MPU-9150
Product Specification
Revision 4.0

CONTENTS

1 Revision History

Revision Date	Revision	Description
5/27/2011	1.0	Initial Release of Product Specification
06/14/2011	2.0	Modified for Rev C Silicon (sections 5.2, 6.2, 6.4, 6.6, 8.2, 8.3, 8.4) Edits for clarity (several sections)
10/21/2011	2.1	Updated Supply current vs. operating modes (sections 5.3, 5.4, 6.4) Modified Self-Test Response of Accelerometers (section 6.2) Modified absolute maximum rating for acceleration (section 6.9) Updated latch up current rating (sections 6.9, 12.2) Modified package dimensions and PCB design guidelines (sections 11.2, 11.3) Updated assembly precautions (section 11.4) Updated qualification test plan (section 12.2) Edits for clarity (several sections)
10/24/2011	3.0	Modified for Rev D Silicon (sections 6.2, 8.2, 8.3, 8.4) Edits for Clarity (several sections)
12/23/2011	3.1	Updated package dimensions (section 11.2)
5/14/2012	4.0	Added Gyroscope specifications (section 6.1) Added Accelerometer specifications (section 6.2) Updated Electrical Other Common Specifications (section 6.3) Updated latch-up information (section 6.9) Updated Block Diagram (section 7.5) Update Self-Test description (section 7.13) Updated PCB design guidelines (section 11.3) Updated packing and shipping information (sections 11.8, 11.9, 11.10, 11.11) Updated reliability references (section 12.2)

2 Purpose and Scope

This product specification provides preliminary information regarding the electrical specification and design related information for the MPU-9150™ Motion Processing Unit™ or MPU™.

Electrical characteristics are based upon design analysis and simulation results only. 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-9150 Register Map and Register Descriptions document.

3 Product Overview

3.1 MPU-9150 Overview

MotionInterface™ is becoming a "must-have" function being adopted by smartphone and tablet manufacturers due to the enormous value it adds to the end user experience. In smartphones, it finds use in applications such as gesture commands for applications and phone control, enhanced gaming, augmented reality, panoramic photo capture and viewing, and pedestrian and vehicle navigation. With its ability to precisely and accurately track user motions, MotionTracking technology can convert handsets and tablets into powerful 3D intelligent devices that can be used in applications ranging from health and fitness monitoring to location-based services. Key requirements for MotionInterface enabled devices are small package size, low power consumption, high accuracy and repeatability, high shock tolerance, and application specific performance programmability – all at a low consumer price point.

The MPU-9150 is the world's first integrated 9-axis MotionTracking device that combines a 3-axis MEMS gyroscope, a 3-axis MEMS accelerometer, a 3-axis MEMS magnetometer and a Digital Motion Processor™ (DMP™) hardware accelerator engine. The MPU-9150 is an ideal solution for handset and tablet applications, game controllers, motion pointer remote controls, and other consumer devices. The MPU-9150's 9-axis MotionFusion combines acceleration and rotational motion plus heading information into a single data stream for the application. This MotionProcessing™ technology integration provides a smaller footprint and has inherent cost advantages compared to discrete gyroscope, accelerometer, plus magnetometer solutions. The MPU-9150 is also designed to interface with multiple non-inertial digital sensors, such as pressure sensors, on its auxiliary I^2C port to produce a 10-Axis sensor fusion output. The MPU-9150 is a 3rd generation motion processor and is footprint compatible with the MPU-60X0 and MPU-30X0 families.

The MPU-9150 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 13-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 ±1200µT.

The MPU-9150 is a multi-chip module (MCM) consisting of two dies integrated into a single LGA package. One die houses the 3-Axis gyroscope and the 3-Axis accelerometer. The other die houses the AK8975 3-Axis magnetometer from Asahi Kasei Microdevices Corporation.

An on-chip 1024 Byte FIFO buffer helps lower system power consumption by allowing the system processor to read the sensor data in bursts and then enter a low-power mode as the MPU collects more data. With all the necessary on-chip processing and sensor components required to support many motion-based use cases, the MPU-9150 uniquely supports a variety of advanced motion-based applications entirely on-chip. The MPU-9150 thus enables low-power MotionProcessing in portable applications with reduced processing requirements for the system processor. By providing an integrated MotionFusion output, the DMP in the MPU-9150 offloads the intensive MotionProcessing computation requirements from the system processor, minimizing the need for frequent polling of the motion sensor output.

Communication with all registers of the device is performed using I^2C at 400kHz. Additional features include an embedded temperature sensor and an on-chip oscillator with ±1% variation over the operating temperature range.

