
Chipsmall
深圳市津利帝科技有限公司
Geelead Technology Limited
采购部

MPU-9250
Product Specification
Revision 1.0

CONTENTS

1 Document Information

1.1 Revision History

Revision Date	Revision	Description
01/17/14	1.0	Initial Release

1.2 Purpose and Scope

This document is a preliminary product specification, providing a description, specifications, and design related information on the MPU-9250™ MotionTracking device. The device is housed in a small 3x3x1mm 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-9250 Register Map and Register Descriptions document.

1.3 Product Overview

MPU-9250 is a multi-chip module (MCM) consisting of two dies integrated into a single QFN package. One die houses the 3-Axis gyroscope and the 3-Axis accelerometer. The other die houses the AK8963 3-Axis magnetometer from Asahi Kasei Microdevices Corporation. Hence, the MPU-9250 is a 9-axis MotionTracking device that combines a 3-axis gyroscope, 3-axis accelerometer, 3-axis magnetometer and a Digital Motion Processor™ (DMP) all in a small 3x3x1mm package available as a pin-compatible upgrade from the MPU-6515. With its dedicated I^2C sensor bus, the MPU-9250 directly provides complete 9-axis MotionFusion™ output. The MPU-9250 MotionTracking device, with its 9-axis integration, on-chip MotionFusion™, 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-9250 is also designed to interface with multiple non-inertial digital sensors, such as pressure sensors, on its auxiliary I^2C port.

MPU-9250 features three 16-bit analog-to-digital converters (ADCs) for digitizing the gyroscope outputs, three 16-bit ADCs for digitizing the accelerometer outputs, and three 16-bit ADCs for digitizing the magnetometer outputs. For precision tracking of both fast and slow motions, the parts feature a user-programmable gyroscope full-scale range of ±250, ±500, ±1000, and ±2000°/sec (dps), a user-programmable accelerometer full-scale range of ±2*g*, ±4*g*, ±8*g*, and ±16*g*, and a magnetometer full-scale range of ±4800µT.

Other industry-leading features include 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 2.4V to 3.6V, and a separate digital IO supply, VDDIO from 1.71V to VDD.

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 3x3x1mm, 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-9250 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
- Sleep mode current: 8µA
- Factory calibrated sensitivity scale factor
- Self-test

2.2 Accelerometer Features

The triple-axis MEMS accelerometer in MPU-9250 includes a wide range of features:

- Digital-output triple-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: 8.4µA at 0.98Hz, 19.8µA at 31.25Hz
- Sleep mode current: 8µA
- User-programmable interrupts
- Wake-on-motion interrupt for low power operation of applications processor
- Self-test

2.3 Magnetometer Features

The triple-axis MEMS magnetometer in MPU-9250 includes a wide range of features:

- 3-axis silicon monolithic Hall-effect magnetic sensor with magnetic concentrator
- Wide dynamic measurement range and high resolution with lower current consumption.
- Output data resolution of 14 bit (0.6µT/LSB) or 16 bit (15µT/LSB)
- Full scale measurement range is ±4800µT
- Magnetometer normal operating current: 280µA at 8Hz repetition rate
- Self-test function with internal magnetic source to confirm magnetic sensor operation on end products

2.4 Additional Features

The MPU-9250 includes the following additional features:

- Auxiliary master I^2C bus for reading data from external sensors (e.g. pressure sensor)
- 3.5mA operating current when all 9 motion sensing axes and the DMP are enabled
- VDD supply voltage range of 2.4 – 3.6V
- VDDIO reference voltage for auxiliary I^2C devices
- Smallest and thinnest QFN package for portable devices: 3x3x1mm
- Minimal cross-axis sensitivity between the accelerometer, gyroscope and magnetometer 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

2.5 MotionProcessing

- Internal Digital Motion Processing™ (DMP™) engine supports advanced MotionProcessing and low power functions such as gesture recognition using programmable interrupts
- 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 = 2.5V, VDDIO = 2.5V, T_A=25°C, unless otherwise noted.

