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MPU-6500
Product Specification
Revision 1.1

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1 Document Information

1.1 Revision History

Revision Date	Revision	Description
09/18/2013	1.0	Initial Release
03/05/2014	1.1	Updated Sections 1, 2, 4, 9, 11

1.2 Purpose and Scope

This document is a preliminary product specification, providing a description, specifications, and design related information on the MPU-6500™ MotionTracking device. The device is housed in a small 3x3x0.90mm 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 MPU-6500 Register Map and Register Descriptions document.

1.3 Product Overview

The MPU-6500 is a 6-axis MotionTracking device that combines a 3-axis gyroscope, 3-axis accelerometer, and a Digital Motion Processor™ (DMP) all in a small 3x3x0.9mm package. It also features a 512-byte FIFO that 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. With its dedicated I^2C sensor bus, the MPU-6500 directly accepts inputs from external I^2C devices. MPU-6500, with its 6-axis integration, on-chip DMP, and run-time calibration firmware, enables manufacturers to eliminate the costly and complex selection, qualification, and system level integration of discrete devices, guaranteeing optimal motion performance for consumers. MPU-6500 is also designed to interface with multiple non-inertial digital sensors, such as pressure sensors, on its auxiliary I^2C port.

The gyroscope has a programmable full-scale range of ±250, ±500, ±1000, and ±2000 degrees/sec and very low rate noise at 0.01 dps/√Hz. The accelerometer has a user-programmable accelerometer full-scale range of ±2*g*, ±4*g*, ±8*g*, and ±16*g*. Factory-calibrated initial sensitivity of both sensors 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^2C 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.

Communication with all registers of the device is performed using either I^2C at 400kHz or SPI at 1MHz. For applications requiring faster communications, the sensor and interrupt registers may be read using SPI at 20MHz.

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 package size down to a footprint and thickness of 3x3x0.90mm (24-pin QFN), to provide a very small yet high performance low cost package. The device provides high robustness by supporting 10,000*g* shock reliability.

1.4 Applications

- *TouchAnywhere*™ technology (for "no touch" UI Application Control/Navigation)
- *MotionCommand*™ technology (for Gesture Short-cuts)
- Motion-enabled game and application framework
- Location based services, points of interest, and dead reckoning
- Handset and portable gaming
- Motion-based game controllers
- 3D remote controls for Internet connected DTVs and set top boxes, 3D mice
- Wearable sensors for health, fitness and sports

2 Features

2.1 Gyroscope Features

The triple-axis MEMS gyroscope in the MPU-6500 includes a wide range of features:

- Digital-output X-, Y-, and Z-axis angular rate sensors (gyroscopes) with a user-programmable full-scale range of ±250, ±500, ±1000, and ±2000°/sec and integrated 16-bit ADCs
- Digitally-programmable low-pass filter
- Gyroscope operating current: 3.2mA
- Factory calibrated sensitivity scale factor
- Self-test

2.2 Accelerometer Features

The triple-axis MEMS accelerometer in MPU-6500 includes a wide range of features:

- Digital-output X-, Y-, and Z-axis accelerometer with a programmable full scale range of ±2*g*, ±4*g*, ±8*g* and ±16*g* and integrated 16-bit ADCs
- Accelerometer normal operating current: 450µA
- Low power accelerometer mode current: 6.37µA at 0.98Hz, 17.75µA at 31.25Hz
- User-programmable interrupts
- Wake-on-motion interrupt for low power operation of applications processor
- Self-test

2.3 Additional Features

The MPU-6500 includes the following additional features:

- Auxiliary master I^2C bus for reading data from external sensors (e.g. magnetometer)
- 3.4mA operating current when all 6 motion sensing axes are active
- VDD supply voltage range of 1.8 – 3.3V ± 5%
- VDDIO reference voltage of 1.8 – 3.3V ± 5% for auxiliary I^2C devices
- Smallest and thinnest QFN package for portable devices: 3x3x0.9mm
- Minimal cross-axis sensitivity between the accelerometer and gyroscope axes
- 512 byte FIFO buffer enables the applications processor to read the data in bursts
- Digital-output temperature sensor
- User-programmable digital filters for gyroscope, accelerometer, and temp sensor
- 10,000 *g* shock tolerant
- 400kHz Fast Mode I^2C for communicating with all registers
- 1MHz SPI serial interface for communicating with all registers
- 20MHz SPI serial interface for reading sensor and interrupt registers
- MEMS structure hermetically sealed and bonded at wafer level
- RoHS and Green compliant

2.4 MotionProcessing

- Internal Digital Motion Processing™ (DMP™) engine supports advanced MotionProcessing and low power functions such as gesture recognition using programmable interrupts
- In addition to the angular rate, this device optionally outputs the angular position (angle).
- Low-power pedometer functionality allows the host processor to sleep while the DMP maintains the step count.

3 Electrical Characteristics

3.1 Gyroscope Specifications

Typical Operating Circuit of section 4.2, VDD = 1.8V, VDDIO = 1.8V, T_A=25°C, unless otherwise noted.