By leveraging its patented and volume-proven Nasiri-Fabrication platform, which integrates MEMS wafers with companion CMOS electronics through wafer-level bonding, InvenSense has driven the MPU-9150 package size down to a revolutionary footprint of 4x4x1mm (LGA), while providing the highest performance, lowest noise, and the lowest cost semiconductor packaging required for handheld consumer electronic devices. The part features a robust 10,000*g* shock tolerance, and has programmable low-pass filters for the gyroscopes, accelerometers, magnetometers, and the on-chip temperature sensor.

4 Applications

- *BlurFree*™ technology (for Video/Still Image Stabilization)
- *AirSign*™ technology (for Security/Authentication)
- *TouchAnywhere*™ technology (for “no touch” UI Application Control/Navigation)
- *MotionCommand*™ technology (for Gesture Short-cuts)
- Motion-enabled game and application framework
- InstantGesture™ iG™ gesture recognition
- 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
- Toys
- Pedestrian based navigation
- Navigation
- Electronic Compass

5 Features

5.1 Gyroscope Features

The triple-axis MEMS gyroscope in the MPU-9150 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
- External sync signal connected to the FSYNC pin supports image, video and GPS synchronization
- Integrated 16-bit ADCs enable simultaneous sampling of gyros
- Enhanced bias and sensitivity temperature stability reduces the need for user calibration
- Improved low-frequency noise performance
- Digitally-programmable low-pass filter
- Factory calibrated sensitivity scale factor
- User self-test

5.2 Accelerometer Features

The triple-axis MEMS accelerometer in MPU-9150 includes a wide range of features:

- Digital-output 3-Axis accelerometer with a programmable full scale range of ±2*g*, ±4*g*, ±8*g* and ±16*g*
- Integrated 16-bit ADCs enable simultaneous sampling of accelerometers while requiring no external multiplexer
- Orientation detection and signaling
- Tap detection
- User-programmable interrupts
- High-G interrupt
- User self-test

5.3 Magnetometer Features

The triple-axis MEMS magnetometer in MPU-9150 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 is 13 bit (0.3 µT per LSB)
- Full scale measurement range is ±1200 µT
- Self-test function with internal magnetic source to confirm magnetic sensor operation on end products

5.4 Additional Features

The MPU-9150 includes the following additional features:

- 9-Axis MotionFusion via on-chip Digital Motion Processor (DMP)
- Auxiliary master I^{2}C bus for reading data from external sensors (e.g., pressure sensor)
- Flexible VLOGIC reference voltage supports multiple I^{2}C interface voltages
- Smallest and thinnest package for portable devices: 4x4x1mm LGA
- Minimal cross-axis sensitivity between the accelerometer, gyroscope and magnetometer axes
- 1024 byte FIFO buffer reduces power consumption by allowing host processor to read the data in bursts and then go into a low-power mode as the MPU collects more data
- 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
- MEMS structure hermetically sealed and bonded at wafer level
- RoHS and Green compliant

5.5 MotionProcessing

- Internal Digital Motion Processing™ (DMP™) engine supports 3D MotionProcessing and gesture recognition algorithms
- The MPU-9150 collects gyroscope, accelerometer and magnetometer data while synchronizing data sampling at a user defined rate. The total dataset obtained by the MPU-9150 includes 3-Axis gyroscope data, 3-Axis accelerometer data, 3-Axis magnetometer data, and temperature data.
- The FIFO buffers the complete data set, reducing timing requirements on the system processor by allowing the processor burst read the FIFO data. After burst reading the FIFO data, the system processor can save power by entering a low-power sleep mode while the MPU collects more data.
- Programmable interrupt supports features such as gesture recognition, panning, zooming, scrolling, zero-motion detection, tap detection, and shake detection
- Digitally-programmable low-pass filters.
- Low-power pedometer functionality allows the host processor to sleep while the DMP maintains the step count.