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Full-Scale Range	FS_SEL=0		±250		º/s
	FS_SEL=1		±500		º/s
	FS_SEL=2		±1000		º/s
	FS_SEL=3		±2000		º/s
Gyroscope ADC Word Length			16		bits
Sensitivity Scale Factor	FS_SEL=0		131		LSB/(º/s)
	FS_SEL=1		65.5		LSB/(º/s)
	FS_SEL=2		32.8		LSB/(º/s)
	FS_SEL=3		16.4		LSB/(º/s)
Sensitivity Scale Factor Tolerance	25°C		±3		%
Sensitivity Scale Factor Variation Over Temperature	-40°C to +85°C		±4		%
Nonlinearity	Best fit straight line; 25°C		±0.1		%
Cross-Axis Sensitivity			±2		%
Initial ZRO Tolerance	25°C		±5		º/s
ZRO Variation Over Temperature	-40°C to +85°C		±30		º/s
Total RMS Noise	DLPFCFG=2 (92 Hz)		0.1		º/s-rms
Rate Noise Spectral Density			0.01		°/s/√Hz
Gyroscope Mechanical Frequencies		25	27	29	KHz
Low Pass Filter Response	Programmable Range	5		250	Hz
Gyroscope Startup Time	From Sleep mode		35		ms
Output Data Rate	Programmable, Normal mode	4		8000	Hz

Table 1 Gyroscope Specifications

3.2 Accelerometer Specifications

Typical Operating Circuit of section 4.2, VDD = 2.5V, VDDIO = 2.5V, T_A=25°C, unless otherwise noted.

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Full-Scale Range	AFS_SEL=0		±2		*g*
	AFS_SEL=1		±4		*g*
	AFS_SEL=2		±8		*g*
	AFS_SEL=3		±16		*g*
ADC Word Length	Output in two's complement format		16		bits
Sensitivity Scale Factor	AFS_SEL=0		16,384		LSB/*g*
	AFS_SEL=1		8,192		LSB/*g*
	AFS_SEL=2		4,096		LSB/*g*
	AFS_SEL=3		2,048		LSB/*g*
Initial Tolerance	Component-Level		±3		%
Sensitivity Change vs. Temperature	-40°C to +85°C AFS_SEL=0 Component-level		±0.026		%/°C
Nonlinearity	Best Fit Straight Line		±0.5		%
Cross-Axis Sensitivity			±2		%
Zero-G Initial Calibration Tolerance	Component-level, X,Y		±60		m*g*
	Component-level, Z		±80		m*g*
Zero-G Level Change vs. Temperature	-40°C to +85°C		±1.5		m*g*/°C
Noise Power Spectral Density	Low noise mode		300		µ*g*/√Hz
Total RMS Noise	DLPFCFG=2 (94Hz)			8	mg-rms
Low Pass Filter Response	Programmable Range	5		260	Hz
Intelligence Function Increment			4		m*g*/LSB
Accelerometer Startup Time	From Sleep mode		20		ms
	From Cold Start, 1ms V_{DD} ramp		30		ms
Output Data Rate	Low power (duty-cycled)	0.24		500	Hz
	Duty-cycled, over temp		±15		%
	Low noise (active)	4		4000	Hz

Table 2 Accelerometer Specifications

3.3 Magnetometer Specifications

Typical Operating Circuit of section 4.2, VDD = 2.5V, VDDIO = 2.5V, T_A=25°C, unless otherwise noted.

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
MAGNETOMETER SENSITIVITY					
Full-Scale Range			±4800		µT
ADC Word Length			14		bits
Sensitivity Scale Factor			0.6		µT / LSB
ZERO-FIELD OUTPUT					
Initial Calibration Tolerance			±500		LSB

3.4 Electrical Specifications

3.4.1 D.C. Electrical Characteristics

Typical Operating Circuit of section 4.2, VDD = 2.5V, VDDIO = 2.5V, T_A=25°C, unless otherwise noted.

