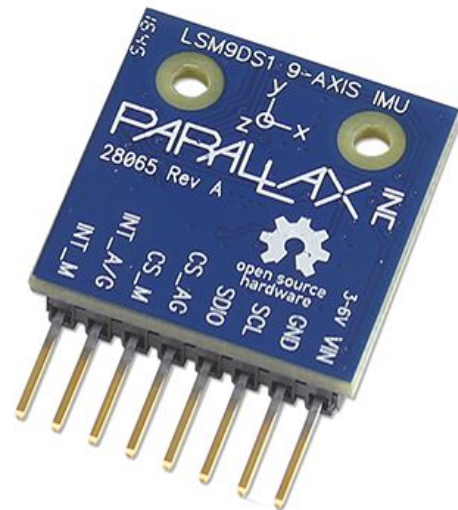


## Parallax LSM9DS1 9-axis IMU Module (#28065)

With the LSM9DS1 9-axis motion sensor module, your projects can measure direction, orientation, and motion. The LSM9DS1 sensor, used on our ELEV-8 v3 Quadcopter's Flight Controller, is now available in a SIP module for easy prototyping or conveniently studying the physics involved in motion tracking.

This LSM9DS1 sensor is a “system-on-a-chip” that takes 4 kinds of measurements, using: a 3-axis accelerometer (for measuring gravity or acceleration in 3D space), a 3-axis gyroscope (for measuring rotation), a 3-axis magnetometer (for measuring magnetic field strength - used to find Magnetic North), and a temperature sensor.



The LSM9DS1 9-axis motion sensor module can be used with nearly any microcontroller. It can be powered by 2.8, 3.3 or 5 volts and it uses either a 3-pin SPI interface or an I2C bus. Use it as a single sensor—accelerometer, a gyroscope, a magnetometer, or a temperature sensor—or all of the measurements can be read together for use in inertial measurement or dead-reckoning applications. It can also be configured to drive an interrupt when detecting impacts, free-fall, or magnetic field ranges.

### Features

- Measures linear acceleration, angular velocity, and magnetic field strength on three axes
- Measures the temperature, and internally temperature compensates all readings
- Low power usage—great for battery-powered applications
- 16-bit precision with selectable sensitivity, adaptable to many project's needs
- Breadboard friendly SIP form-factor

## Application Ideas

- Physics studies
- Stall, tilt, and collision sensing
- Free-fall detection
- UAV control systems
- Platform level/balance
- Compass navigation
- Gesture-based game controller

## Key Specifications

- 3 acceleration channels, 3 angular rate channels, 3 magnetic field channels
- $\pm 2/\pm 4/\pm 8/\pm 16$  g linear acceleration full scale
- $\pm 4/\pm 8/\pm 12/\pm 16$  gauss magnetic full scale
- $\pm 245/\pm 500/\pm 2000$  dps angular rate full scale
- 16-bit data output
- Up to 952 Hz refresh rate for accelerometer and gyro
- Up to 80 Hz refresh rate for magnetometer
- Programmable interrupt generators
- Embedded temperature sensor
- Voltage requirements: 2.6 to 6.5 VDC
- Current requirements: 5 mA
- Communication: 3-wire SPI, I2C
- Dimensions: 0.87 x 1.19 in (22 x 30.15 mm)
- Operating temperature range: -40 to +185 °F (-40 to +85 °C)

## Functional Description

The LSM9DS1 is a system-in-package featuring a 3D digital linear acceleration sensor, a 3D digital angular rate sensor, and a 3D digital magnetic sensor. This module has a linear acceleration full scale of  $\pm 2/\pm 4/\pm 8/\pm 16$  g, a magnetic field full scale of  $\pm 4/\pm 8/\pm 12/\pm 16$  gauss and an angular rate of  $\pm 245/\pm 500/\pm 2000$  dps. The LSM9DS1 includes an SPI serial standard interface. Magnetic, accelerometer and gyroscope sensing can be enabled or set in power-down mode separately for smart power management.

The logic level shifters ensure that the I/O connections operate at the same voltage supplied to the VIN pin. This means the module is compatible with 2.8V, 3.3V, and 5V microcontrollers.

Reverse polarity protection will protect your IMU module in-case the connections to VIN and GND are accidentally reversed. The onboard 2.5V Low Dropout (LDO) regulator ensures the correct operating voltage for the LSM9DS1 IC and level shifters.