5.6 Clocking

- On-chip timing generator ±1% frequency variation over full temperature range
- Optional external clock inputs of 32.768kHz or 19.2MHz

6 Electrical Characteristics

6.1 Gyroscope Specifications

VDD = 2.375V-3.465V, VLOGIC= 1.8V±5% or VDD, T_A = 25℃

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	NOTES
GYROSCOPE SENSITIVITY						
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℃	-3		+3	%	
Sensitivity Scale Factor Variation Over Temperature	-40℃ to +85℃		±0.04		%/℃	
Nonlinearity	Best fit straight line; 25℃		0.2		%	
Cross-Axis Sensitivity			±2		%	
GYROSCOPE ZERO-RATE OUTPUT (ZRO)						
Initial ZRO Tolerance	Component level (25℃)		±20		º/s	
ZRO Variation Over Temperature	-40℃ to +85℃		±20		º/s	
SELF-TEST RESPONSE	Change from factory trim	-14		14	%	
GYROSCOPE NOISE PERFORMANCE	**FS_SEL=0**					
Total RMS Noise	DLPFCFG=2 (92Hz)		0.06		º/s-rms	
Rate Noise Spectral Density	At 10Hz		0.005		º/s/ √Hz	
GYROSCOPE MECHANICAL FREQUENCIES						
X-Axis		30	33	36	kHz	
Y-Axis		27	30	33	kHz	
Z-Axis		24	27	30	kHz	
LOW PASS FILTER RESPONSE	Programmable Range	5		256	Hz	
OUTPUT DATA RATE	Programmable	4		8,000	Hz	
GYROSCOPE START-UP TIME	**DLPFCFG=0**					
ZRO Settling	to ±1º/s of Final		30		ms	

6.2 Accelerometer Specifications

VDD = 2.375V-3.465V, VLOGIC= 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	NOTES
ACCELEROMETER SENSITIVITY						
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 Calibration Tolerance			±3		%	
Sensitivity Change vs. Temperature	AFS_SEL=0, -40°C to +85°C		±0.02		%/°C	
Nonlinearity	Best Fit Straight Line		0.5		%	
ZERO-G OUTPUT						
Initial Calibration Tolerance	X and Y axes		±80		m*g*	
	Z axis		±150		m*g*	
Change over specified temperature – Component level -25°C to 85°C	X & Y Axis		±0.75		mg/°C	
	Z Axis		±1.50		mg/°C	
SELF-TEST RESPONSE	Change from factory trim	-14		14	%	
NOISE PERFORMANCE						
Power Spectral Density	X, Y & Z Axes, @10Hz, AFS_SEL=0 & ODR=1kHz		400		µg/ √Hz	
Total RMS Noise	AFS = 0 @100Hz		4		mg-rms	
LOW PASS FILTER RESPONSE	Programmable Range	5		260	Hz	
OUTPUT DATA RATE	Programmable Range	4		1,000	Hz	
INTELLIGENCE FUNCTION INCREMENT			32		m*g*/LSB	

6.3 Magnetometer Specifications

VDD = 2.375V-3.465V, VLOGIC= 1.8V±5% or VDD, T_A = 25℃

The information in the following table is from the AKM AK8975 datasheet.

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	NOTES
MAGNETOMETER SENSITIVITY						
Full-Scale Range			±1200		µT	
ADC Word Length	Output in two's complement format		13		bits	
Sensitivity Scale Factor		0.285	0.3	0.315	µT /LSB	
ZERO-FIELD OUTPUT						
Initial Calibration Tolerance		-1000		1000	LSB	
SELF-TEST RESPONSE						
	X-axis	-100		100		
	Y-axis	-100		100	LSB	
	Z-axis	-1000		-300		

6.4 Electrical and Other Common Specifications

VDD = 2.375V-3.465V, VLOGIC= 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	Units	Notes
TEMPERATURE SENSOR						
Range			-40 to +85		°C	
Sensitivity	Untrimmed		340		LSB/ºC	
Temperature Offset	35°C		-521		LSB	
Linearity	Best fit straight line (-40°C to +85°C)		±1		°C	
VDD POWER SUPPLY						
Operating Voltages		2.375		3.465	V	
Power Supply Ramp Rate	Monotonic ramp. Ramp rate is 10% to 90% of the final value			100	ms	
OPERATING CURRENT						
Normal Operating Current	Gyro at all rates; Gyro+Accel (Magnetometer and DMP disabled)		3.9		mA	
	Accel at 1kHz sample rate; Accel + Magnetometer (Gyro and DMP disabled)		900		µA	
	Magnetometer at 8Hz repetition rate; Magnetometer only (DMP, Gyro, and Accel disabled)		350		µA	
Accelerometer Low Power Mode Current	1.25 Hz update rate		10		µA	
	5 Hz update rate		20		µA	
	20 Hz update rate		70		µA	
	40 Hz update rate		140		µA	
Magnetometer Full Power Mode Current	100% Duty Cycle		6		mA	
Full-Chip Idle Mode Supply Current			6		µA	
VLOGIC REFERENCE VOLTAGE						
Voltage Range	VLOGIC must be ≤VDD at all times	1.71		VDD	V	
Power Supply Ramp Rate	Monotonic ramp. Ramp rate is 10% to 90% of the final value			3	ms	
Normal Operating Current			100		µA	
TEMPERATURE RANGE						
Specified Temperature Range	Performance parameters are not applicable beyond Specified Temperature Range	-40		+85	°C	