PARAMETER	CONDITIONS	MIN	TYP	MAX	Units	Notes
SUPPLY VOLTAGES						
VDD		2.4	2.5	3.6	V	
VDDIO		1.71	1.8	VDD	V	
SUPPLY CURRENTS						
Normal Mode	9-axis (no DMP), 1 kHz gyro ODR, 4 kHz accel ODR, 8 Hz mag. repetition rate		3.7		mA	
	6-axis (accel + gyro, no DMP), 1 kHz gyro ODR, 4 kHz accel ODR		3.4		mA	
	3-axis Gyroscope only (no DMP), 1 kHz ODR		3.2		mA	
	6-axis (accel + magnetometer, no DMP), 4 kHz accel ODR, mag. repetition rate = 8 Hz		730		µA	
	3-Axis Accelerometer, 4kHz ODR (no DMP)		450		µA	
	3-axis Magnetometer only (no DMP), 8 Hz repetition rate		280		µA	
Accelerometer Low Power Mode (DMP, Gyroscope, Magnetometer disabled)	0.98 Hz update rate		8.4		µA	1
	31.25 Hz update rate		19.8		µA	1
Full Chip Idle Mode Supply Current			8		µA	
TEMPERATURE RANGE						
Specified Temperature Range	Performance parameters are not applicable beyond Specified Temperature Range	-40		+85	°C	

Table 3 D.C. Electrical Characteristics

Notes:

1. 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:

   Supply Current in µA = Sleep Current + Update Rate * 0.376

3.4.2 A.C. Electrical Characteristics

Typical Operating Circuit of section 4.2, VDD = 2.5V, VDDIO = 2.5V, T_A=25°C, unless otherwise noted.

Parameter	Conditions	MIN	TYP	MAX	Units
Supply Ramp Time	Monotonic ramp. Ramp rate is 10% to 90% of the final value	0.1		100	ms
Operating Range	Ambient	-40		85	°C
Sensitivity	Untrimmed		333.87		LSB/°C
Room Temp Offset	21°C		0		LSB
Supply Ramp Time (T_{RAMP})	Valid power-on RESET	0.01	20	100	ms
Start-up time for register read/write	From power-up		11	100	ms
I²C ADDRESS	AD0 = 0 AD0 = 1		1101000 1101001		
V_{IH}, High Level Input Voltage		0.7*VDDIO			V
V_{IL}, Low Level Input Voltage				0.3*VDDIO	V
C_I, Input Capacitance			< 10		pF
V_{OH}, High Level Output Voltage	R_{LOAD}=1MΩ;	0.9*VDDIO			V
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
V_{IL}, LOW Level Input Voltage		-0.5V		0.3*VDDIO	V
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
V_{IL}, LOW-Level Input Voltage		-0.5V		0.3*VDDIO	V
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
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
Sample Rate	Fchoice=0,1,2 SMPLRT_DIV=0		32		kHz
	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		+10	%
	CLK_SEL=1,2,3,4,5		±1		%

Table 4 A.C. Electrical Characteristics

3.4.3 Other Electrical Specifications

Typical Operating Circuit of section 4.2, VDD = 2.5V, VDDIO = 2.5V, T_A=25°C, unless otherwise noted.