## Getting Started

### Propeller Microcontroller and BlocklyProp Resources

If you are using the Propeller microcontroller and are new to using sensors of this type, the simplest way to get started is by using the BlocklyProp graphical programming language (<http://blockly.parallax.com>). It has a set of blocks dedicated to this LSM9DS1 9-axis IMU Module. The block reference is available from <http://learn.parallax.com/ab-blocks/LSM9DS1>.

For C programming, the library `lsm9ds1.h` is included in the Propeller C Learn folder as of 1/18/2017. That folder is included in the SimpleIDE programming tool beginning with version 1.1. The latest versions of both are free downloads from [www.parallax.com](http://www.parallax.com).

### General Instructions for Use with Microcontrollers

Connect the LSM9DS1 9-axis motion sensor module to the same power (2.6 to 6.5 VDC) and ground supplies as the microcontroller, and connect either a 3-wire [Serial Peripheral Bus \(SPI\)](#) or [Inter-IC Control Interface \(I2C\)](#) as outlined in those sections below.

If using the accelerometer, gyroscope, or temperature sensor with a 3-wire SPI bus, on power-up write a hexadecimal value of 0x0C to the CTRL\_REG8 register, at a hexadecimal address of 0x22, to enable return communications on the three-wire bus.

When reading or writing accelerometer, gyroscope, or temperature sensor registers, use the CS\_A/G select line in the 3-wire SPI bus or the hex 0x6A 7-bit address on the I2C bus.

If using the magnetometer with a 3-wire SPI bus, on power-up write a hexadecimal value of 0x07 to the CTRL\_REG3\_M register, at a hexadecimal address of 0x22, to enable return communications on the three-wire bus.

When reading or writing accelerometer, gyroscope, or temperature sensor registers, use the CS\_M select line in the 3-wire SPI bus or the hex 0x1C 7-bit address on the I2C bus.

To enable the accelerometer, write the desired output data rate, scale, and bandwidth limit to the CTRL\_REG6\_XL register, at a hexadecimal address of 0x20, using the format given in section

7.24 of the LSM9DS1 datasheet. For example, a write a hex value of 0xD8 to set an output data rate of 952 Hz, with a scale of  $\pm 8$  g, and a bandwidth of 408 Hz.

The temperature sensor is enabled whenever the accelerometer is enabled.

To enable the gyroscope, first enable the accelerometer, then write the desired output data rate, scale, and bandwidth limit to the CTRL\_REG1\_G register, at a hexadecimal address of 0x10, using the format given in section 7.12 of the LSM9DS1 datasheet. For example, a write a hex value of 0xDB to set an output data rate of 952 Hz, with a scale of  $\pm 2000$  degrees per second, and a bandwidth cut-off of 100 Hz.

To enable the magnetometer, set the power mode in the CTRL\_REG3\_M register, at a hexadecimal address of 0x22, using the format given in section 8.7 of the LSM9DS1 datasheet. For example, a write a hex value of 0x24 to use continuous conversion mode.

To read from any of the sensors, once enabled, use the register listed in the the Register Functionality section below.

## Sensors

### Gyroscope

The gyroscope output matches a polar coordinate system, with a positive output for counterclockwise rotation, and a negative output for a clockwise rotation, pivoting around the indicated axis. The output indicates a rate of rotation, in degrees per second. It is possible to accumulate the rotation over time, to calculate an angular position, but small inaccuracies in the rate readings will accumulate as well, causing the the angular position to drift. Reading the earth's gravity, using the accelerometer, and magnetic field, using the magnetometer, can provide additional data to detect, and compensate for, drift in the calculated angular position.

When enabled, the gyroscope can operate at six different refresh rates: 14.9, 59.5, 119, 238, 476, or 952 Hz. The 16-bit signed output covers a selectable scale of  $\pm 245$ , 500, or 2000 degrees per second.

### Accelerometer

The accelerometer measures acceleration, as well gravity, in units of gravity (g). When no acceleration is applied, the accelerometer can measure the direction of the pull of gravity to determine the module's spacial orientation.

The accelerometer must be enabled when the gyroscope is enabled. When enabled, the accelerometer can operate at six different refresh rates: 14.9, 59.5, 119, 238, 476, or 952 Hz. The 16-bit signed output covers a selectable scale of  $\pm 2, 4, 8,$  or 16 g.

## **Magnetometer (Compass)**

The magnetometer measures magnetic fields, including the earth's magnetic field.