6.5 Electrical Specifications, Continued

VDD = 2.375V-3.465V, VLOGIC= 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	Units	Notes
SERIAL INTERFACE						
I^2C Operating Frequency	All registers, Fast-mode			400	kHz	
	All registers, Standard-mode			100	kHz	
I^2C ADDRESS	AD0 = 0		1101000			
	AD0 = 1		1101001			
DIGITAL INPUTS (SDA, AD0, SCL, FSYNC, CLKIN)						
V_{IH}, High Level Input Voltage		0.7*VLOGIC			V	
V_{IL}, Low Level Input Voltage				0.3*VLOGIC	V	
C_I, Input Capacitance			< 5		pF	
DIGITAL OUTPUT (INT)						
V_{OH}, High Level Output Voltage	R_{LOAD}=1MΩ	0.9*VLOGIC			V	
V_{OL1}, LOW-Level Output Voltage	R_{LOAD}=1MΩ			0.1*VLOGIC	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	
DIGITAL OUTPUT (CLKOUT)						
V_{OH}, High Level Output Voltage	RLOAD=1MΩ	0.9*VDD			V	
V_{OL1}, LOW-Level Output Voltage	RLOAD=1MΩ			0.1*VDD	V	

6.6 Electrical Specifications, Continued

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.465V, VLOGIC= 1.8V±5% or VDD, T_A = 25°C

Parameters	Conditions	Typical	Units	Notes
Primary I²C I/O (SCL, SDA)				
VIL, LOW Level Input Voltage		-0.5V to 0.3*VLOGIC	V	
VIH, HIGH-Level Input Voltage		0.7*VLOGIC to VLOGIC + 0.5V	V	
Vhys, Hysteresis		0.1*VLOGIC	V	
V_{OL1}, LOW-Level Output Voltage	3mA sink current	0 to 0.4	V	
I_{OL}, LOW-Level Output Current	V_{OL} = 0.4V	3	mA	
	V_{OL} = 0.6V	5	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 to 250	ns	
C_I, Capacitance for Each I/O pin		< 10	pF	
Auxiliary I²C I/O (ES_CL, ES_DA)				
V_{IL}, LOW-Level Input Voltage		-0.5 to 0.3*VDD	V	
V_{IH}, HIGH-Level Input Voltage		0.7*VDD to VDD+0.5V	V	
V_{hys}, Hysteresis		0.1*VDD	V	
V_{OL1}, LOW-Level Output Voltage	1mA sink current	0 to 0.4	V	
I_{OL}, LOW-Level Output Current	V_{OL} = 0.4V	1	mA	
	V_{OL} = 0.6V	1	mA	
Output Leakage Current		100	nA	
t_{of}, Output Fall Time from V_{IHmax} to V_{ILmax}	C_b bus cap. in pF	20+0.1C_b to 250	ns	
C_I, Capacitance for Each I/O pin		< 10	pF	

6.7 Electrical Specifications, Continued

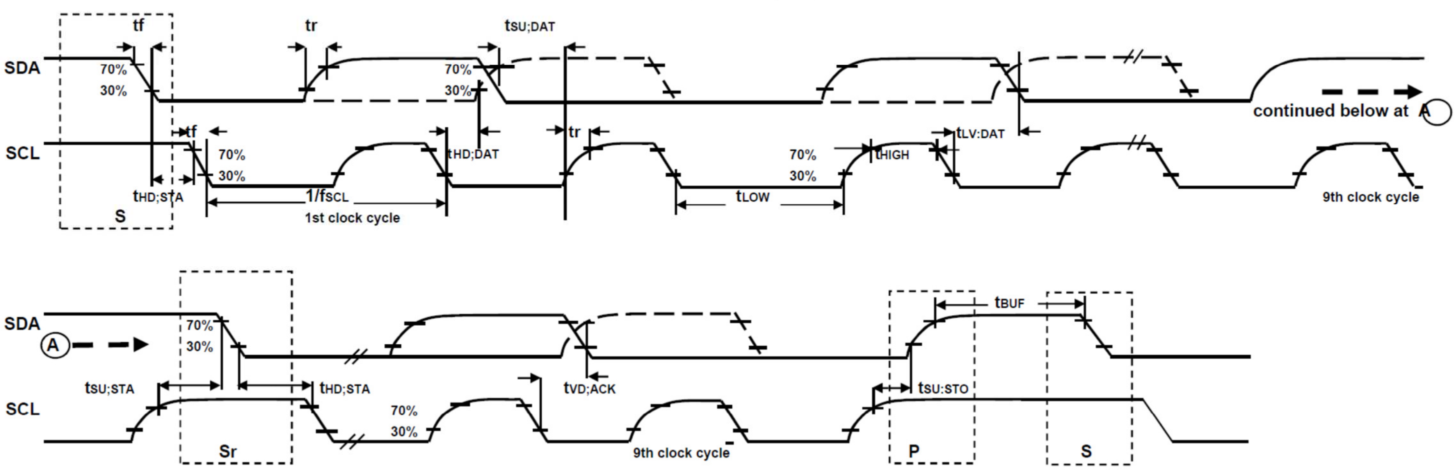
Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.465V, VLOGIC= 1.8V±5% or VDD, T_A = 25°C