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

Table 5 Other Electrical Specifications

3.5 I2C Timing Characterization

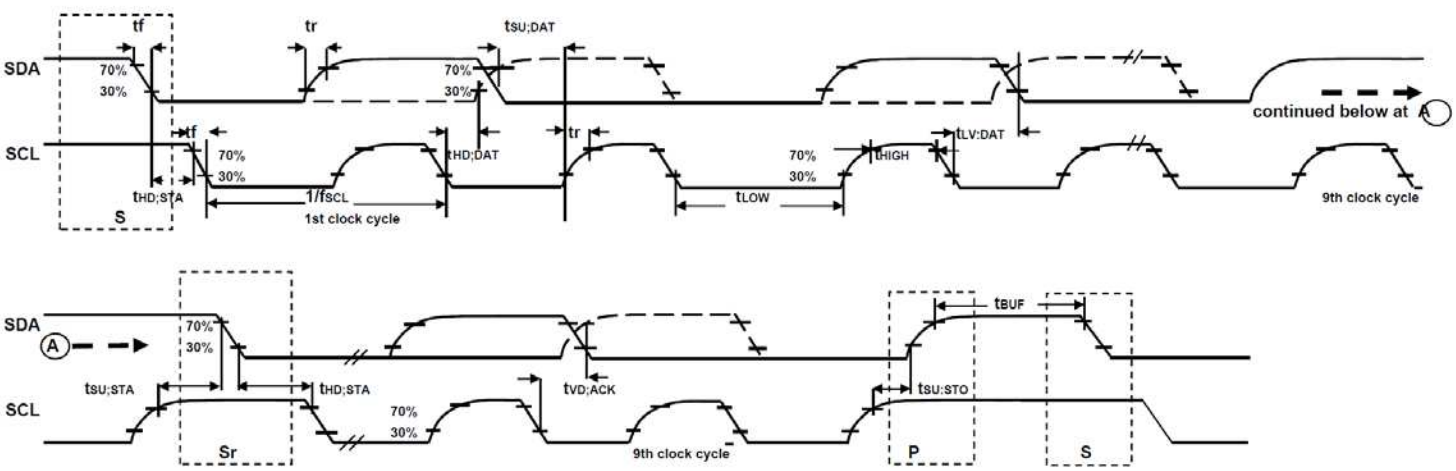
Typical Operating Circuit of section 4.2, VDD = 2.4V to 3.6V, VDDIO = 1.71 to VDD, T_A=25°C, unless otherwise noted.

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

Table 6 I^2C Timing Characteristics

Notes:

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



I^2C Bus Timing Diagram

3.6 SPI Timing Characterization

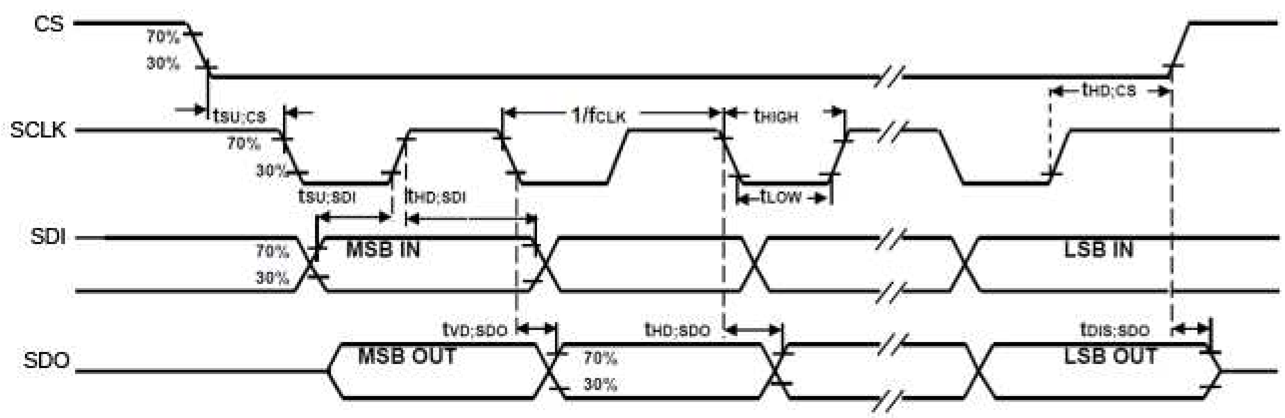
Typical Operating Circuit of section 4.2, VDD = 2.4V to 3.6V, VDDIO = 1.71V to VDD, T_A=25°C, unless otherwise noted.

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

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



SPI Bus Timing Diagram

3.6.1 fSCLK = 20MHz

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

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

Table 8 fCLK = 20MHz

Note:

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

3.7 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.