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	NOTES
			GYROSCOPE SENSITIVITY			
Full-Scale Range	FS_SEL=0		±250		º/s	3
	FS_SEL=1		±500		º/s	3
	FS_SEL=2		±1000		º/s	3
	FS_SEL=3		±2000		º/s	3
Gyroscope ADC Word Length			16		bits	3
Sensitivity Scale Factor	FS_SEL=0		131		LSB/(º/s)	3
	FS_SEL=1		65.5		LSB/(º/s)	3
	FS_SEL=2		32.8		LSB/(º/s)	3
	FS_SEL=3		16.4		LSB/(º/s)	3
Sensitivity Scale Factor Tolerance	25°C		±3		%	2
Sensitivity Scale Factor Variation Over Temperature	-40°C to +85°C		±4		%	1
Nonlinearity	Best fit straight line; 25°C		±0.1		%	1
Cross-Axis Sensitivity			±2		%	1
			ZERO-RATE OUTPUT (ZRO)			
Initial ZRO Tolerance	25°C		±5		º/s	2
ZRO Variation Over Temperature	-40°C to +85°C		±0.24		º/s/°C	1
			GYROSCOPE NOISE PERFORMANCE (FS_SEL=0)			
Total RMS Noise	DLPFCFG=2 (92 Hz)		0.1		º/s-rms	2
Rate Noise Spectral Density			0.01		º/s/√Hz	4
GYROSCOPE MECHANICAL FREQUENCIES		25	27	29	KHz	2
LOW PASS FILTER RESPONSE	Programmable Range	5		250	Hz	3
GYROSCOPE START-UP TIME	From Sleep mode		35		ms	1
OUTPUT DATA RATE	Programmable, Normal (Filtered) mode	4		8000	Hz	1

Table 1: Gyroscope Specifications

Notes:

1. Derived from validation or characterization of parts, not guaranteed in production.
2. Tested in production.
3. Guaranteed by design.
4. Calculated from Total RMS Noise.

Please refer to the following document for information on Self-Test: *MPU-6500 Accelerometer and Gyroscope Self-Test Implementation; AN-MPU-6500A-02*

3.2 Accelerometer Specifications

Typical Operating Circuit of section 4.2, VDD = 1.8V, VDDIO = 1.8V, T_A=25°C, unless otherwise noted.

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	NOTES
ACCELEROMETER SENSITIVITY						
Full-Scale Range	AFS_SEL=0		±2		*g*	3
	AFS_SEL=1		±4		*g*	3
	AFS_SEL=2		±8		*g*	3
	AFS_SEL=3		±16		*g*	3
ADC Word Length	Output in two's complement format		16		bits	3
Sensitivity Scale Factor	AFS_SEL=0		16,384		LSB/*g*	3
	AFS_SEL=1		8,192		LSB/*g*	3
	AFS_SEL=2		4,096		LSB/*g*	3
	AFS_SEL=3		2,048		LSB/*g*	3
Initial Tolerance	Component-level		±3		%	2
Sensitivity Change vs. Temperature	-40°C to +85°C AFS_SEL=0 Component-level		±0.026		%/°C	1
Nonlinearity	Best Fit Straight Line		±0.5		%	1
Cross-Axis Sensitivity			±2		%	1
ZERO-G OUTPUT						
Initial Tolerance	Component-level, all axes		±60		m*g*	2
Zero-G Level Change vs. Temperature	-40°C to +85°C, Board-level: X and Y axes		±0.64		m*g*/°C	1
	-40°C to +85°C, Board-level: Z axis		±1		m*g*/°C	1
NOISE PERFORMANCE						
Power Spectral Density	Low noise mode		300		µ*g*/√Hz	4
LOW PASS FILTER RESPONSE	Programmable Range	5		260	Hz	3
INTELLIGENCE FUNCTION INCREMENT			4		m*g*/LSB	3
ACCELEROMETER STARTUP TIME	From Sleep mode		20		ms	1
	From Cold Start, 1ms V_{DD} ramp		30		ms	1
OUTPUT DATA RATE	Low power (duty-cycled)	0.24		500	Hz	1
	Duty-cycled, over temp		±15		%	
	Low noise (active)	4		4000	Hz	

Table 2: Accelerometer Specifications

Notes:

1. Derived from validation or characterization of parts, not guaranteed in production.
2. Tested in production.
3. Guaranteed by design.
4. Calculated from Total RMS Noise.

Please refer to the following document for information on Self-Test: *MPU-6500 Accelerometer and Gyroscope Self-Test Implementation; AN-MPU-6500A-02*

3.3 Electrical Specifications

3.3.1 D.C. Electrical Characteristics

Typical Operating Circuit of section 4.2, VDD = 1.8V, VDDIO = 1.8V, T_A=25°C, unless otherwise noted.

PARAMETER	CONDITIONS	MIN	TYP	MAX	Units	Notes
SUPPLY VOLTAGES						
VDD		1.71	1.8	3.45	V	1
VDDIO		1.71	1.8	3.45	V	1
SUPPLY CURRENTS						
Normal Mode	6-axis		3.4		mA	1
	3-axis Gyroscope		3.2		mA	1
	3-Axis Accelerometer, 4kHz ODR		450		µA	1
Accelerometer Low Power Mode	0.98 Hz update rate		7.27		µA	1,2
	31.25 Hz update rate		18.65		µA	1,2
Standby Mode			1.6		mA	1
Full-Chip Sleep Mode			6		µA	1
TEMPERATURE RANGE						
Specified Temperature Range	Performance parameters are not applicable beyond Specified Temperature Range	-40		+85	°C	1

Table 3: D.C. Electrical Characteristics

Notes:

1. Derived from validation or characterization of parts, not guaranteed in production.
2. Accelerometer Low Power Mode supports the following output data rates (ODRs): 0.24, 0.49, 0.98, 1.95, 3.91, 7.81, 15.63, 31.25, 62.50, 125, 250, 500Hz. Supply current for any update rate can be calculated as:
    a. Supply Current in µA = 6.9 + Update Rate * 0.376

3.3.2 A.C. Electrical Characteristics

Typical Operating Circuit of section 4.2, VDD = 1.8V, VDDIO = 1.8V, T_A=25°C, unless otherwise noted.