Parameters	Conditions	Min	Typical	Max	Units	Notes
INTERNAL CLOCK SOURCE	**CLK_SEL=0,1,2,3**					
Gyroscope Sample Rate, Fast	DLPFCFG=0 SAMPLERATEDIV = 0		8		kHz	
Gyroscope Sample Rate, Slow	DLPFCFG=1,2,3,4,5, or 6 SAMPLERATEDIV = 0		1		kHz	
Accelerometer Sample Rate			1		kHz	
Reference Clock Output	CLKOUTEN = 1		1.024		MHz	
Clock Frequency Initial Tolerance	CLK_SEL=0, 25°C	-5		+5	%	
	CLK_SEL=1,2,3; 25°C	-1		+1	%	
Frequency Variation over Temperature	CLK_SEL=0		-15 to +10		%	
	CLK_SEL=1,2,3		±1		%	
PLL Settling Time	CLK_SEL=1,2,3		1		ms	
EXTERNAL 32.768kHz CLOCK	**CLK_SEL=4**					
External Clock Frequency			32.768		kHz	
External Clock Allowable Jitter	Cycle-to-cycle rms		1 to 2		µs	
Gyroscope Sample Rate, Fast	DLPFCFG=0 SAMPLERATEDIV = 0		8.192		kHz	
Gyroscope Sample Rate, Slow	DLPFCFG=1,2,3,4,5, or 6 SAMPLERATEDIV = 0		1.024		kHz	
Accelerometer Sample Rate			1.024		kHz	
Reference Clock Output	CLKOUTEN = 1		1.0486		MHz	
PLL Settling Time			1		ms	
EXTERNAL 19.2MHz CLOCK	**CLK_SEL=5**					
External Clock Frequency			19.2		MHz	
Gyroscope Sample Rate	Full programmable range	3.9		8000	Hz	
Gyroscope Sample Rate, Fast Mode	DLPFCFG=0 SAMPLERATEDIV = 0		8		kHz	
Gyroscope Sample Rate, Slow Mode	DLPFCFG=1,2,3,4,5, or 6 SAMPLERATEDIV = 0		1		kHz	
Accelerometer Sample Rate			1		kHz	
Reference Clock Output	CLKOUTEN = 1		1.024		MHz	
PLL Settling Time			1		ms	

6.8 I²C Timing Characterization

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.465V, VLOGIC= 1.8V±5% or VDD, T_A = 25°C

Parameters	Conditions	Min	Typical	Max	Units	Notes
I²C TIMING	**I²C 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	



I²C Bus Timing Diagram

6.9 Absolute Maximum Ratings

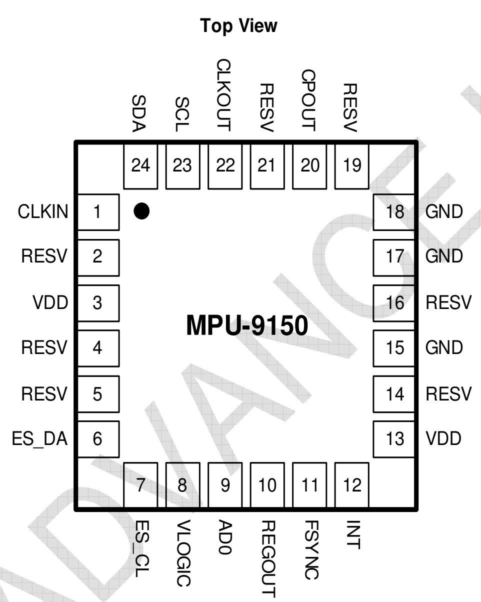
Stress above those listed as “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these conditions is not implied. Exposure to the absolute maximum ratings conditions for extended periods may affect device reliability.

