\circ$	0%
$0.5^\circ$	0.87%
$1^\circ$	1.75%

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

**8.6.6 MEMS Handling Instructions**

MEMS (Micro Electro-Mechanical Systems) are a time-proven, robust technology used in hundreds 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).

The ITG-3701 has been qualified to a shock tolerance of 10,000g. InvenSense packages its gyroscope as it deems proper for protection against normal handling and shipping. It recommends the following handling precautions to prevent potential damage.

- Do not drop individually packaged gyroscope, or trays of gyroscope onto hard surfaces. Components placed in trays could be subject to g-forces in excess of 10,000g if dropped.
- Printed circuit boards that incorporate mounted gyroscope should not be separated by manually snapping apart. This could also create g-forces in excess of 10,000g.
- Do not clean MEMS gyroscope in ultrasonic baths. Ultrasonic baths can induce MEMS damage if the bath energy causes excessive drive motion through resonant frequency coupling.

**8.6.7 ESD Considerations**

Establish and use ESD-safe handling precautions when unpacking and handling ESD-sensitive devices.

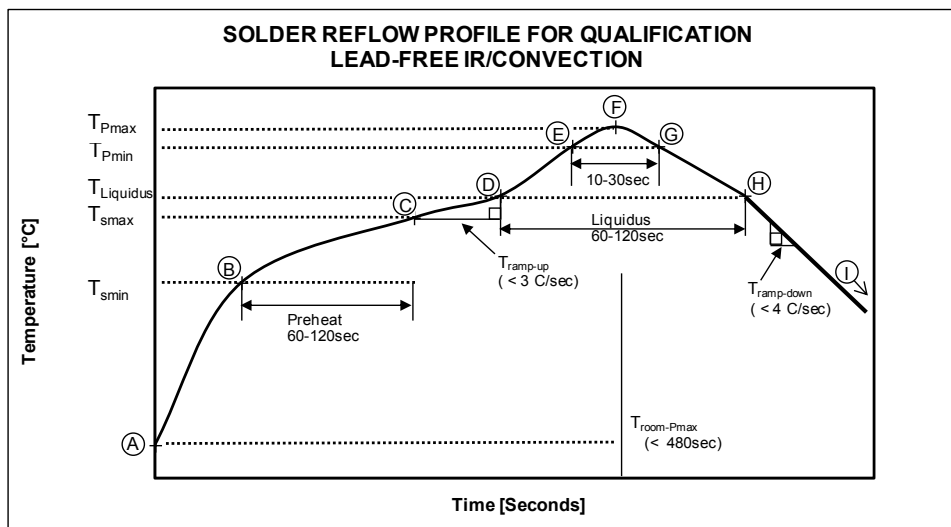
- Store ESD sensitive devices in ESD safe containers until ready for use, such as the original moisture sealed bags, until ready for assembly.
- Restrict all device handling to ESD protected work areas that measure less than 200V static charge. Ensure that all workstations and personnel are properly grounded to prevent ESD.

### 8.6.8 Reflow Specification

**Qualification Reflow Profile:** The ITG-3701 was qualified in accordance with IPC/JEDEC J-STD-020D.1. This standard classifies proper packaging, storage and handling in order to avoid subsequent thermal and mechanical damage during the solder reflow attachment phase of PCB assembly.

The qualification preconditioning process specifies a sequence consisting of a bake cycle, a moisture soak cycle (in a temperature humidity oven), and three consecutive solder reflow cycles, followed by functional device testing.

The peak solder reflow classification temperature requirement for package qualification is (260 +5/-0°C) for lead-free soldering of components measuring less than 1.6 mm in thickness. The qualification profile and a table explaining the set-points are shown below:



Temperature Set Points Corresponding to Reflow Profile Above

Step	Setting	CONSTRAINTS		
		Temp (°C)	Time (sec)	Max. Rate (°C/sec)
A	$T_{room}$	25		
B	$T_{Smin}$	150		
C	$T_{Smax}$	200	$60 < t_{BC} < 120$	
D	$T_{Liquidus}$	217		$r_{(TLiquidus-TPmax)} < 3$
E	$T_{Pmin}$ [255°C, 260°C]	255		$r_{(TLiquidus-TPmax)} < 3$
F	$T_{Pmax}$ [260°C, 265°C]	260	$t_{AF} < 480$	$r_{(TLiquidus-TPmax)} < 3$
G	$T_{Pmin}$ [255°C, 260°C]	255	$10 < t_{EG} < 30$	$r_{(TPmax-TLiquidus)} < 4$
H	$T_{Liquidus}$	217	$60 < t_{DH} < 120$	
I	$T_{room}$	25		

**Notes:** Customers must never exceed the Classification temperature ( $T_{Pmax} = 260^{\circ}C$ ). All temperatures refer to the topside of the QFN package, as measured on the package body surface.

**Production Reflow:** Check the recommendations of your solder manufacturer. For optimum results, use lead-free solders that have lower specified temperature profiles ( $T_{pmax} \sim 235^{\circ}C$ ). Also use lower ramp-up and ramp-down rates than those used in the qualification profile. Never exceed the maximum conditions that we used for qualification, as these represent the maximum tolerable ratings for the device.

### 8.7 Storage Specifications

The storage specification of the ITG-3701 conforms to IPC/JEDEC J-STD-020D.1 Moisture Sensitivity Level (MSL) 3.