Parameter	Conditions	MIN	TYP	MAX	Units	NOTES
SUPPLIES						
Supply Ramp Time	Monotonic ramp. Ramp rate is 10% to 90% of the final value	0.1		100	ms	1
TEMPERATURE SENSOR						
Operating Range	Ambient	-40		85	°C	1
Sensitivity	Untrimmed		333.87		LSB/°C	
Room Temp Offset	21°C		0		LSB	
Power-On RESET						
Supply Ramp Time (T_{RAMP})	Valid power-on RESET	0.01	20	100	ms	1
Start-up time for register read/write	From power-up		11	100	ms	1
I²C ADDRESS	AD0 = 0 AD0 = 1		1101000 1101001			
DIGITAL INPUTS (FSYNC, AD0, SCLK, SDI, CS)						
V_{IH}, High Level Input Voltage		0.7*VDDIO			V	1
V_{IL}, Low Level Input Voltage				0.3*VDDIO	V	
C_I, Input Capacitance			< 10		pF	
DIGITAL OUTPUT (SDO, INT)						
V_{OH}, High Level Output Voltage	R_{LOAD}=1MΩ;	0.9*VDDIO			V	1
V_{OL1}, LOW-Level Output Voltage	R_{LOAD}=1MΩ;			0.1*VDDIO	V	
$V_{OL.INT1}$, INT Low-Level Output Voltage	OPEN=1, 0.3mA sink Current			0.1	V	
Output Leakage Current	OPEN=1		100		nA	
t_{INT}, INT Pulse Width	LATCH_INT_EN=0		50		µs	
I2C I/O (SCL, SDA)						
V_{IL}, LOW Level Input Voltage		-0.5V		0.3*VDDIO	V	1
V_{IH}, HIGH-Level Input Voltage		0.7*VDDIO		VDDIO + 0.5V	V	
V_{hys}, Hysteresis			0.1*VDDIO		V	
V_{OL}, LOW-Level Output Voltage	3mA sink current	0		0.4	V	
I_{OL}, LOW-Level Output Current	V_{OL}=0.4V V_{OL}=0.6V		3 6		mA mA	
Output Leakage Current			100		nA	
t_{of}, Output Fall Time from V_{IHmax} to V_{ILmax}	C_b bus capacitance in pf	20+0.1C_b		250	ns	
AUXILLIARY I/O (AUX_CL, AUX_DA)						
V_{IL}, LOW-Level Input Voltage		-0.5V		0.3*VDDIO	V	1
V_{IH}, HIGH-Level Input Voltage		0.7* VDDIO		VDDIO + 0.5V	V	
V_{hys}, Hysteresis			0.1* VDDIO		V	
V_{OL1}, LOW-Level Output Voltage	VDDIO > 2V; 1mA sink current	0		0.4	V	

Parameter	Conditions	MIN	TYP	MAX	Units	NOTES
V_{OL3}, LOW-Level Output Voltage	VDDIO < 2V; 1mA sink current	0		0.2* VDDIO	V	
I_{OL}, LOW-Level Output Current	V_{OL} = 0.4V V_{OL} = 0.6V		3 6		mA mA	
Output Leakage Current			100		nA	
t_{of}, Output Fall Time from V_{IHmax} to V_{ILmax}	C_b bus capacitance in pF	$20+0.1C_b$		250	ns	
INTERNAL CLOCK SOURCE						
Sample Rate	Fchoice=0,1,2 SMPLRT_DIV=0		32		kHz	2
	Fchoice=3; DLPFCFG=0 or 7 SMPLRT_DIV=0		8		kHz	2
	Fchoice=3; DLPFCFG=1,2,3,4,5,6; SMPLRT_DIV=0		1		kHz	2
Clock Frequency Initial Tolerance	CLK_SEL=0, 6; 25°C	-2		+2	%	1
	CLK_SEL=1,2,3,4,5; 25°C	-1		+1	%	1
Frequency Variation over Temperature	CLK_SEL=0,6	-10		+10	%	1
	CLK_SEL=1,2,3,4,5		±1		%	1

Table 4: A.C. Electrical Characteristics

Notes:

1. Derived from validation or characterization of parts, not guaranteed in production.
2. Guaranteed by design.

3.3.3 Other Electrical Specifications

Typical Operating Circuit of section 4.2, VDD = 1.8V, VDDIO = 1.8V, T_A=25°C, unless otherwise noted.

PARAMETER	CONDITIONS	MIN	TYP	MAX	Units	Notes
SERIAL INTERFACE						
SPI Operating Frequency, All Registers Read/Write	Low Speed Characterization		100 ±10%		kHz	1
	High Speed Characterization		1 ±10%		MHz	1
SPI Operating Frequency, Sensor and Interrupt Registers Read Only			20 ±10%		MHz	1
I^2C Operating Frequency	All registers, Fast-mode			400	kHz	1
	All registers, Standard-mode			100	kHz	1

Table 5: Other Electrical Specifications

Notes:

1. Derived from validation or characterization of parts, not guaranteed in production.

3.4 I2C Timing Characterization

Typical Operating Circuit of section 4.2, VDD = 1.8V, VDDIO = 1.8V, T_A=25°C, unless otherwise noted.