Parameter	Rating
Supply Voltage, VDD	-0.5V to +6V
VLOGIC Input Voltage Level	-0.5V to VDD + 0.5V
REGOUT	-0.5V to 2V
Input Voltage Level (CLKIN, AUX_DA, AD0, FSYNC, INT, SCL, SDA)	-0.5V to VDD + 0.5V
CPOUT (2.5V ≤ VDD ≤ 3.6V)	-0.5V to 30V
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); 200V (MM)
Latch-up	JEDEC Class II (2),125°C ±100mA

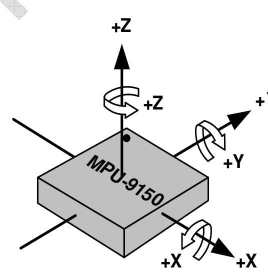
7 Applications Information

7.1 Pin Out and Signal Description

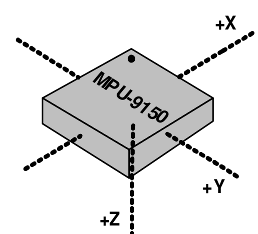
Pin Number	Pin Name	Pin Description
1	CLKIN	Optional external reference clock input. Connect to GND if unused.
6	ES_DA	Auxiliary I^2C master serial data
7	ES_CL	Auxiliary I^2C Master serial clock
8	VLOGIC	Digital I/O supply voltage
9	AD0	I^2C Slave Address LSB (AD0)
10	REGOUT	Regulator filter capacitor connection
11	FSYNC	Frame synchronization digital input. Connect to GND if unused.
12	INT	Interrupt digital output (totem pole or open-drain)
3, 13	VDD	Power supply voltage and Digital I/O supply voltage
15, 17,18	GND	Power supply ground
20	CPOUT	Charge pump capacitor connection
22	CLKOUT	System clock output
23	SCL	I^2C serial clock (SCL)
24	SDA	I^2C serial data (SDA)
2, 4, 5, 14, 16, 19, 21	RESV	Reserved. Do not connect.