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

### 8.8 Label



Barcode Label



Location of Label on Reel

### 8.9 Packaging

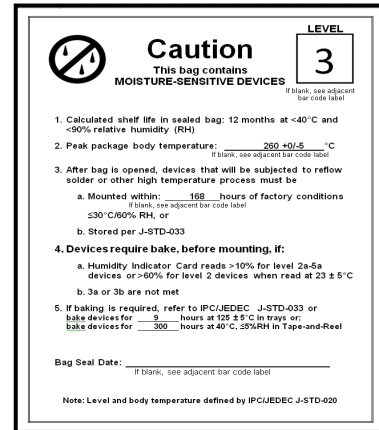
To improve protection for QFN contained in the reel, the reel is packed directly in 10mm thick ESD foam inside the moisture soak bag. The QFN devices are still protected by a foam liner after the pizza box is discarded.



**REEL – with Barcode & Caution labels**



**Sealed Moisture Barrier Bag (Foam Liner & Labels: ESD, MSL3, Caution, & Barcode)**



**MSL3 Label**



**Caution Label**



**ESD Label**



**Moisture Sealed Reel**



**Pizza Box**



**Pizza Boxes Placed in foam-lined shipper box**



**Outer Shipper Label**

8.10 Representative Shipping Carton Label

		<b>INV. NO:</b> <b>111013-99</b>	
<b>From:</b> InvenSense Taiwan, Ltd. 1F, 9 Prosperity 1st Road, Hsinchu Science Park, HsinChu City, 30078, Taiwan TEL: +886 3 6686999 FAX: +886 3 6686777		<b>Ship To:</b> Customer Name Street Address City, State, Country ZIP Attn: Buyer Name Phone: Buyer Phone Number	
<b>SUPP PROD ID:</b> ITG-3701			
LOT#: Q2R994-F1 QTY: 5615		LOT#: _____ QTY: 0	
LOT#: Q3X785-G1 QTY: 4385		LOT#: _____ QTY: 0	
LOT#: Q3Y196-02 QTY: 5000		LOT#: _____ QTY: 0	
LOT#: _____ QTY: 0		LOT#: _____ QTY: 0	
<b>Total Quantity/Carton</b> 15000 		<b>Weight: (KG)</b> 4.05 	
Pb-free	<b>Shipping Carton:</b> 1 OF 3		Category (e4) HF
		OF	



## 9 Reliability

### 9.1 Qualification Test Policy

InvenSense's products complete a Qualification Test Plan before being released to production. The Qualification Test Plan for the ITG-3701 followed the JEDEC JESD471 Standard, "Stress-Test-Driven Qualification of Integrated Circuits." The individual tests are described below.

### 9.2 Qualification Test Plan

#### Accelerated Life Tests

TEST	Method/Condition	Lot Quantity	Sample / Lot	Acc / Reject Criteria
High Temperature Operating Life (HTOL/LFR)	JEDEC JESD22-A108D, Dynamic, 3.63V biased, $T_j > 125^\circ\text{C}$ [read-points 168, 500, 1000 hours]	3	77	(0/1)
Accelerated Moisture Resistance – Unbiased HAST <sup>(1)</sup>	JEDEC JESD22-A118A Condition A, 130°C, 85%RH, 33.3 psia., Unbiased, [read-point 96 hours]	3	77	(0/1)
High Temperature Storage Life (HTS)	JEDEC JESD22-A103D, Cond. A, 125°C, Unbiased [read-points 168, 500, 1000 hours]	3	77	(0/1)

#### Device Component Level Tests

TEST	Method/Condition	Lot Quantity	Sample / Lot	Acc / Reject Criteria
ESD-HBM	JEDEC/ESDA JS-001-2012, (Class 2, 2000V)	1	3	(0/1)
ESD-MM	JEDEC JESD22-A115C, (250V)	1	3	(0/1)
Latch Up	JEDEC JESD78D Class II (2), 125°C; $\pm 100\text{mA}$	1	6	(0/1)
Mechanical Shock	JEDEC JESD22-B104C, Mil-Std-883H, method 2002.5, Cond. E, 10,000g's, 0.2ms, $\pm X, Y, Z$ – 6 directions, 5 times/direction	3	30	(0/1)
Vibration	JEDEC JESD22-B103B, Variable Frequency (random), Cond. B, 5-500Hz, X, Y, Z – 4 times/direction	1	5	(0/1)
Temperature Cycling (TC) <sup>(1)</sup>	JEDEC JESD22-A104D Condition G, [-40°C to +125°C], Soak Mode 2 [5'], 850 cycles	3	77	(0/1)

#### Board Level Tests

TEST	Method/Condition	Lot Quantity	Sample / Lot	Acc / Reject Criteria
Board Mechanical Shock	JEDEC JESD22-B104C, Mil-Std-883H, method 2002.5, Cond. E, 10000g's, 0.2ms, $\pm X, Y, Z$ – 6 directions, 5 times/direction	1	5	(0/1)

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

	<b>ITG-3701 Product Specification</b>	Document Number: PS-ITG-3701A-00 Revision: 1.0 Release Date: 12/13/2013
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## 10 Environmental Compliance

The ITG-3701 is RoHS Green and environmental compliant.

**Environmental Declaration Disclaimer:**

InvenSense believes this environmental information to be correct but cannot guarantee accuracy or completeness. Conformity documents for the above component constitutes are on file. InvenSense subcontracts manufacturing and the information contained herein is based on data received from vendors and suppliers, which has not been validated by InvenSense.

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