Parameters	Conditions	Min	Typical	Max	Units	Notes
I²C TIMING	**I²C FAST-MODE**					1
f_{SCL}, SCL Clock Frequency				400	kHz	2
$t_{HD.STA}$, (Repeated) START Condition Hold Time		0.6			µs	2
t_{LOW}, SCL Low Period		1.3			µs	2
t_{HIGH}, SCL High Period		0.6			µs	2
$t_{SU.STA}$, Repeated START Condition Setup Time		0.6			µs	2
$t_{HD.DAT}$, SDA Data Hold Time		0			µs	2
$t_{SU.DAT}$, SDA Data Setup Time		100			ns	2
t_r, SDA and SCL Rise Time	C_b bus cap. from 10 to 400pF	$20+0.1C_b$		300	ns	2
t_f, SDA and SCL Fall Time	C_b bus cap. from 10 to 400pF	$20+0.1C_b$		300	ns	2
$t_{SU.STO}$, STOP Condition Setup Time		0.6			µs	2
t_{BUF}, Bus Free Time Between STOP and START Condition		1.3			µs	2
C_b, Capacitive Load for each Bus Line			< 400		pF	2
$t_{VD.DAT}$, Data Valid Time				0.9	µs	2
$t_{VD.ACK}$, Data Valid Acknowledge Time				0.9	µs	2

Table 6: I²C Timing Characteristics

Notes:

1. Timing Characteristics apply to both Primary and Auxiliary I2C Bus
2. Based on characterization of 5 parts over temperature and voltage as mounted on evaluation board or in sockets

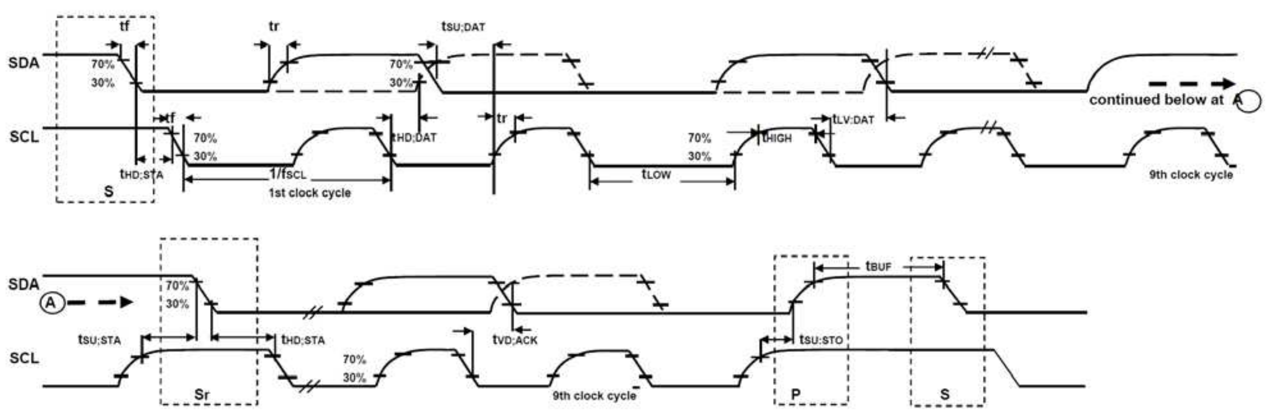


Figure 1: I2C Bus Timing Diagram

3.5 SPI Timing Characterization

Typical Operating Circuit of section 4.2, VDD = 1.8V, VDDIO = 1.8V, T_A=25°C, unless otherwise noted.

Parameters	Conditions	Min	Typical	Max	Units	Notes
SPI TIMING						
f_{SCLK}, SCLK Clock Frequency				1	MHz	1
t_{LOW}, SCLK Low Period		400			ns	1
t_{HIGH}, SCLK High Period		400			ns	1
$t_{SU.CS}$, CS Setup Time		8			ns	1
$t_{HD.CS}$, CS Hold Time		500			ns	1
$t_{SU.SDI}$, SDI Setup Time		11			ns	1
$t_{HD.SDI}$, SDI Hold Time		7			ns	1
$t_{VD.SDO}$, SDO Valid Time	C_{load} = 20pF			100	ns	1
$t_{HD.SDO}$, SDO Hold Time	C_{load} = 20pF	4			ns	1
$t_{DIS.SDO}$, SDO Output Disable Time				50	ns	1

Table 7: SPI Timing Characteristics

Notes:

1. Based on characterization of 5 parts over temperature and voltage as mounted on evaluation board or in sockets

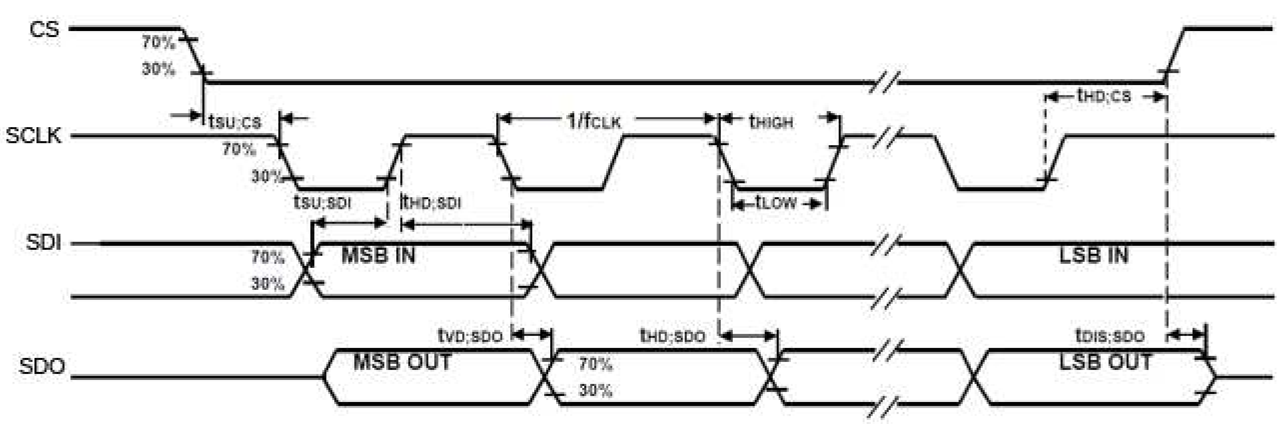


Figure 2: SPI Bus Timing Diagram

3.5.1 fSCLK = 20MHz

Parameters	Conditions	Min	Typical	Max	Units	Notes
SPI TIMING						
f_{SCLK}, SCLK Clock Frequency		0.9		20	MHz	1
t_{LOW}, SCLK Low Period		-		-	ns	
t_{HIGH}, SCLK High Period		-		-	ns	
$t_{SU.CS}$, CS Setup Time		1			ns	1
$t_{HD.CS}$, CS Hold Time		1			ns	1

$t_{SU.SDI}$, SDI Setup Time		0			ns	1
$t_{HD.SDI}$, SDI Hold Time		1			ns	1
$t_{VD.SDO}$, SDO Valid Time	C_{load} = 20pF		25		ns	1
$t_{DIS.SDO}$, SDO Output Disable Time				25	ns	1

Table 8: fCLK = 20MHz

Notes:

1. Based on characterization of 5 parts over temperature and voltage as mounted on evaluation board or in sockets

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.

Parameter	Rating
Supply Voltage, VDD	-0.5V to +4V
Supply Voltage, VDDIO	-0.5V to +4V
REGOUT	-0.5V to 2V
Input Voltage Level (AUX_DA, AD0, FSYNC, INT, SCL, SDA)	-0.5V to VDD + 0.5V
Acceleration (Any Axis, unpowered)	10,000g for 0.2ms
Operating Temperature Range	-40°C to +105°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

Table 9: Absolute Maximum Ratings

4 Applications Information

4.1 Pin Out Diagram and Signal Description

Pin Number	Pin Name	Pin Description
7	AUX_CL	I^2C Master serial clock, for connecting to external sensors
8	VDDIO	Digital I/O supply voltage
9	AD0 / SDO	I^2C Slave Address LSB (AD0); SPI serial data output (SDO)
10	REGOUT	Regulator filter capacitor connection
11	FSYNC	Frame synchronization digital input. Connect to GND if unused.
12	INT	Interrupt digital output (totem pole or open-drain) ***Note: The Interrupt line should be connected to a pin on the Application Processor (AP) that can bring the AP out of suspend mode.***
13	VDD	Power supply voltage and Digital I/O supply voltage
18	GND	Power supply ground
19	RESV	Reserved. Do not connect.
20	RESV	Reserved. Connect to GND.
21	AUX_DA	I^2C master serial data, for connecting to external sensors
22	nCS	Chip select (SPI mode only)
23	SCL / SCLK	I^2C serial clock (SCL); SPI serial clock (SCLK)
24	SDA / SDI	I^2C serial data (SDA); SPI serial data input (SDI)
1 – 6, 14 - 17	NC	No Connect pins. Do not connect.

Table 10: Signal Descriptions

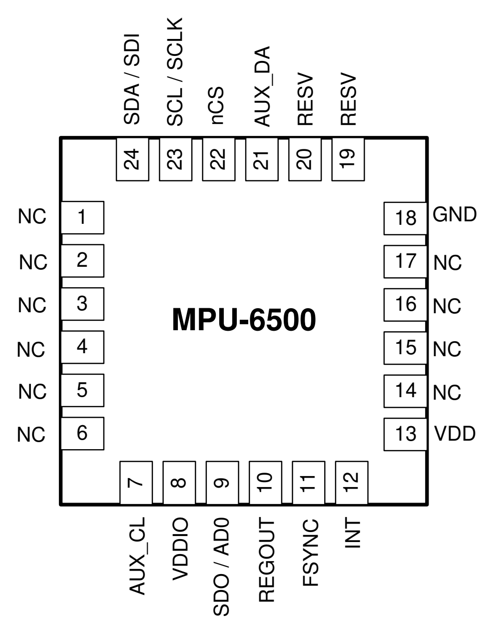
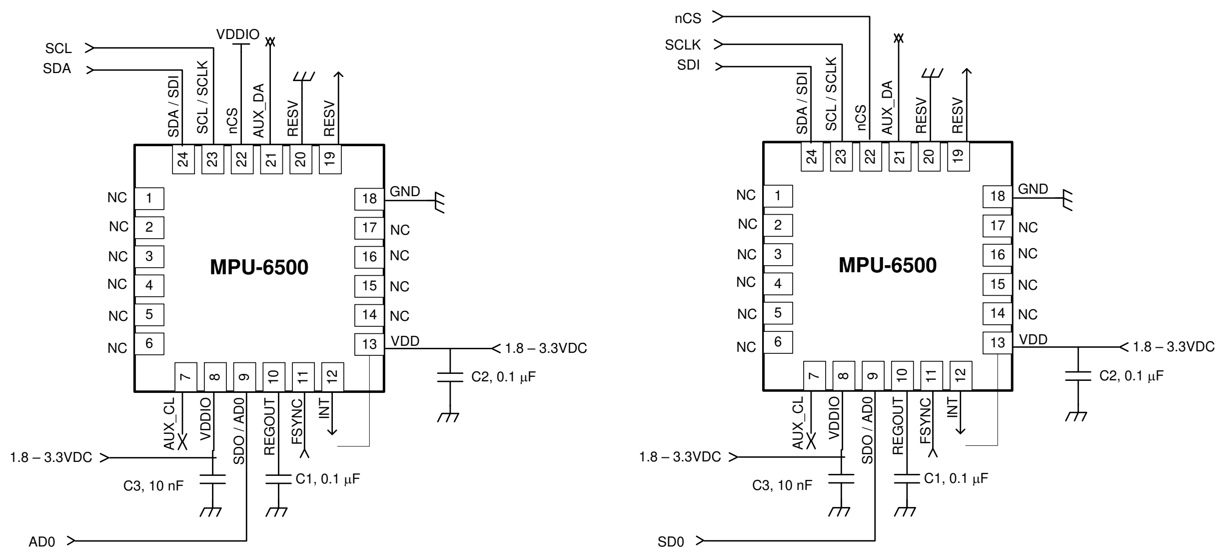