LGA Package
24-pin, 4mm x 4mm x 1mm

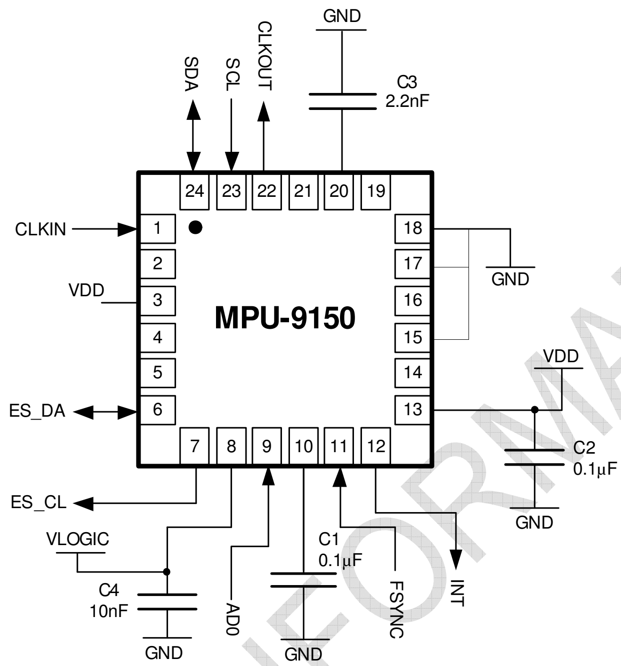


Orientation of Axes of Sensitivity and Polarity of Rotation for Accel & Gyro



Orientation of Axes of Sensitivity for Magnetometer

7.2 Typical Operating Circuit

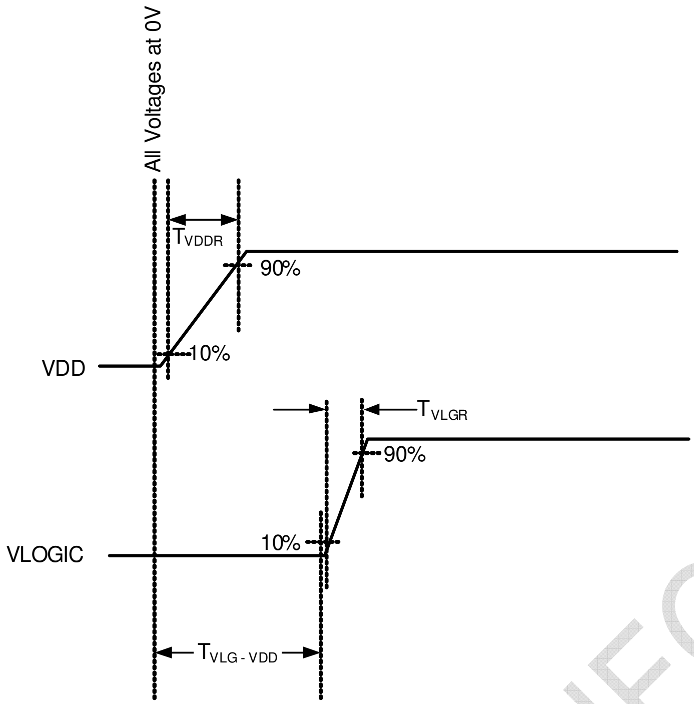


Typical Operating Circuits

7.3 Bill of Materials for External Components

Component	Label	Specification	Quantity
Regulator Filter Capacitor (Pin 10)	C1	Ceramic, X7R, 0.1µF ±10%, 2V	1
VDD Bypass Capacitor (Pin 13)	C2	Ceramic, X7R, 0.1µF ±10%, 4V	1
Charge Pump Capacitor (Pin 20)	C3	Ceramic, X7R, 2.2nF ±10%, 50V	1
VLOGIC Bypass Capacitor (Pin 8)	C4*	Ceramic, X7R, 10nF ±10%, 4V	1

