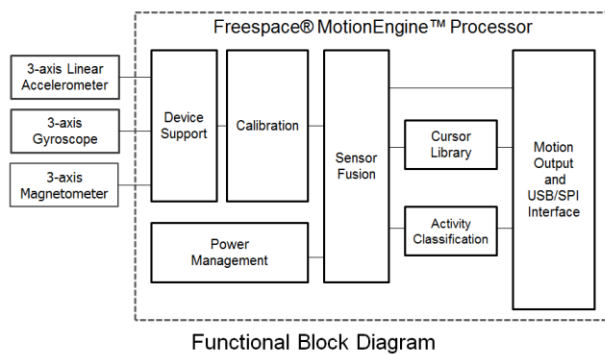


## Freespace® Sensor Module (FSM) with USB Interface

The FSM-9 is a low cost, battery operable, fully calibrated Inertial Measurement Unit (IMU) / Attitude Heading Reference System (AHRS). The FSM provides a simple, highly cost effective solution for integrating accurate, multi-axis inertial sensing into a wide range of consumer and industrial applications, eliminating the complexity and investment associated with a discrete design. This compact module contains state of the art MEMS technology including a tri-axial gyroscope, a tri-axial accelerometer and a tri-axial magnetometer. Combining these sensors with the onboard Hillcrest Freespace MotionEngine™ Processor, the FSM-9 provides precise real-time 3D orientation, heading, calibrated acceleration and calibrated angular velocity, as well as more advanced outputs such as cursor.

### Complete Inertial Motion Tracking System



- Tri-axial accelerometer, gyroscope and magnetometer enable complete motion tracking
- Calibrated for misalignment and scale
- Dynamically calibrates sensor data for temperature, and aging
- Patented real time signal processing algorithms produces 9-axis sensor fusion via on board processor

### Power Management Features

- Low-power sleep modes optimize power
- Flexible gyroscope power control
- Wake-on-Motion feature allows for rapid return to motion processing when module picked up
- Activity state detection such as 'OnTable' or 'Stable' enables intelligent use of low power modes

### Extensive Data Modes

- Linear acceleration ( $\text{mm/s}^2$ )
- Angular velocity ( $\text{mrad/s}$ )
- Compass heading
- Angular position (quaternion)
- Accurate, low-latency X-Y pointer data for cursor control applications
- Data returned at configurable sample rates

Product Models: FSM-9 Reference Kit, FSM-9, FSM-9 OEM (without enclosure)

### Compact Design



- Available for PCB mounting or with enclosure
- Small form factor PCA module ideal for embedded application (19mm x 18mm x 4mm)
- Enclosure w/micro USB (38mm x 23mm x 9mm)
- Communicates with an external system via USB or a Serial Peripheral Interface (SPI)

### Advanced Processing Options

- Adaptive tremor removal - Ensures smooth, steady motion when held in a human hand
- AR/VR Stabilization - Provides visually improved angular position output
- Orientation compensation – Compensates for tilt by translating motion from the FSM's frame of reference to the user's
- Button motion suppression – Minimizes inadvertent cursor movement caused by button and scroll events

### Developer Tools

- Freespace MotionStudio - PC-based evaluation and configuration tool
- libfreespace - Open source C I/O library with Java bindings

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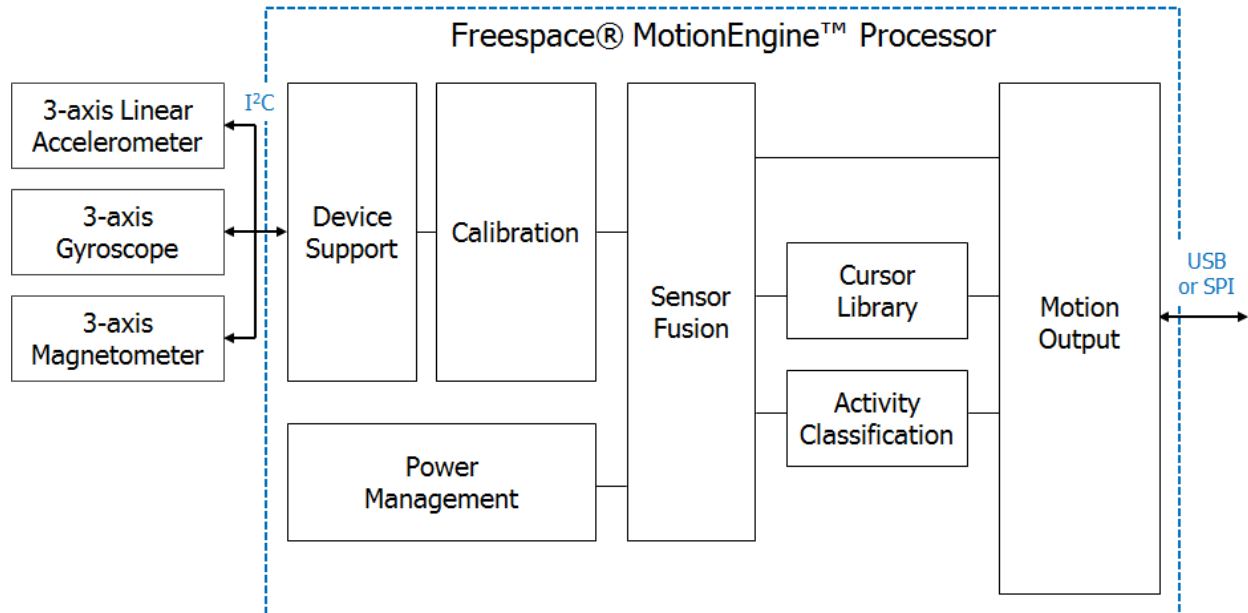
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# 1 Functional Overview

The FSM-9 is a complete motion processing module. MEMS inertial sensors measure motion around three orthogonal axes. The module includes a 3-axis accelerometer, a 3-axis gyroscope and a 3-axis magnetometer. A processor evaluates the data retrieved from the sensors and provides the results over USB or a Serial Peripheral Interface (SPI) to the host. The serial interface is available with FSM-9 OEM only.



**Figure 1: FSM-9 Block Diagram**

At the center of the FSM-9 is the Freespace® Processor running Hillcrest's MotionEngine™ software. This digital signal processing software takes raw motion data from the MEMS inertial sensors and translates this raw data into precise motion information. These accurate motion outputs can be used for gesture detection and a variety of advanced motion-controlled applications. For pointer based applications, MotionEngine™ algorithms interpret natural motions and translate these motions to on-screen cursor movements. The FSM software also includes sophisticated power management functionality.

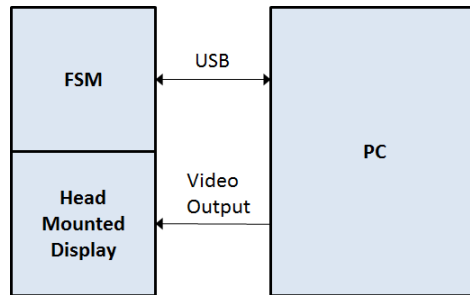
The FSM-9 can communicate with the system host over a USB 2.0 interface. The FSM supports full speed operation (~ 12Mbps). The FSM can also be attached to a PCB and communicate over an industry standard serial peripheral interface (SPI).