Figure 3: Pin out Diagram for MPU-6500 3.0x3.0x0.9mm QFN

4.2 Typical Operating Circuit



(a) (b)

Figure 4: MPU-6500 QFN Application Schematic. (a) I2C operation, (b) SPI operation.

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

Table 11: Bill of Materials

4.4 Block Diagram

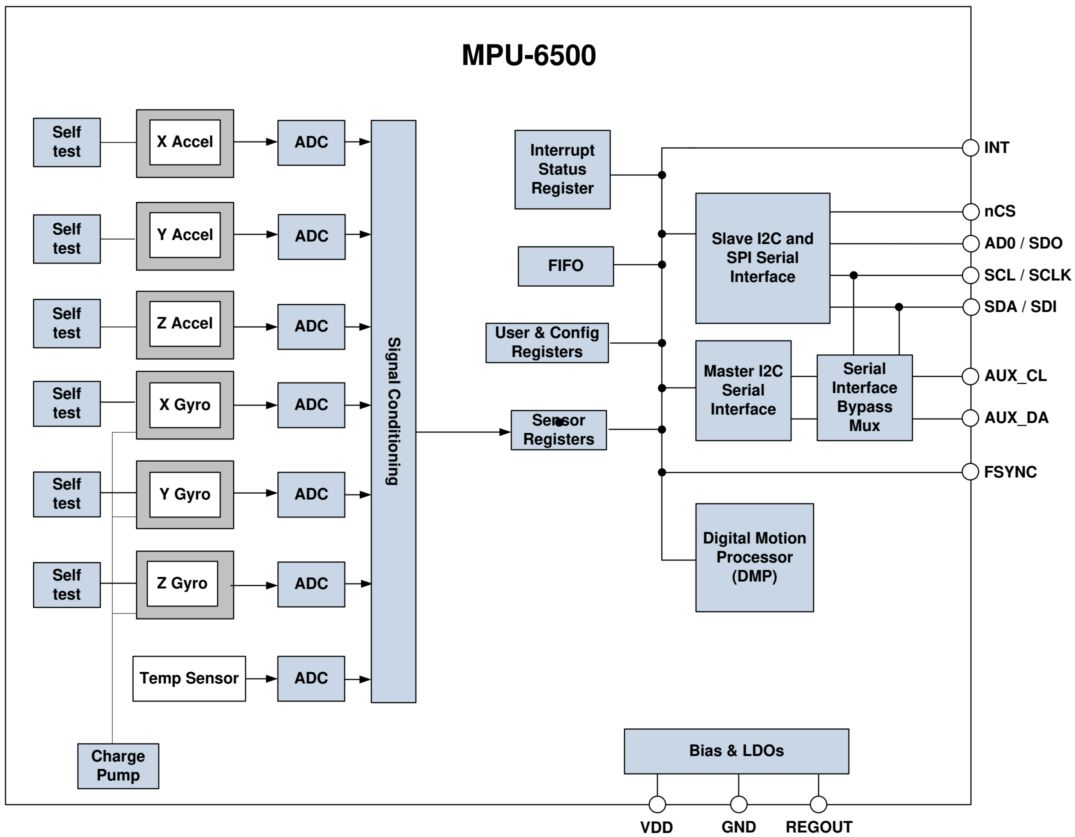


Figure 5: MPU-6500 Block Diagram

Note: The Interrupt line should be connected to a pin on the Application Processor (AP) that can bring the AP out of suspend mode.

4.5 Overview

The MPU-6500 is comprised of the following key blocks and functions:

- Three-axis MEMS rate gyroscope sensor with 16-bit ADCs and signal conditioning
- Three-axis MEMS accelerometer sensor with 16-bit ADCs and signal conditioning
- Digital Motion Processor (DMP) engine
- Primary I^2C and SPI serial communications interfaces
- Auxiliary I^2C serial interface
- Self-Test
- Clocking
- Sensor Data Registers
- FIFO
- Interrupts
- Digital-Output Temperature Sensor
- Bias and LDOs
- Charge Pump
- Standard Power Modes

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

The MPU-6500 consists of three independent vibratory MEMS rate gyroscopes, which detect rotation about the X-, Y-, and Z- Axes. When the gyros are rotated about any of the sense axes, the Coriolis Effect causes a vibration that is detected by a capacitive pickoff. 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 full-scale range of the gyro sensors may be digitally programmed to ±250, ±500, ±1000, or ±2000 degrees per second (dps). The ADC sample rate is programmable from 8,000 samples per second, down to 3.9 samples per second, and user-selectable low-pass filters enable a wide range of cut-off frequencies.