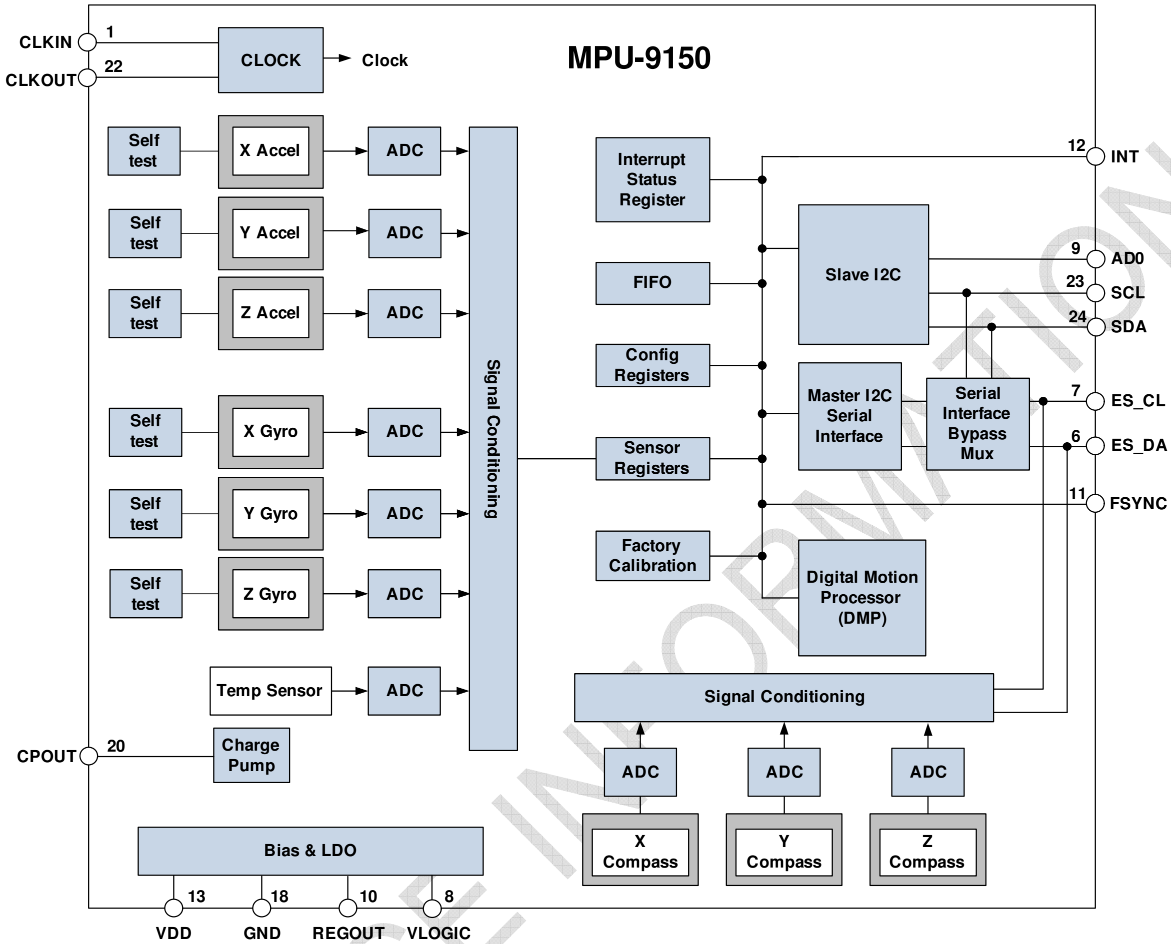
7.4 Recommended Power-on Procedure



Power-Up Sequencing

1. VLOGIC amplitude must always be ≤VDD amplitude
2. T_{VDDR} is VDD rise time: Time for VDD to rise from 10% to 90% of its final value
3. T_{VDDR} is ≤100msec
4. T_{VLGR} is VLOGIC rise time: Time for VLOGIC to rise from 10% to 90% of its final value
5. T_{VLGR} is ≤3msec
6. $T_{VLG-VDD}$ is the delay from the start of VDD ramp to the start of VLOGIC rise
7. $T_{VLG-VDD}$ is ≥0ms;
8. VDD and VLOGIC must be monotonic ramps

7.5 Block Diagram



7.6 Overview

The MPU-9150 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 13-bit ADCs and signal conditioning
- Digital Motion Processor (DMP) engine
- Primary I²C serial communications interface
- Auxiliary I²C serial interface for 3rd party sensors
- Clocking
- Sensor Data Registers
- FIFO
- Interrupts
- Digital-Output Temperature Sensor
- Gyroscope, Accelerometer and Magnetometer Self-test
- Bias and LDO
- Charge Pump

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

The MPU-9150 includes a 3-Axis vibratory MEMS rate gyroscope, which detect rotations about the X-, Y-, and Z- Axes. When the gyro is 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 sensor 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.

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

The MPU-9150'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-9150's architecture reduces the accelerometer's susceptibility to fabrication variations as well as to thermal drift. When the device is placed on a flat surface, it will measure 0g on the X- and Y-axes and +1g on the Z-axis. The accelerometer's 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*.

7.9 Three-Axis MEMS Magnetometer with 13-bit ADCs and Signal Conditioning

The 3-axis magnetometer uses highly sensitive Hall sensor technology. The compass 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 13-bit resolution and a full scale range of ±1200 µT.

7.10 Digital Motion Processor

The embedded Digital Motion Processor (DMP) is located within the MPU-9150 and offloads computation of motion processing algorithms from the host processor. The DMP acquires data from accelerometers, gyroscopes, magnetometers and additional 3rd party sensors such as pressure 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.

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.

7.11 Primary I²C

The MPU-9150 communicates to a system processor using an I²C serial interface. The MPU-9150 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 VLOGIC pin. The LSB of the of the I²C slave address is set by pin 9 (AD0).

7.12 Auxiliary I²C Serial Interface

The MPU-9150 has an auxiliary I²C bus for communicating to off-chip sensors. This bus has two operating modes:

- I²C Master Mode: The MPU-9150 acts as a master to any external sensors connected to the auxiliary I²C bus
- Pass-Through Mode: The MPU-9150 directly connects the primary and auxiliary I²C 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-9150 to directly access the data registers of external digital sensors, such as a pressure sensor. In this mode, the MPU-9150 directly obtains data from auxiliary sensors, allowing the on-chip DMP to generate sensor fusion data without intervention from the system applications processor.

  For example, In I²C Master mode, the MPU-9150 can be configured to perform burst reads, returning the following data from a triple-Axis external sensor:

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

- The I²C Master can be configured to read up to 24 bytes from up to 3 auxiliary sensors. A fourth 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 (ES_DA and ESCL). In this mode, the auxiliary I²C bus control logic (3rd-party sensor interface block) of the MPU-9150 is disabled, and the auxiliary I²C pins ES_DA and ES_CL (Pins 6 and 7) are connected to the main I²C bus (Pins 23 and 24) through analog switches.

  Pass-Through Mode is useful for configuring the external sensor, or for keeping the MPU-9150 in a low-power mode when only the external sensors are used. In Pass-Through Mode the system processor can still access MPU-9150 data through the I²C interface.

Auxiliary I²C Bus IO Logic Level

The logic level of the auxiliary I²C bus is VDD.

For further information regarding the MPU-9150's logic level, please refer to Section 10.2.

7.13 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 controlling the bits of the Gyro and Accel control registers.

When 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