The FSM supports Hillcrest's proprietary HCOMM protocol. This protocol allows the application to configure the FSM and receive processed data. Freespace® motion and data packets sent over this interface are in a Human Interface Device (HID) format, which allows for maximum compatibility with other communication links.

More details of the MotionEngine™ features and HCOMM can be found in reference 1 (HCOMM Reference Manual, Hillcrest Labs).

## 1.1 Reference Design Configurations

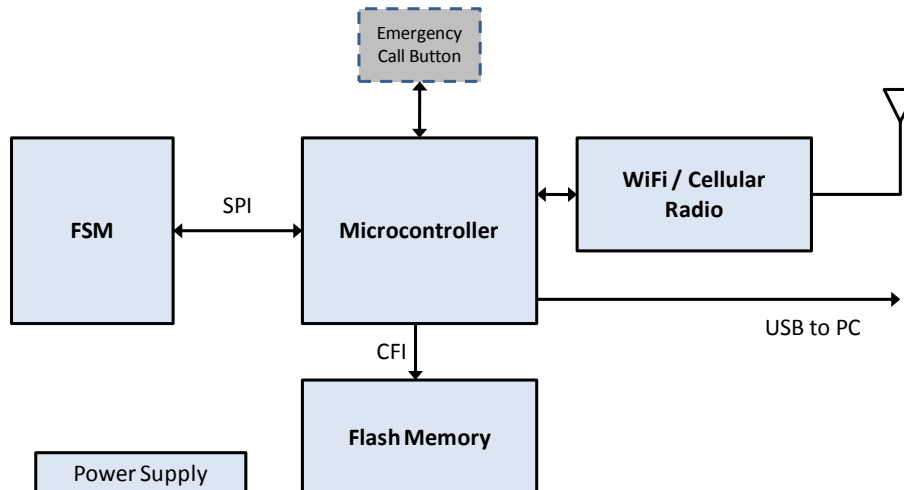
### 1.1.1 Virtual Reality Head Tracker



**Figure 2: Virtual Reality Head Tracker**

The FSM-9 can be integrated into head tracker equipment allowing the user to be immersed in either a virtual reality or an augmented reality scenario. The FSM provides accurate angular position data allowing navigation of this virtual world. A USB connection with support for HID allows for easy integration with all modern operating systems.

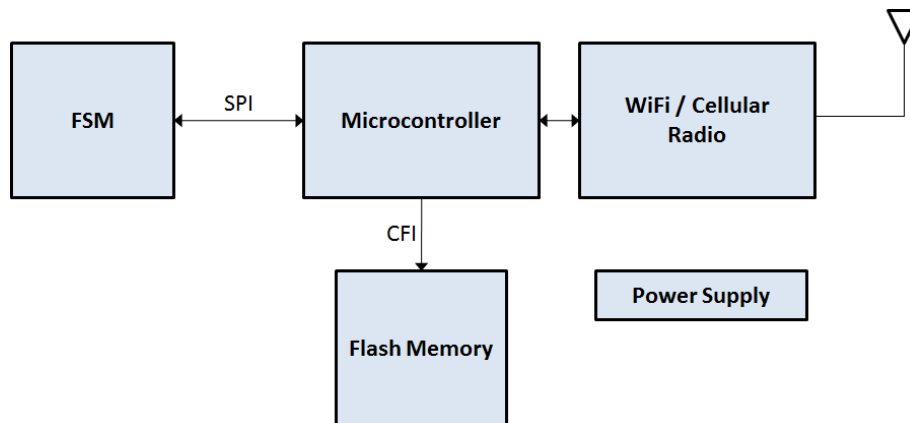
### 1.1.2 Patient Activity and Orientation Application



**Figure 3: Block Diagram of FSM-9 in a Typical Patient Activity and Orientation Application**

The FSM-9 can be integrated into wearable patient monitoring devices as shown in Figure 3. The FSM is treated as a sensor peripheral and data is retrieved from it as it becomes available. The microcontroller uses the FSM data to track orientation changes and activity events, and can transmit potentially dangerous patient conditions via WiFi or a cellular service. Optionally, flash memory can be used to store logs of orientation and activity for future analysis on a PC.

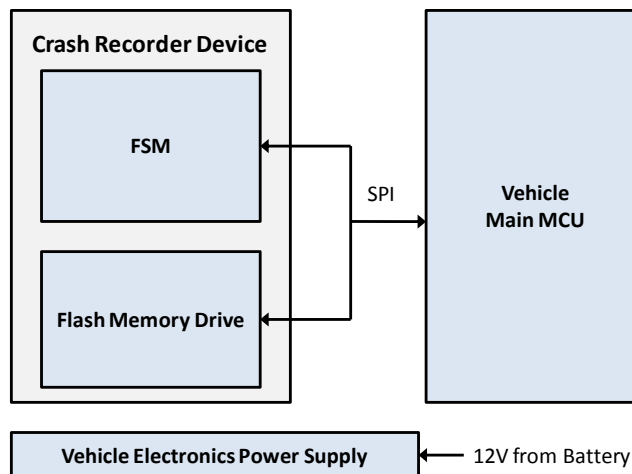
### 1.1.3 Industrial Motion Analysis Application



**Figure 4: Block Diagram of FSM-9 in a Typical Motion Analysis Application**

The FSM-9 can be integrated into industrial equipment as shown in Figure 4. The FSM is treated as a sensor peripheral and data is retrieved by the microcontroller as it becomes available. The microcontroller can use the FSM data to determine whether the current motion is consistent with past motion performance and/or whether one or more motion characteristics represent a potential failure scenario for the industrial facility. The microcontroller can use WiFi or cellular service to communicate such failure scenarios to a central monitoring facility. The flash memory in this system is used to store logs of FSM data as well as other processed data from the microcontroller.

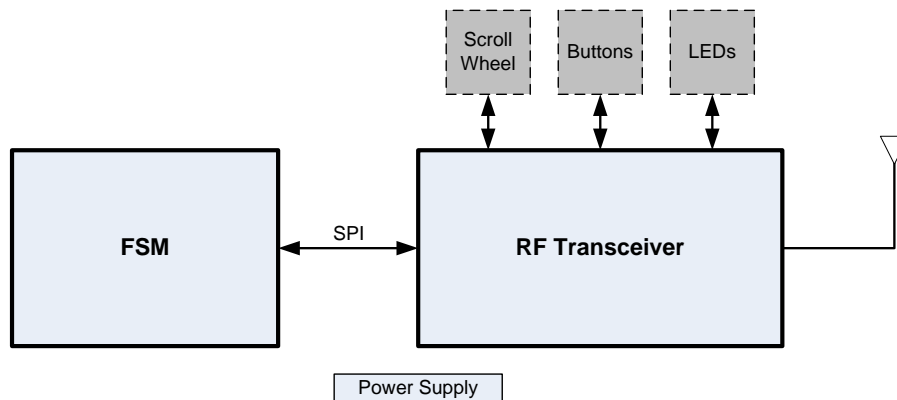
### 1.1.4 Vehicle Crash Recording Application



**Figure 5: Block Diagram of FSM-9 in a Typical Crash Recording Application**

The FSM-9 can be integrated with vehicle electronics to provide crash recording capabilities as shown in Figure 5. The FSM is treated as a sensor peripheral and data is retrieved by the vehicle's main MCU. The MCU maintains a FIFO store on the flash memory drive sending newly received FSM data to the drive until such time as the MCU detects a crash scenario, such as by air bag deployment. The Crash Recorder Device can then be removed from the vehicle for analysis of the car's motion preceding the crash.