4.7 Three-Axis MEMS Accelerometer with 16-bit ADCs and Signal Conditioning

The MPU-6500's 3-Axis accelerometer uses separate proof masses for each axis. Acceleration along a particular axis induces displacement on the corresponding proof mass, and capacitive sensors detect the displacement differentially. The MPU-6500's architecture reduces the accelerometers' susceptibility to fabrication variations as well as to thermal drift. When the device is placed on a flat surface, it will measure 0*g* on the X- and Y-axes and +1*g* on the Z-axis. The accelerometers' scale factor is calibrated at the factory and is nominally independent of supply voltage. Each sensor has a dedicated sigma-delta ADC for providing digital outputs. The full scale range of the digital output can be adjusted to ±2*g*, ±4*g*, ±8*g*, or ±16*g*.

4.8 Digital Motion Processor

The embedded Digital Motion Processor (DMP) within the MPU-6500 offloads computation of motion processing algorithms from the host processor. The DMP acquires data from accelerometers, gyroscopes, and additional 3rd party sensors such as magnetometers, and processes the data. The resulting data can be read from the FIFO. The DMP has access to one of the MPU's external pins, which can be used for generating interrupts.

The purpose of the DMP is to offload both timing requirements and processing power from the host processor. Typically, motion processing algorithms should be run at a high rate, often around 200Hz, in order to provide accurate results with low latency. This is required even if the application updates at a much lower rate; for example, a low power user interface may update as slowly as 5Hz, but the motion processing should still run at 200Hz. The DMP can be used to minimize power, simplify timing, simplify the software architecture, and save valuable MIPS on the host processor for use in applications.

The DMP supports the following functionality:

- Low Power Quaternion (3-Axis Gyroscope)
- Screen Orientation (A low-power implementation of Android's screen rotation algorithm)
- Pedometer (InvenSense implementation)

4.9 Primary I2C and SPI Serial Communications Interfaces

The MPU-6500 communicates to a system processor using either a SPI or an I^{2}C serial interface. The MPU-6500 always acts as a slave when communicating to the system processor. The LSB of the of the I^{2}C slave address is set by pin 9 (AD0).

4.9.1 MPU-6500 Solution Using I2C Interface

In the figure below, the system processor is an I^{2}C master to the MPU-6500. In addition, the MPU-6500 is an I^{2}C master to the optional external compass sensor. The MPU-6500 has limited capabilities as an I^{2}C Master, and depends on the system processor to manage the initial configuration of any auxiliary sensors.

The MPU-6500 has an interface bypass multiplexer, which connects the system processor I²C bus pins 23 and 24 (SDA and SCL) directly to the auxiliary sensor I²C bus pins 6 and 7 (AUX_DA and AUX_CL).

Once the auxiliary sensors have been configured by the system processor, the interface bypass multiplexer should be disabled so that the MPU-6500 auxiliary I²C master can take control of the sensor I²C bus and gather data from the auxiliary sensors.

For further information regarding I²C master control, please refer to section 6.

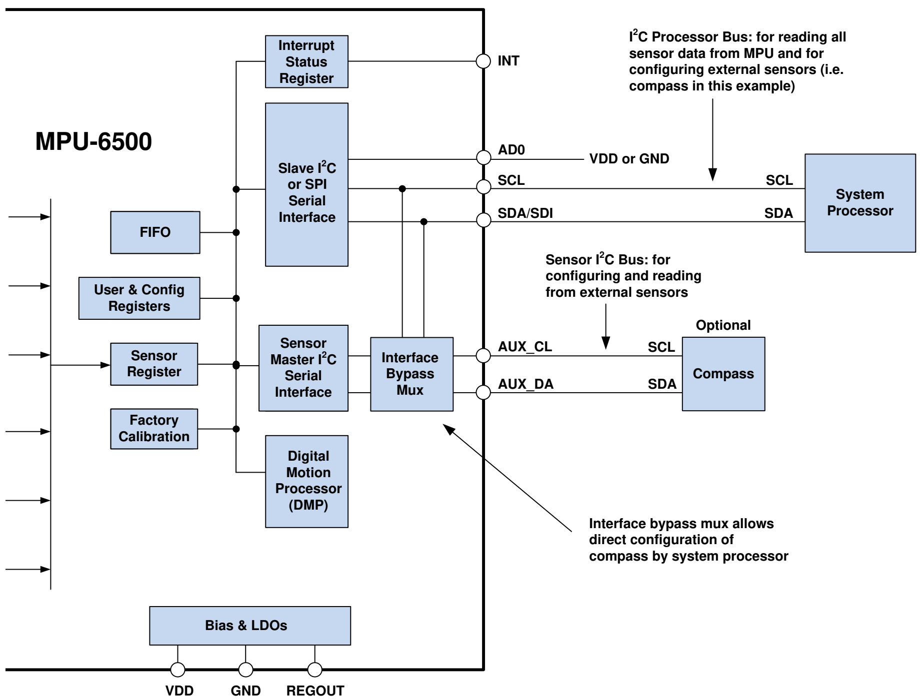


Figure 6: MPU-6500 Solution Using I²C Interface

Note: The Interrupt line should be connected to a pin on the Application Processor (AP) that can bring the AP out of suspend mode.

4.9.2 MPU-6500 Solution Using SPI Interface

In the figure below, the system processor is an SPI master to the MPU-6500. Pins 8, 9, 23, and 24 are used to support the CS, SDO, SCLK, and SDI signals for SPI communications. Because these SPI pins are shared with the I^2C slave pins (9, 23 and 24), the system processor cannot access the auxiliary I^2C bus through the interface bypass multiplexer, which connects the processor I^2C interface pins to the sensor I^2C interface pins. Since the MPU-6500 has limited capabilities as an I^2C Master, and depends on the system processor to manage the initial configuration of any auxiliary sensors, another method must be used for programming the sensors on the auxiliary sensor I^2C bus pins 6 and 7 (AUX_DA and AUX_CL).