Specification	Symbol	Conditions	MIN	MAX	Units
Supply Voltage	V_{DD}		-0.5	4.0	V
	V_{DDIO}		-0.5	4.0	V
Acceleration		Any axis, unpowered, 0.2ms duration		10,000	*g*
Temperature		Operating	-40	105	°C
		Storage	-40	125	°C
ESD Tolerance		HBM	2		KV
		MM	250		V

4 Applications Information

4.1 Pin Out and Signal Description

Pin Number	Pin Name	Pin Description
1	RESV	Reserved. Connect to VDDIO.
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)
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)
2 – 6, 14 - 17	NC	Not internally connected. May be used for PCB trace routing.

Table 9 Signal Descriptions

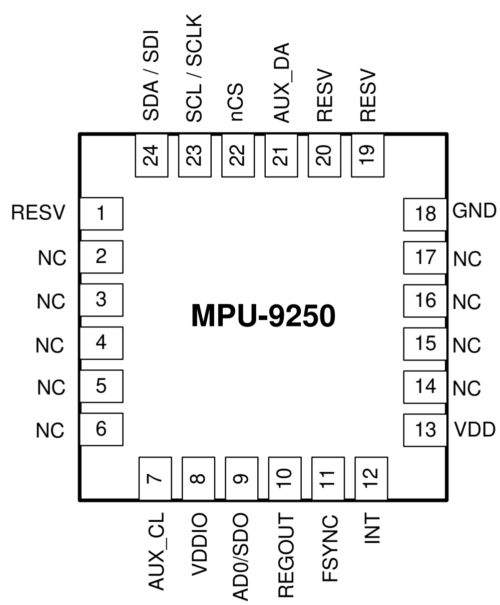
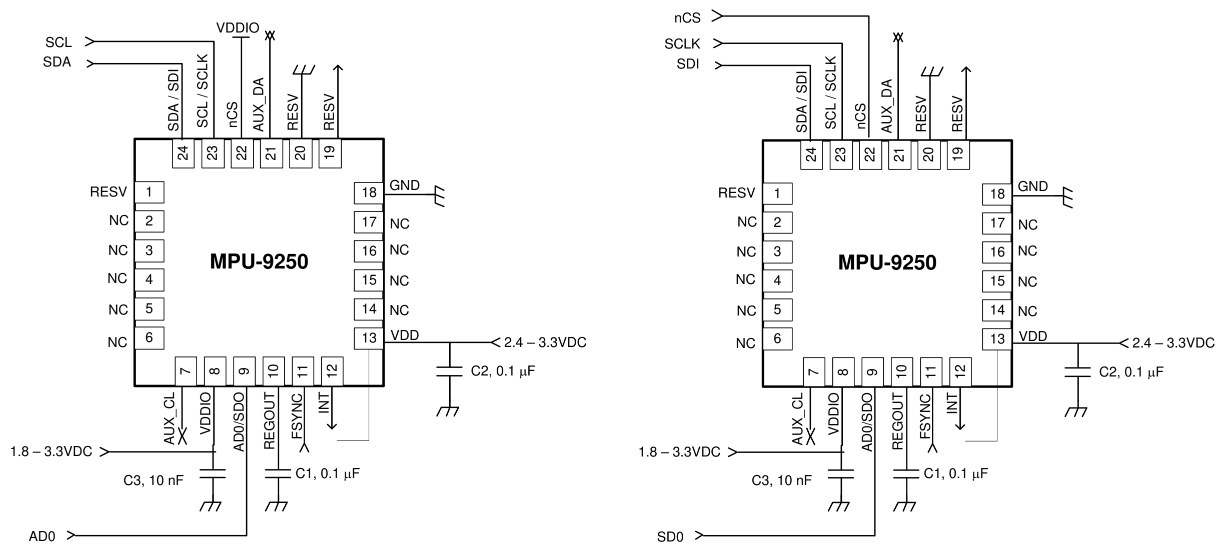


Figure 1 Pin Out Diagram for MPU-9250 3.0x3.0x1.0mm QFN

4.2 Typical Operating Circuit



(a) (b)

Figure 2 MPU-9250 QFN Application Schematic: (a) I2C operation, (b) SPI operation