### 1.1.5 3D Pointing Remote Control Application

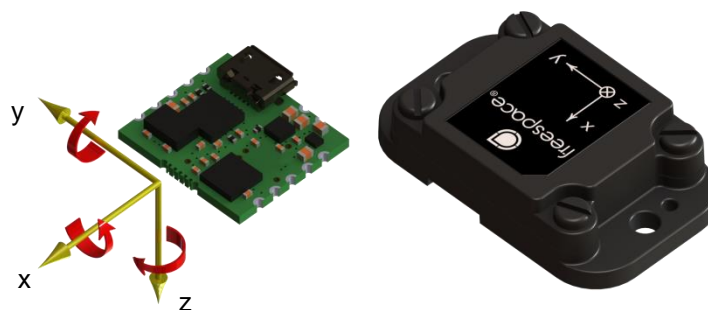


**Figure 6: Block Diagram of FSM-9 in a Typical 3D Pointing Remote Control Application**

The FSM-9 can be integrated into a remote control design as shown in Figure 6. The RF transceiver handles buttons, scroll wheels, LEDs and other peripherals that the remote control may contain. The FSM-9 is treated as a sensor peripheral and provides cursor data. The RF transceiver is responsible for configuring the FSM and informing the FSM of button and scroll events.

### 1.2 Motion Outputs

The FSM-9 provides 6 degrees of freedom in motion sensing using a right-handed coordinate system. The FSM can therefore measure pitch, roll and yaw as well as motion along the x, y and z axes as defined in the diagram below.



**Figure 7: FSM-9 Co-ordinate System**

The FSM performs constant dynamic calibration of the sensors to ensure a drift free estimation of motion and an accurate compass heading. Sensor fusion is then employed to provide an estimation of the angular orientation of the device. The FSM provides the following data to the user:

- Calibrated acceleration data (includes gravity)
- Calibrated linear acceleration data with gravity removed
- Inclination
- Angular velocity of the FSM
- Angular position (orientation) of the FSM as a quaternion
- Orientation compensated cursor data
- Magnetic field strength
- Compass heading

All data is presented in HID format to simplify integration with all operating systems.

## 1.3 FSM Calibration

Inertial motion tracking systems such as the FSM-9 require calibration for optimal performance. For ease of integration and manufacturing, the FSM-9 comes pre-calibrated from the factory in the following orientation:

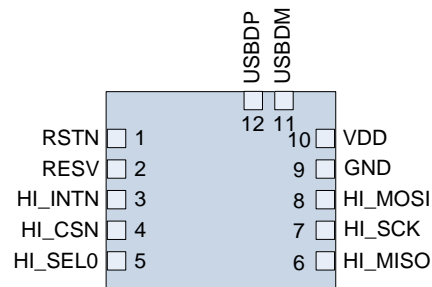


**Figure 8: FSM-9 Orientation**

Hillcrest's factory calibration procedure measures various parameters within the MEMS sensors while under highly accurate Gimbal-controlled motion and creates a record which is used by the MotionEngine software. This record allows the MotionEngine software to produce more accurate motion data and hence improves the overall interpretation of that data. The MotionEngine executes further in-use calibration algorithms to adjust the FSM's calibration dynamically over time and temperature.

## 1.4 Pinout

The FSM provides a micro-B USB connector allowing (with the appropriate cable) direct access to any system incorporating a USB interface. The FSM-9 can also connect to a PCB via castellation connections on the lower surface of the PCB. When mounted on a PCB the FSM can communicate over USB or a serial peripheral interface (SPI).



**Figure 9: FSM-9 Pinout (top view)**



## 1.5 Pin Descriptions

Figure 10 describes the function of each pin.

| Pin Number | Name    | Mode | 5V tolerant | Description  |
|------------|---------|------|-------------|--|
| 1          | RSTN    | O/D  | No          | Active-low open-drain reset signal with a 30k $\Omega$ to 50k $\Omega$ internal resistor to VDD. The module drives this signal low during reset with 2 mA drive capability. External hardware can drive the signal low to reset the processor. |
| 2          | RESV    | I    | No          | This pin should be tied to GND   |
| 3          | HI_INTN | O    | Yes         | Host interface interrupt   |
| 4          | HI_CSN  | I    | Yes         | Host interface chip select   |
| 5          | HI_SEL0 | I    | No          | VDD (or floating): USB<br>GND : SPI mode   |
| 6          | HI_MISO | O    | Yes         | Host interface SPI master input, slave output  |
| 7          | HI_SCK  | I    | Yes         | Host interface SPI clock   |
| 8          | HI_MOSI | I    | Yes         | Host interface SPI master output, slave input  |
| 9          | GND     | I    |             | Ground supply  |
| 10         | VDD     | I    |             | Positive supply voltage  |
| 11         | USBDM   | I/O  | Yes         | Negative polarity USB data line  |
| 12         | USBDP   | I/O  | Yes         | Positive polarity USB data line  |

**Figure 10: FSM-9 Pin Descriptions**

## 2 Motion Functions

### 2.1 Configuration

The FSM-9 powers up with all sensors disabled and no processing enabled. The application must therefore configure the FSM before use. The application can configure the type of output, the sensors to use and their sampling rate, the activity classification thresholds and the style of power management. The Data Mode Control V2 Request and Sensor Period Request referenced below are HCOMM messages which are detailed in reference 1.

#### 2.1.1 Motion Outputs

The motion output is configured via a “Data Mode Control V2 Request” command. Two types of motion packet can be generated by the FSM-9:

- A HID mouse packet providing (dx, dy) relative cursor output
- A MotionEngine Output packet. This packet can be configured to provide various types of motion data.

The types of motion data provided by the FSM are:

- Linear acceleration (includes gravity)
- Acceleration (gravity removed)
- Inclination
- Angular velocity
- Magnetometer reading
- Compass heading
- Angular position (or orientation)

The Data Mode Control V2 Request command also allows the operating mode of the module to be configured. For instance the application will want to turn on motion processing (set to Full Motion) to enable the output to be generated.

\*\*Note that the FSM-9 should be configured for “Format Select = 3” in the Data Mode Control V2 Request message to ensure the full 8g of acceleration is available when the user requires acceleration measured in  $m/s^2$ .