When enabled, the magnetometer can operate at eight different refresh rates: 0.625, 1.25, 2.5, 5, 10, 20, 40, or 80 Hz. The 16-bit signed output covers a selectable scale of  $\pm 4, 8, 12,$  or 16 gauss.

## **Calibration**

Nearby metallic objects, including the header pins and other portions of the module itself, as well as any hardware the 9-axis IMU module is attached to, have a measurable effect on weak magnetic fields, such as the earth's magnetic field. The magnetometer stores an internal 16-bit offset for each axis, to compensate for the effects.

After installing the 9-axis IMU module into a device, perform the following calibration procedure, to determine the offsets:

- Locate the device in an area clear from large metal objects.
- Continuously read the magnetometer outputs on all three axes, and store the most positive and most negative readings, for each axis.
- For a device that can rotate freely in 3D space, such as anything hand-held, or an aerobatic aircraft of any scale:
  - At a slow consistent rate, preferably less than 15 degrees per second, rotate the device around all three axes, so that each axis includes a 360° rotation.
  - A figure-eight pattern, similar to the pattern a marshal would use while waving a racing flag, meets the rotation requirements in a few wrist movements.
  - Google's "Calibrate your compass" page includes an animation of an effective figure-8 pattern: <https://support.google.com/maps/answer/6145351>.
- For a device that rotates on a single plane, such as a vehicle :
  - At a slow consistent rate, preferably less than 15 degrees per second, rotate the device at least 360°, keeping it level on the intended plane.
- For each axis, average its highest and lowest readings, and negate the result, to determine the offset for that axis, and write the offset to the magnetometer offset register for that axis.

The magnetometer offsets are non-volatile, so the calibration will stay valid indefinitely. When moving the module to a new device, perform the calibration procedure again.

## Temperature Sensor

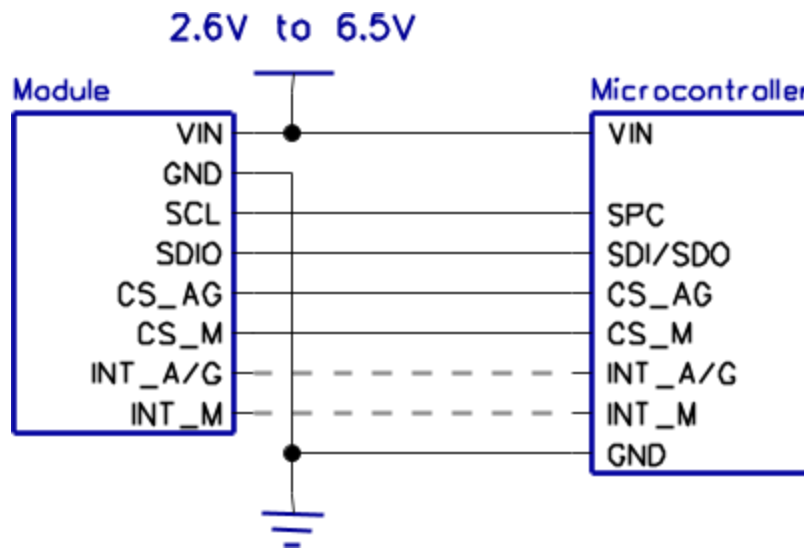
If the gyroscope is enabled, the temperature output refreshes at 59.5 Hz, otherwise it refreshes at 50 Hz. The reading is in sixteenths of a degrees Celsius.

## Communication Protocols

### I/O voltages

All I/O pins are open-collector outputs, pulled to VIN, through a 100 kilo-ohm resistor. All other pins have a maximum input voltage of 6.5 VDC, regardless of the voltage at VIN. The interrupt pins, INT\_A/G and INT\_M, are output-only and have no input functionality.