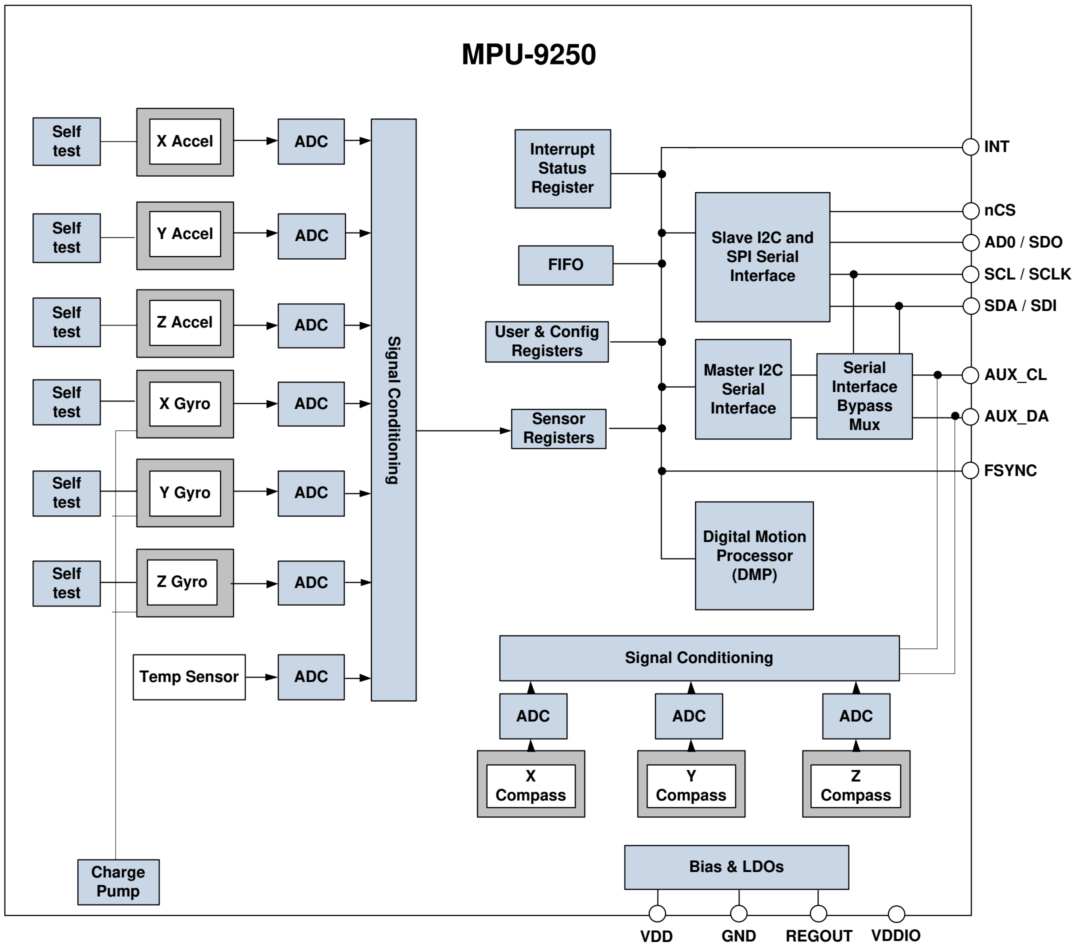
Note that the INT pin should be connected to a GPIO pin on the system processor that is capable of waking the system processor from suspend mode.

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 10 Bill of Materials

4.4 Block Diagram



4.5 Overview

The MPU-9250 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
- Three-axis MEMS magnetometer 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 for 3^{rd} party sensors
- Clocking
- Sensor Data Registers
- FIFO
- Interrupts
- Digital-Output Temperature Sensor
- Gyroscope, Accelerometer and Magnetometer Self-test
- Bias and LDO
- Charge Pump

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

The MPU-9250 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-9250'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-9250'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 Three-Axis MEMS Magnetometer with 16-bit ADCs and Signal Conditioning

The 3-axis magnetometer uses highly sensitive Hall sensor technology. The magnetometer portion of the IC incorporates magnetic sensors for detecting terrestrial magnetism in the X-, Y-, and Z- Axes, a sensor driving circuit, a signal amplifier chain, and an arithmetic circuit for processing the signal from each sensor. Each ADC has a 16-bit resolution and a full scale range of ±4800 µT.