#### 2.1.2 Sampling Rate

The sensor sampling defaults to a period of 8ms. The application can modify the sample rate of the sensor system through the “Sensor Period Request” command. The FSM-9 support sensor rate configurations in 1ms increments up to 255ms.

The FSM-9 allows configuration of the following sensors:

| Sensor        | Sample rates      |
|---------------|-------------------|
| Accelerometer | 0 or 2ms to 255ms |
| Gyroscope     | 0 or 2ms to 255ms |
| Magnetometer  | 0 or 2ms to 255ms |
| Sensor Fusion | 0 or 4ms to 255ms |

**Figure 11: Supported Sensor Rates**

A period of 0ms disables the sensor. If the gyroscope is enabled the accelerometer is also enabled as the accelerometer is used within the algorithms to calibrate the gyroscope. The magnetometer is always turned on when any sensor is enabled.

The gyroscope provides the timing for sensor fusion and its setting will override all other sensor rates (i.e. the accelerometer and magnetometer will be slaved to the gyroscope sample rate). When sensor fusion is enabled the actual sample rate of the system will be the lowest of the sensor fusion setting or gyroscope setting.

If the FSM is configured for cursor output, the fusion rate will be used to generate the cursor. Hillcrest recommends that the sample rate for cursor be greater than 80Hz (12.5ms).

### 2.1.3 Flash Record System

The FSM-9 provides a flash record system that is used to store various records (called FRS records) useful to the operation of the FSM. The static calibration record is configured at manufacturing and describes the sensor set and the orientation. The other records default to empty, but are available to the application to modify the behavior of the FSM. Complete documentation of these records is provided in reference 1 and the use of these records is referenced within this datasheet.

| Description                             | FRS Record ID |
|---|---------------|
| Static calibration data record          | 0x7979        |
| MotionEngine Orientation record         | 0x2D3E        |
| MotionEngine Power Management record    | 0xD3E2        |
| MotionEngine AR/VR Stabilization record | 0x3E2D        |

Figure 12: FRS Records

## 2.2 Power management

The FSM-9 provides features that enable a system to manage the power of a system more effectively. The FSM-9 can be in one of three operating modes:

- Full Motion – motion outputs are being provided
- Wake-on-motion – a sleep mode in which the gyroscope and magnetometer are disabled and the accelerometer is configured to detect a change in acceleration, such as a user picking up the module. The event would force the FSM back into Full Motion mode
- Sleep – the device is asleep and needs to be commanded to transition to Full Motion

The power management state machine is captured in Figure 13.

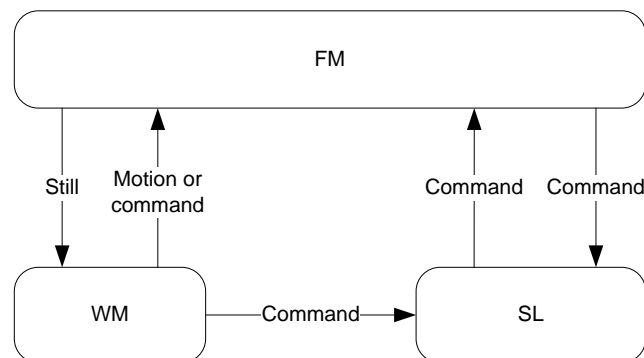


Figure 13: FSM-9 Operating Mode State Machine

Note that there is also an operating mode: “Full Motion On” which will force the FSM-9 to stay in the Full Motion state regardless of the motion data.

The FSM-9 monitors the motion data and generates activity classification messages upon a change in activity. There are three active states:

- OnTable – The FSM-9 is very stable, likely on a stationary surface
- Stable – The FSM-9 is stable, likely held in a fixed orientation (but not as stable as OnTable)

- Active – the FSM-9 is in motion

OnTable or Stable are generalized to “Still” in Figure 13.

These activity classification messages can be used by applications to power down elements of a system based on the stability of the device. The parameters used to create Stable are captured in the Power Management FRS record.

The Power Management record also enables the use of a feature called “gyro power save”. The gyro is the sensor that consumes the most power on the FSM and turning it off can be beneficial in battery powered systems. The configuration of this record allows the FSM to cycle the gyro on and off when the device is in various states of stability. The penalty is that the start-up time of the gyro is approximately 50ms so data will be missing during the start of motion.

Note that the “gyro power save” feature conflicts with the wake-on-motion mode described above and should be used in scenarios where the device may become temporarily stable frequently and transitioning to wake-on-motion mode would be undesirable. It should therefore be used in “Full Motion On” mode to prevent this conflict.

Modifying the FRS record requires a reset of the module for the updated parameters to be used.

## 2.3 Button Motion Suppression

The FSM-9 can output a cursor, allowing a motion based remote control or air mouse to be designed. One of the major issues with a motion based remote control is the unintentional movement that a button press can cause on the cursor displayed on the screen. When the button is pressed it is highly likely that the remote control will dip causing the cursor to change its position at just the point in time that the user is trying to select an onscreen icon. To prevent this unintended motion the cursor data can be filtered after the button event. The application issues a Button Motion Suppression Request to the FSM and data after the button event will be filtered. The request can be made on both the button press and button release. To be most effective the request to suppress motion must be as close to the event as possible to ensure the majority of the unintended motion is removed.

The Button Mode Suppression Request is a HCOMM message and is detailed in reference 1.

## 2.4 Orientation Reconfiguration

The FSM-9 presents angular position data based on the module’s frame of reference (or orientation). The factory default orientation is displayed in Figure 8. The FSM-9 may be mounted on equipment that does not follow this default frame of reference. The orientation data from the FSM-9 can be translated by the host application to represent the frame of reference within which it is mounted.

However if cursor output is required the frame of reference must be corrected on the FSM itself. The orientation of the FSM and the device to which it is mounted can be aligned by modifying the MotionEngine Orientation FRS record. For the cursor to be generated correctly the X-axis should point forward, so if the device is mounted on a head tracker (for instance) the X-axis of the device should be in the direction the user is looking.

The FRS record accepts a quaternion which represents the rotation from the default orientation to the desired orientation.

Modifying the FRS record requires a reset of the module for the updated parameter to be used.

## 2.5 AR/VR Stabilization

Over time and especially during large, fast motions the angular position estimate output can become misaligned with the actual angular position. When the device slows or stops, angular position can be determined accurately and the angular position output updated accordingly. However a step update to the output can be undesirable in some applications (for instance virtual reality). AR/VR Stabilization addresses this issue by correcting angular position errors only when the device is moving.

The FSM-9 provides an FRS record to enable the correction of the angular position output in a more controlled manner. The FRS record provides parameters that allow the response to be tuned per the application’s need:

- Scaling – Fraction of angular velocity to use to correct angular position errors

- Max rotation – Maximum amount of angular correction that can be applied
- Max error – Maximum error that is allowed to accumulate before a step update is forced
- Stability magnitude – Amount of error needed before an update should be applied

Modification of the FRS record requires the FSM to be reset for the changes to take effect.