### Serial Peripheral Interface (SPI)



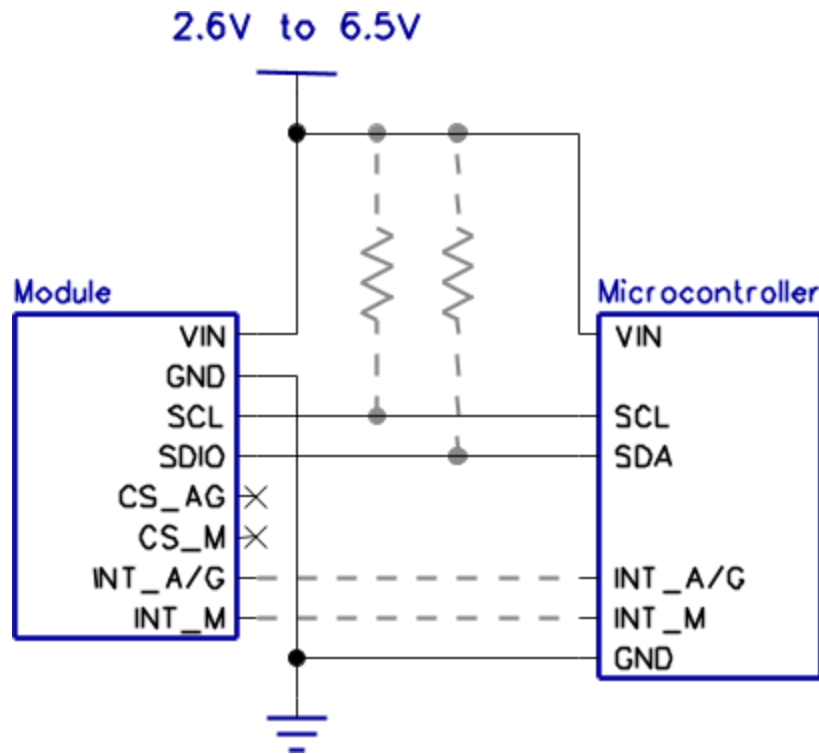
The accelerometer, gyroscope, and temperature sensor share a three-wire SPI interface, initiating communications by driving CS\_AG low, transmitting and receiving data on SDIO, clocking data on SCL, and ending communications by driving or letting CS\_AG float high. The magnetometer shares the SPI data and clock pins, but uses the CS\_M pin to start and end communications.

The SPI bus operates in 3-wire mode, so on power-up the SIM bits in the CTRL\_REG8 and CTRL\_REG3\_M registers must be set to '1', before reading data from the module.

The INT\_A/G and INT\_M are optional interrupt outputs.

The SPI bus can read and write data with a clock rate up to 10 MHz. For timing information, see sections 2.4.1, 5.2 and 5.3 of the LSM9DS1 datasheet.

## Inter-IC Control Interface (I2C)



The SDIO and SCL pins also support I2C communications. The pins have internal 100 kilo-ohm pull-up resistors, but external resistors may optionally be used for longer runs or higher speeds. The accelerometer, gyroscope, and temperature sensor have a 7-bit I2C slave address, in hexadecimal, of 0x6A, and the magnetometer has a 7-bit I2C slave address, in hexadecimal, of 0x1C.

The INT\_A/G and INT\_M are optional interrupt outputs.

The I2C bus can read and write data with a clock rate up to 400 kHz. For timing and command information, see sections 2.4.2 and 5.1 of the LSM9DS1 datasheet.

### Register Functionality

All of the sensor outputs are 16-bit values, and all registers are eight bits wide, so each output includes a high and low register. The following registers are especially useful for basic usage of the 9-axis IMU module:

### Accelerometer, Gyroscope, and Temperature Sensor

Register	Address (in hexadecimal)	Function
CTRL_REG1_G	10	Gyroscope operating mode
OUT_TEMP_L	15	Low byte of temperature reading
OUT_TEMP_H	16	High byte of temperature reading
OUT_X_L_G	18	Low byte of X gyroscope axis
OUT_X_H_G	19	High byte of X gyroscope axis
OUT_Y_L_G	1A	Low byte of Y gyroscope axis
OUT_Y_H_G	1B	High byte of Y gyroscope axis
OUT_Z_L_G	1C	Low byte of Z gyroscope axis
OUT_Z_H_G	1D	High byte of Z gyroscope axis
CTRL_REG6_XL	20	Accelerometer operating mode
CTRL_REG8	22	Configuration register including 3-wire SPI mode
OUT_X_L_XL	28	Low byte of X accelerometer axis
OUT_X_H_XL	29	High byte of X accelerometer axis
OUT_Y_L_XL	2A	Low byte of Y accelerometer axis
OUT_Y_H_XL	2B	High byte of Y accelerometer axis
OUT_Z_L_XL	2C	Low byte of Z accelerometer axis
OUT_Z_H_XL	2D	High byte of Z accelerometer axis