4.9 Digital Motion Processor

The embedded Digital Motion Processor (DMP) is located within the MPU-9250 and offloads computation of motion processing algorithms from the host processor. The DMP acquires data from accelerometers, gyroscopes, magnetometers and additional 3rd party sensors, and processes the data. The resulting data can be read from the DMP's registers, or can be buffered in a FIFO. The DMP has access to one of the MPU's external pins, which can be used for generating interrupts. This pin (pin 12) should be connected to a pin on the host processor that can wake the host from suspend mode.

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 as a tool in order to minimize power, simplify timing, simplify the software architecture, and save valuable MIPS on the host processor for use in the application.

4.10 Primary I2C and SPI Serial Communications Interfaces

The MPU-9250 communicates to a system processor using either a SPI or an I^2C serial interface. The MPU-9250 always acts as a slave when communicating to the system processor. The LSB of the of the I^2C slave address is set by pin 9 (AD0).

4.11 Auxiliary I2C Serial Interface

The MPU-9250 has an auxiliary I^2C bus for communicating to off-chip sensors. This bus has two operating modes:

- I^2C Master Mode: The MPU-9250 acts as a master to any external sensors connected to the auxiliary I^2C bus
- Pass-Through Mode: The MPU-9250 directly connects the primary and auxiliary I^2C buses together, allowing the system processor to directly communicate with any external sensors.
- Note: AUX_DA and AUX_CL should be left unconnected if the Auxiliary I^2C mode is not used.

Auxiliary I^2C Bus Modes of Operation:

- I^2C Master Mode: Allows the MPU-9250 to directly access the data registers of external digital sensors, such as a magnetometer. In this mode, the MPU-9250 directly obtains data from auxiliary sensors without intervention from the system applications processor.

  For example, In I^2C Master mode, the MPU-9250 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 I^2C 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 I^2C bus pins (AUX_DA and AUX_CL). In this mode, the auxiliary I^2C bus control logic (3rd party sensor interface block) of the MPU-9250 is disabled, and the auxiliary I^2C pins AUX_DA and AUX_CL are connected to the main I^2C bus through analog switches internally.

Pass-Through mode is useful for configuring the external sensors, or for keeping the MPU-9250 in a low-power mode when only the external sensors are used. In this mode, the system processor can still access MPU-9250 data through the I^2C interface.
Pass-Through mode is also used to access the AK8963 magnetometer directly from the host. In this configuration the slave address for the AK8963 is 0X0C or 12 decimal.

Auxiliary I^2C Bus IO Logic Levels

For MPU-9250, the logic level of the auxiliary I^2C bus is VDDIO. For further information regarding the MPU-9250 logic levels, please refer to Section 10.2.

4.12 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

When the value of the self-test response is within the appropriate limits, the part has passed self-test. When the self-test response exceeds the appropriate values, the part is deemed to have failed self-test. It is recommended to use InvenSense MotionApps software for executing self-test. Further details, including the self-test limits are included in the MPU-9250 Self-Test applications note available from InvenSense.

4.13 MPU-9250 Solution Using I2C Interface

In the figure below, the system processor is an I^2C master to the MPU-9250. In addition, the MPU-9250 is an I^2C master to the optional external 3rd party sensor. The MPU-9250 has limited capabilities as an I^2C Master, and depends on the system processor to manage the initial configuration of any auxiliary sensors. The MPU-9250 has an interface bypass multiplexer, which connects the system processor I^2C bus (SDA and SCL) directly to the auxiliary sensor I^2C bus (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-9250 auxiliary I^2C master can take control of the sensor I^2C bus and gather data from the auxiliary sensors. The INT pin should be connected to a GPIO on the system processor that can wake the system from suspend mode.