## 3 Host Interface

The FSM-9 presents itself to the system as a sensor peripheral. As such a host processor (the controlling processor in the system) would configure the FSM and receive data from the module. The FSM can operate directly over USB or can be embedded into a system and operate over a serial peripheral interface (SPI). The mode is selected by the HI\_SEL0 pin:

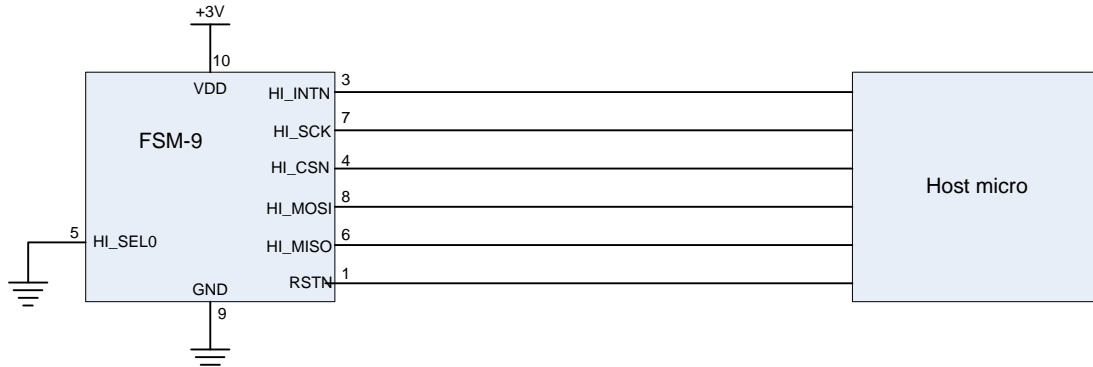


Figure 14: Typical circuit design for SPI mode

For USB mode the HI\_SEL0 pin can be left floating or pulled to VDD.

### 3.1 USB 2.0 Interface

The FSM-9 provides a micro-B USB receptacle. The FSM enumerates as a full speed USB 2.0 device when connected to a USB port on systems running most operating systems. The FSM supports a number of messages detailed in reference 1 and summarized in section 3.3 that allow various types of motion data to be produced and to provide additional configuration information about the FSM. Hillcrest provides a Microsoft Windows application, MotionStudio, which can provide information about the FSM and enable the user to monitor motion data and other data from the device.

Hillcrest has also developed an open source project called libfreespace (available at [libfreespace.hillcrestlabs.com](http://libfreespace.hillcrestlabs.com)) which allows for the development of motion based applications. The FSM-9 in conjunction with libfreespace is an ideal motion analysis development platform.

### 3.2 HCOMM Serial Peripheral Interface

The host interface is an augmented SPI interface. The FSM communicates with the host processor via the HCOMM protocol, which is a message based protocol. In particular the FSM presents itself as the slave side of the HCOMM SPI (HSPI) protocol. The host microcontroller must implement the master side of the HSPI protocol. See reference 1 for a detailed description of the commands and formats.

#### 3.2.1 Host Interface Signals

The signals used to connect the FSM-9 to the host microcontroller are shown in Figure 15.

| Signal  | Reference Manual Name | Direction     | Type              | Description                     |
|---------|-----------------------|---------------|-------------------|---------------------------------|
| HI_SCK  | SPI_SCK               | M → S         | CMOS              | SPI clock                       |
| HI_MISO | SPI_MISO              | S → M         | CMOS or Tri-state | SPI data from slave to master   |
| HI_MOSI | SPI_MOSI              | M → S         | CMOS              | SPI data from master to slave   |
| HI_CSN  | SPI_CSN               | M → S         | CMOS              | Active low chip select to slave |
| HI_INTN | SPI_INTN              | S → M         | CMOS              | Active low interrupt to master  |
| RSTN    |                       | Bidirectional | OD /w Pull-up     | System wide reset               |

Figure 15: Signal Interface

The reset signal may be used to generate a system wide reset. This signal can be driven into the FSM. The signal is also driven by the FSM after a power-on reset, brown-out reset, or software-generated reset.

### 3.2.2 HSPI Initialization

The FSM-9 initializes various state machines and configures itself immediately after reset. To ensure reliable operation the application must wait for the FSM-9 to initiate the first HSPI access before communicating with the device. See Figure 26.

### 3.2.3 HSPI Timing Parameters

The FSM-9 HSPI timing parameters are defined in Figure 16 and Figure 17. Pay close attention to the clock phase and clock polarity, this mode is typically called SPI Mode 3.