When using SPI communications between the MPU-6500 and the system processor, configuration of devices on the auxiliary I^2C sensor bus can be achieved by using I^2C Slaves 0-4 to perform read and write transactions on any device and register on the auxiliary I^2C bus. The I^2C Slave 4 interface can be used to perform only single byte read and write transactions. Once the external sensors have been configured, the MPU-6500 can perform single or multi-byte reads using the sensor I^2C bus. The read results from the Slave 0-3 controllers can be written to the FIFO buffer as well as to the external sensor registers.

For further information regarding the control of the MPU-6500's auxiliary I^2C interface, please refer to the MPU-6500 Register Map and Register Descriptions document.

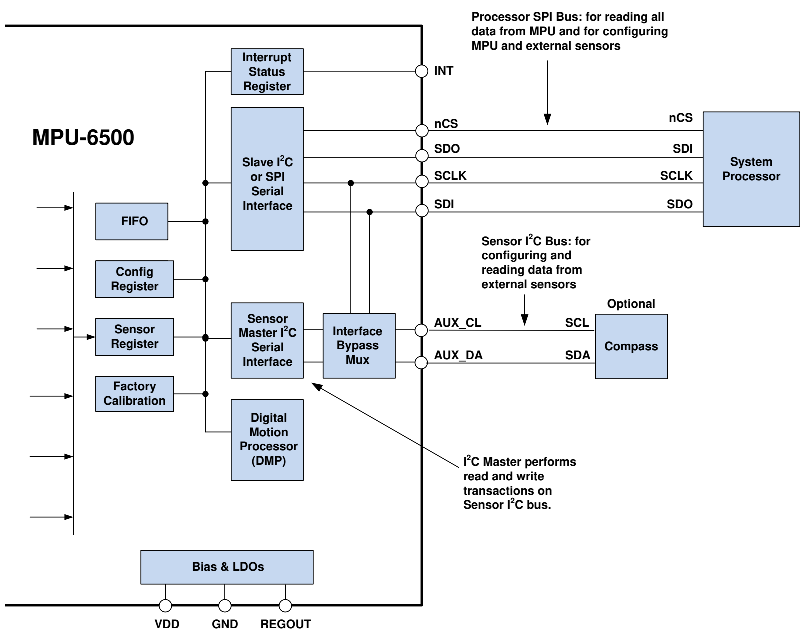


Figure 7: MPU-6500 Solution Using SPI Interface

Note: The Interrupt line should be connected to a pin on the Application Processor (AP) that can bring the AP out of suspend mode.

4.10 Auxiliary I2C Serial Interface

The MPU-6500 has an auxiliary I^2C bus for communicating to an off-chip 3-Axis digital output magnetometer or other sensors. This bus has two operating modes:

- I^2C Master Mode: The MPU-6500 acts as a master to any external sensors connected to the auxiliary I^2C bus
- Pass-Through Mode: The MPU-6500 directly connects the primary and auxiliary I^2C buses together, allowing the system processor to directly communicate with any external sensors.

Auxiliary I²C Bus Modes of Operation:

- I²C Master Mode: Allows the MPU-6500 to directly access the data registers of external digital sensors, such as a magnetometer. In this mode, the MPU-6500 directly obtains data from auxiliary sensors without intervention from the system applications processor.

  For example, In I²C Master mode, the MPU-6500 can be configured to perform burst reads, returning the following data from a magnetometer:

  - X magnetometer data (2 bytes)
  - Y magnetometer data (2 bytes)
  - Z magnetometer data (2 bytes)

  The I²C Master can be configured to read up to 24 bytes from up to 4 auxiliary sensors. A fifth sensor can be configured to work single byte read/write mode.

- Pass-Through Mode: Allows an external system processor to act as master and directly communicate to the external sensors connected to the auxiliary I²C bus pins (AUX_DA and AUX_CL). In this mode, the auxiliary I²C bus control logic (3rd party sensor interface block) of the MPU-6500 is disabled, and the auxiliary I²C pins AUX_DA and AUX_CL (Pins 6 and 7) are connected to the main I²C bus (Pins 23 and 24) through analog switches internally.
  Pass-Through mode is useful for configuring the external sensors, or for keeping the MPU-6500 in a low-power mode when only the external sensors are used. In this mode the system processor can still access MPU-6500 data through the I²C interface.

4.11 Self-Test

Please refer to the register map document for more details on self-test.

Self-test allows for the testing of the mechanical and electrical portions of the sensors. The self-test for each measurement axis can be activated by means of the gyroscope and accelerometer self-test registers (registers 13 to 16).

When the self-test is activated, the electronics cause the sensors to be actuated and produce an output signal. The output signal is used to observe the self-test response.

The self-test response is defined as follows:

Self-test response = Sensor output with self-test enabled – Sensor output without self-test enabled

The self-test response for each gyroscope axis is defined in the gyroscope specification table, while that for each accelerometer axis is defined in the accelerometer specification table.

When the value of the self-test response is within the specified min/max limits of the product specification, the part has passed self-test. When the self-test response exceeds the min/max values, the part is deemed to have failed self-test. It is recommended to use InvenSense MotionApps software for executing self-test.

4.12 Clocking

The MPU-6500 has a flexible clocking scheme, allowing a variety of internal clock sources to be used for the internal synchronous circuitry. This synchronous circuitry includes the signal conditioning and ADCs, the DMP, and various control circuits and registers. An on-chip PLL provides flexibility in the allowable inputs for generating this clock.

Allowable internal sources for generating the internal clock are:

- An internal relaxation oscillator
- Any of the X, Y, or Z gyros (MEMS oscillators with a variation of ±1% over temperature)