## Magnetometer

Register	Address (in hexadecimal)	Function
OFFSET_X_REG_L_M	05	Low byte of X axis calibration offset
OFFSET_X_REG_H_M	06	High byte of X axis calibration offset
OFFSET_Y_REG_L_M	07	Low byte of Y axis calibration offset
OFFSET_Y_REG_H_M	08	High byte of Y axis calibration offset
OFFSET_Z_REG_L_M	09	Low byte of Z axis calibration offset
OFFSET_Z_REG_H_M	0A	High byte of Z axis calibration offset
CTRL_REG3_M	22	Configuration register including 3-wire SPI mode
OUT_X_L_M	28	Low byte of X axis
OUT_X_H_M	29	High byte of X axis
OUT_Y_L_M	2A	Low byte of Y axis
OUT_Y_H_M	2B	High byte of Y axis
OUT_Z_L_M	2C	Low byte of Z axis
OUT_Z_H_M	2D	High byte of Z axis

For a complete list of all registers and their functions, see sections 6 through 8 of the LSM9DS1 datasheet.

### First-In First-Out (FIFO) Buffer

The accelerometer and gyroscope have a 32-entry first-in-first-out buffer to facilitate readings at regular intervals, when isochronous positional data is necessary. When using the buffer, the time between each reading is constant, which reduces error in accumulation calculations, for example when using the gyroscope to determine an angular position.

Should the buffer overflow, it can either reject new data or overwrite old data, depending on the configuration stored to the FIFO\_CTRL register.

## Interrupts

The 9-axis IMU module has two interrupt pins, one for the accelerometer, gyroscope, and temperature sensor, and another for the magnetometer. It can trigger an output signal from any of the following events:

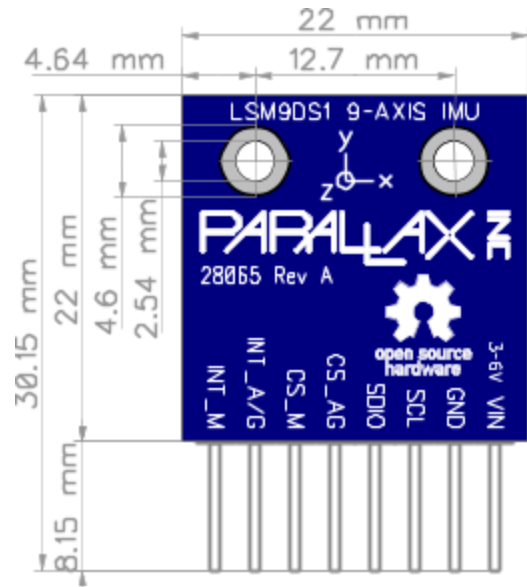
- The FIFO buffer has reached a specific threshold and should be read
- Unbuffered data is ready to read
- The accelerometer data is above or below a set threshold on the specified axes
- The gyroscope data is above or below a set threshold on the specified axes
- The magnetometer data is above or below a set threshold on the specified axes

The accelerometer interrupt is especially useful for detecting freefall, by selecting a threshold significantly lower than one g, then generating an interrupt when all three axes are below that threshold.

The accelerometer, gyroscope, and magnetometer sensors each have a single interrupt threshold. Each axis on any of those sensors can trigger when either above or below the threshold. If an interrupt is set on multiple axes of the same sensor, the output can either trigger when a single selected axis is beyond the threshold, or when all selected axes are beyond their thresholds

Interrupts output on either the INT1\_A/G or INT2\_A/G will drive the INT\_A/G output on the 9-axis IMU module.

## PCB Dimensions



## Pin Descriptions

Pin	Type	Function
<b>VIN</b>	Power	Connect to the same power supply as the SPI master device. The module is capable of operation on SPI busses running between 2.6V to 6.5V DC.
<b>GND</b>	Power	Ground (0 V supply)
<b>SCL</b>	Open collector	Clock for SPI (SPC) and I2C (SCL)
<b>SDIO</b>	Open collector	Serial data input/output for SPI (SDIO) and I2C (SDA)
<b>CS_AG</b>	Open collector	SPI mode selection for the accelerometer and gyroscope 1: SPI idle mode, I2C enabled 0: SPI communication mode, I2C disabled
<b>CS_M</b>	Open collector	SPI mode selection for the magnetometer 1: SPI idle mode, I2C enabled 0: SPI communication mode, I2C disabled
<b>INT_A/G</b>	Open collector	Accelerometer and gyroscope interrupt 1 & 2
<b>INT_M</b>	Open collector	Magnetic sensor interrupt