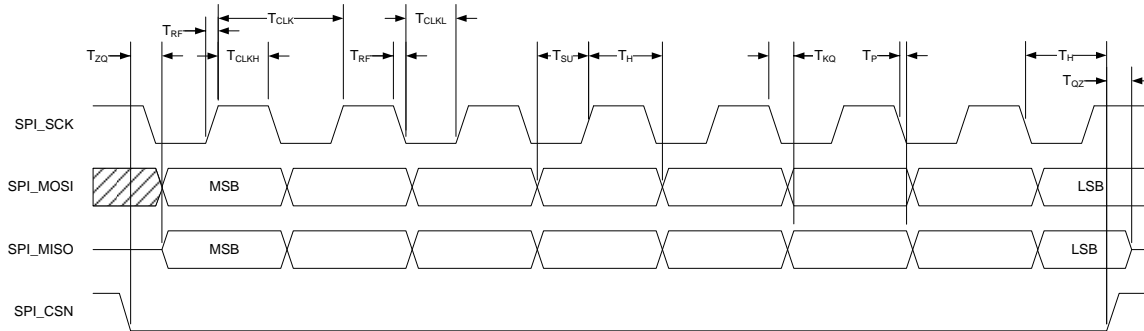


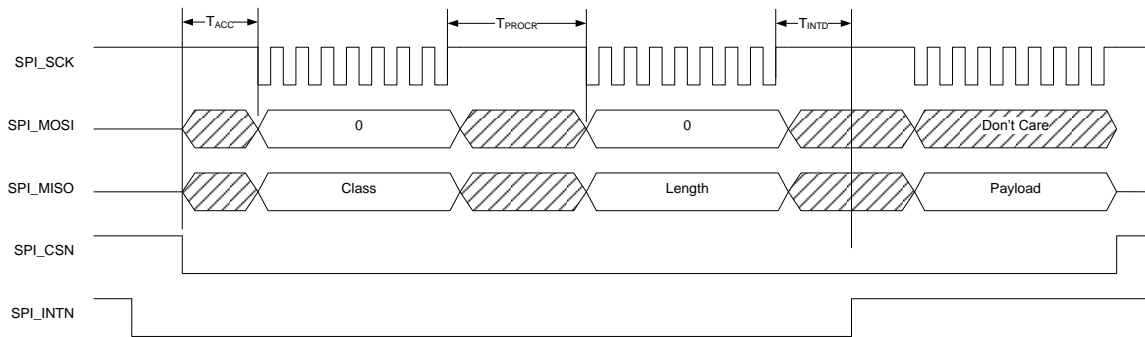
Figure 16: HSPI Timing Diagram

| Parameter                                     | Symbol      | Conditions | Min | Typ | Max        | Unit    |
|---|-------------|------------|-----|-----|------------|---------|
| SPI_SCK period                                | $T_{CLK}$   |            | 333 |     |            | ns      |
| SPI_SCK high time                             | $T_{CLKH}$  |            | 133 |     |            | ns      |
| SPI_SCK low time                              | $T_{CLKL}$  |            | 133 |     |            | ns      |
| SPI_SCK rise/fall time                        | $T_{RF}$    |            |     |     | 8          | ns      |
| Setup before SPI_SCK                          | $T_{SU}$    |            | 5   |     |            | ns      |
| Hold after SPI_SCK                            | $T_H$       |            | 4   |     |            | ns      |
| SPI_SCK to data valid                         | $T_{KQ}$    |            |     |     | 25         | ns      |
| SPI_SCK to data invalid                       | $T_P$       |            | 15  |     |            | ns      |
| Access time, SPI_CSN asserted to SPI_SCK fall | $T_{ACC}$   |            | 0   |     |            | ns      |
| SPI_CSN idle between transactions             | $T_{IDLE}$  |            | 50  |     |            | $\mu$ s |
| SPI_INTN deasserted for aborted transaction   | $T_{ABORT}$ |            |     |     | $T_{IDLE}$ | $\mu$ s |
| SPI_INTN deasserted after length byte sent    | $T_{INTD}$  |            |     |     | 500        | $\mu$ s |
| SPI_CSN low to MISO out                       | $T_{ZQ}$    |            |     |     | 400        | ns      |
| SPI_CSN high to High Z                        | $T_{QZ}$    |            |     |     | 10         | ns      |
| Inter-byte spacing                            | $T_{PROCR}$ |            | 0   |     |            | ns      |

Figure 17: HSPI Timing Parameters

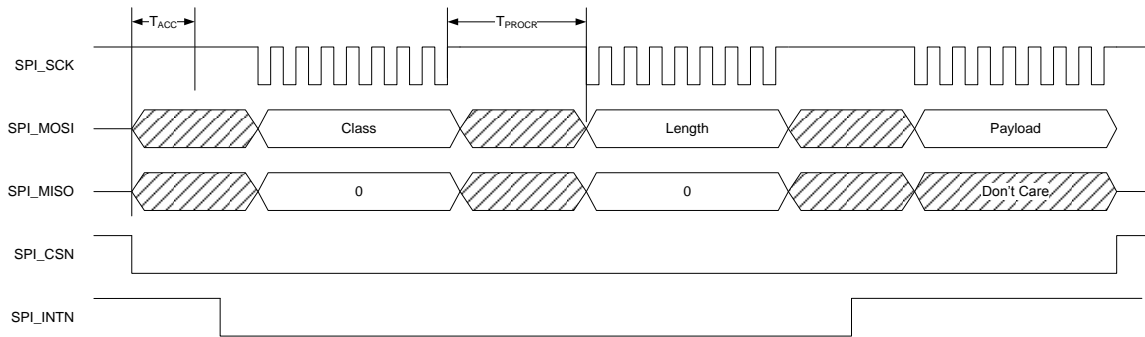
### 3.2.4 Message Protocol

If the FSM requires attention (i.e. has data to deliver) it will assert its interrupt pin. The length field is the second byte of the data delivered by either the master or the slave and dictates how many clocks the SPI master must provide to ensure all the data is transferred. It is possible for the master and slave to transfer data in the same transaction so whichever device has the most data to send governs the number of clock cycles generated. If the master has no data to deliver it must set its length to zero.



**Figure 18: Slave to Master Data Transfer**

If the host has data to provide to the FSM it asserts the chip select. The FSM will respond by asserting the interrupt line. Only after the interrupt line has been asserted can the master respond with the data. In a similar fashion the host and slave must honor the deassertion of the interrupt line after the length field has been clocked out of the two devices. The interrupt line deassertion ensures that all parties have an understanding of how much data is to be transferred. If the FSM has no data to deliver on a host initiated transfer it will set the length field to zero.



**Figure 19: Master to Slave Data Transfer**



### 3.3 HCOMM Message Support

The FSM-9 supports the following messages:

| Packet                                  | Class | Sub class | Source | Target | Usage   |
|---|-------|-----------|--------|--------|---|
| FRS Write Request                       | 0x7   | 0x6       | Host   | FSM    | Request for FRS write   |
| FRS Write Response                      | 0x5   | 0x6       | FSM    | Host   | Response to FRS write   |
| FRS Write Data                          | 0x7   | 0x7       | Host   | FSM    | FRS write data  |
| FRS Read Request                        | 0x7   | 0x8       | Host   | FSM    | Request for FRS write   |
| FRS Read Response                       | 0x6   | 0x8       | FSM    | Host   | FRS record read data  |
| Product ID Request                      | 0x7   | 0x9       | Host   | FSM    | Request Product ID  |
| Product ID Response                     | 0x6   | 0x9       | FSM    | Host   | Product ID data   |
| Freespace Data Mode Control V2 Request  | 0x7   | 0x14      | Host   | FSM    | Requests operation mode of device   |
| Freespace Data Mode Control V2 Response | 0x5   | 0x14      | FSM    | Host   | Reports operation mode of device  |
| Activity Classification                 | 0x7   | 0x12      | FSM    | Host   | Activity classification messages for power management                                   |
| Sensor Period Request                   | 0x7   | 0x16      | Host   | FSM    | Configures sample rate  |
| Sensor Period Response                  | 0x5   | 0x16      | FSM    | Host   | Reports sensor rate   |
| Button Motion Suppression Notification  | 0x7   | 0x17      | Host   | FSM    | Indicates a button event which allows MotionEngine to suppress unintended cursor motion |
| Mouse Packet                            | 0x2   | -         | FSM    | Host   | Provides mouse cursor data  |
| MotionEngine Output                     | 0x26  | -         | FSM    | Host   | Provides fused sensor data  |
| DFU Status Request                      | 0x7   | 0x43      | Host   | FSM    | Request for bootloader status   |
| DFU Command                             | 0x7   | 0x47      | Host   | FSM    | Triggers bootloader operation   |
| DFU Write Data                          | 0x7   | 0x49      | Host   | FSM    | Data to write during upgrade  |
| DFU Status Response                     | 0x5   | 0x43      | FSM    | Host   | Status from bootloader  |

**Figure 20: Supported HCOMM Messages**

The messages are fully described in reference 1.

## 4 Electrical Characteristics

This section describes the electrical characteristics of the FSM-9. In SPI mode, all of the FSM I/O pins meet CMOS and TTL requirements.

### 4.1 Absolute Maximum Ratings

Exposure to maximum rating conditions for extended periods may affect device reliability.

| Parameter                             | Symbol    | Rating         | Unit |
|---------------------------------------|-----------|----------------|------|
| Supply voltage in USB mode            | $V_{USB}$ | 6.0            | V    |
| Supply voltage in SPI mode            | $V_{DD}$  | 4.0            | V    |
| Input voltage on 5V tolerant pins     |           | 5.5            | V    |
| Input voltage on non-5V tolerant pins |           | $V_{DD} + 0.3$ | V    |
| Storage temperature                   |           | -40 to +125    | °C   |

Figure 21: FSM-9 Maximum Ratings

### 4.2 Recommended Operating Conditions

| Parameter                  | Symbol    | Conditions | Min | Typ | Max | Unit |
|----------------------------|-----------|------------|-----|-----|-----|------|
| Supply voltage in USB mode | $V_{USB}$ |            |     | 5.0 |     | V    |
| Supply voltage in SPI mode | $V_{DD}$  |            | 2.9 | 3.0 | 3.3 | V    |
| Operating temperature      |           |            | 0   |     | 50  | °C   |

Figure 22: FSM-9 Operating Conditions

### 4.3 Electrical Characteristics

| Parameter                           | Symbol          | Conditions                 | Min  | Typ   | Max            | Unit    |
|-------------------------------------|-----------------|----------------------------|------|-------|----------------|---------|
| Input high voltage                  | $V_{IH}$        |                            | 1.82 |       | $V_{DD} + 0.5$ | V       |
| Input low voltage                   | $V_{IL}$        |                            |      |       | 1.0            | V       |
| Output high voltage for non-USB I/O | $V_{OH}$        | $I_{OH}=8mA$               | 2.4  |       | 2.8 **         | V       |
| Output low voltage For non-USB I/O  | $V_{OL}$        | $I_{OL}=8mA$               |      |       | 0.4            | V       |
| Input leakage current               | $I_{IL}/I_{IH}$ |                            |      |       | 1              | $\mu A$ |
| I/O source current                  |                 |                            |      |       | 8              | mA      |
| I/O sink current                    |                 |                            |      |       | 8              | mA      |
| USB mode operating current          |                 | FM mode, 250Hz             |      | 24    |                | mA      |
| USB mode operating current          |                 | FM mode, 125Hz             |      | 18.3  |                | mA      |
| USB mode operating current          |                 | FM mode, 100Hz             |      | 17.5  |                | mA      |
| USB mode operating current          |                 | Wake-on-motion/<br>Sleep   |      | 7.7   |                | mA      |
| SPI mode operating current          |                 | Vdd = 3.0V, FM mode, 250Hz |      | 20    |                | mA      |
| SPI mode operating current          |                 | Vdd = 3.0V, FM mode, 125Hz |      | 15.25 |                | mA      |
| SPI mode operating current          |                 | Vdd = 3.0V, FM mode, 100Hz |      | 14.5  |                | mA      |
| SPI mode operating current          |                 | Vdd = 3.0V, Wake-on-motion |      | 0.16  |                | mA      |
| SPI mode operating current          |                 | Vdd = 3.0V, Sleep          |      | 0.1   |                | mA      |

**Figure 23: FSM-9 Electrical Characteristics**

\*\* The FSM-9 contains a 2.8V LDO to condition the power supply for the MEMS sensors.

## 4.4 Performance Specification

| Parameter                    | Typical               |
|------------------------------|-----------------------|
| Latency                      | 1.8ms <sup>(1)</sup>  |
| Sensor Fusion Rate           | ≤250Hz                |
| Angular Velocity             |                       |
| Range                        | +/- 1833°/s           |
| Resolution                   | 0.04°/s               |
| Bias (zero rate offset)      | 0.01 rad/s            |
| Sensitivity accuracy         | 1%                    |
| Non-linearity (% full scale) | 0.2%                  |
| Linear Acceleration          |                       |
| Range                        | +/- 8g <sup>(2)</sup> |
| Resolution                   | < 6mg                 |
| Bias (zero-g offset)         | < 20mg                |
| Sensitivity accuracy         | 2%                    |
| Non-linearity (% full scale) | 0.5%                  |
| Magnetometer                 |                       |
| Range                        | +/- 600 μT            |
| Resolution                   | < 1 μT                |
| Bias                         | < 5 μT                |
| Sensitivity accuracy         | 5%                    |
| Non-linearity (% full scale) | 0.5%                  |
| Orientation Specification    |                       |
| Static Accuracy              | 1.5°                  |
| Static Heading               | 1.0°                  |
| Static Non-heading           | 1.0°                  |
| Dynamic Accuracy             | 1.5°                  |
| Dynamic Heading              | 1.0°                  |
| Dynamic Non-heading          | 1.0°                  |
| Pointer Performance          |                       |
| Sensor Fusion Rate           | > 80Hz                |
| Sensitivity                  | 33 mickeys/°          |
| Angle Error                  | < 2°                  |
| Tremor Cancellation          | 70%                   |

**Figure 24: FSM-9 Performance Specification**

Specification derived via simulation and verified with device measurements. Typical specifications are not guaranteed. Orientation specification applies to sensor fusion at 250Hz. For optimal cursor (pointing) performance the sensor fusion rate should be set to greater than 80Hz.

1. Latency is measured from the gyroscope making data available until the completion of sensor fusion and the fused data being made available over the SPI interface or for the USB interface.
2. The FSM-9 should be configured for "Format Select = 3" in the Data Mode Control V2 Request message to ensure the full 8g of acceleration is available when using units of m/s<sup>2</sup> versus g.

## 4.5 AC Characteristics

| Parameter                                  | Symbol            | Conditions                        | Min  | Typ  | Max  | Unit |
|--|-------------------|-----------------------------------|------|------|------|------|
| Wake-on-motion wake up time <sup>(2)</sup> |                   | movement to motion data available |      | 200  |      | ms   |
| Reset pulse width                          | T <sub>RST</sub>  |                                   | 1043 |      |      | μs   |
| Reset to init start                        | T <sub>RI</sub>   |                                   |      | 900  | 5000 | μs   |
| Initialization time                        | T <sub>INIT</sub> |                                   |      | 1520 |      | ms   |

Figure 25: FSM-9 AC Characteristics

<sup>2</sup> Wake-on-motion time characterized from device measurements.

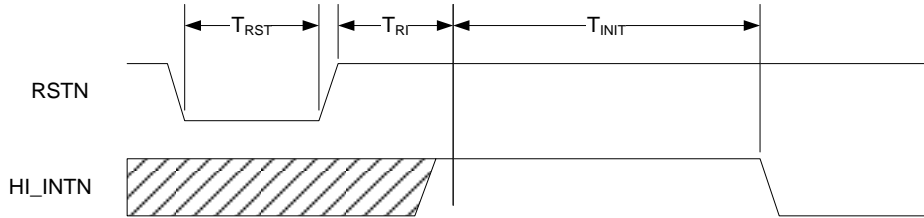


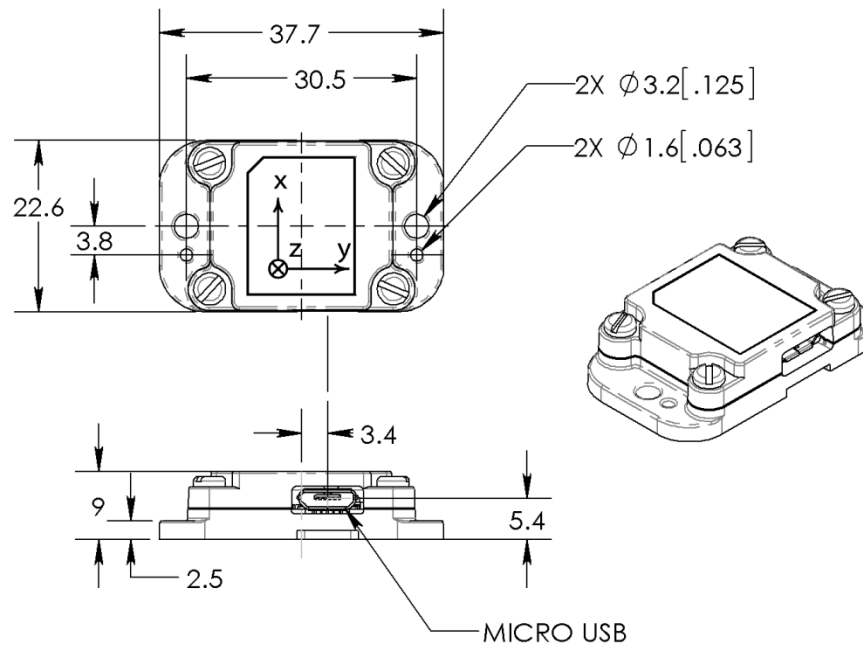
Figure 26: FSM-9 Startup Timing

Note that no HSPI transactions should occur until the FSM first asserts the HI\_INTN signal.

## 5 Miscellaneous

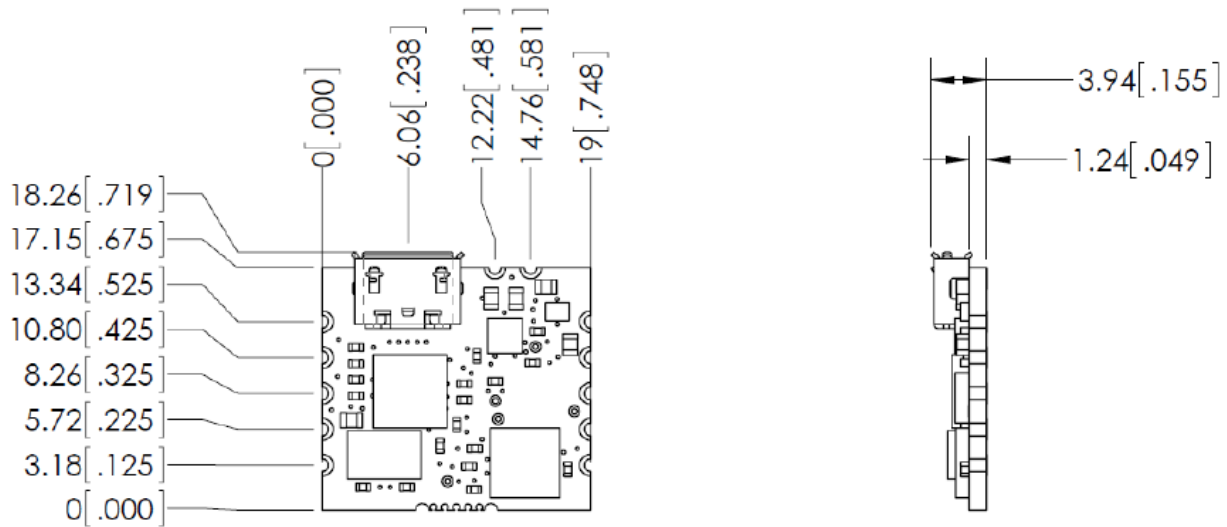
### 5.1 Mechanical Information

The mechanical dimensions of the FSM-9 are presented below (dimensions in mm[inches]). Mechanical CAD files are available on [www.Hillcrestlabs.com](http://www.Hillcrestlabs.com)



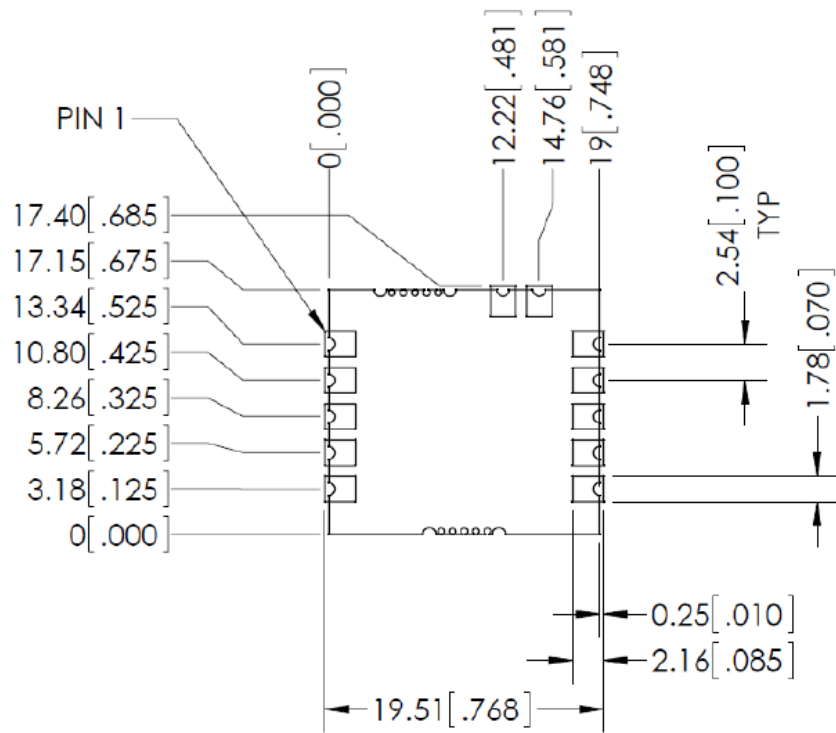
**Figure 27: FSM-9 Enclosure Mechanical Outline**

The FSM-9 is also available without the enclosure as a printed circuit assembly only (FSM-9 OEM). See below for mechanical dimensions and PCB footprint information.



**Figure 28: FSM-9 OEM Mechanical Outline**

The recommended PCB footprint for the FSM-9 OEM is presented below. It is recommended that the module be attached to the mating PCB manually. Contact Hillcrest if reflow is required.



**Figure 29: FSM-9 OEM PCB Footprint**

## 5.2 Ordering Information

The FSM-9 is available in three models.

| Model Description                                       | Part Number         |
|---|---------------------|
| Module Reference Kit with enclosure in blister pack     | FSM-9 Reference Kit |
| Module with enclosure in bulk packaging                 | FSM-9               |
| Module Printed Circuit Assembly (PCA) in bulk packaging | FSM-9 OEM           |

**Figure 30: Ordering Information**



## 6 References

1. 1000-2984 - HCOMM Reference Manual, Hillcrest Labs.

## 7 Notices

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