

Introduction

The FSP200 is a 6-axis IMU processor that provides heading and orientation outputs. When connected to one of several supported sensors, it performs all the accelerometer and gyroscope sensor fusion processing necessary to produce stable and accurate heading and orientation outputs. The FSP200 is suitable for use in robotic products such as consumer floor care products, garden and lawn robots, pool cleaners and follow me and assistant robots used in the hospitality and medical markets.

The FSP200 offers the following features.

- Outputs
 - Calibrated acceleration
 - Linear acceleration
 - Gravity
 - Calibrated gyroscope
 - Uncalibrated gyroscope
 - Game rotation vector quaternion
 - Yaw, pitch and roll
 - Raw accelerometer
 - Raw gyroscope
- Interfaces
 - UART-RVC
 - UART-SHTP
 - UART-RVC-LOG
- Sensors
 - BMI055
 - LSM6DSR
 - ICM42688P
- Simple calibration

The FSP200 interfaces are compatible with CEVA's Hillcrest Labs business unit's BNO08x.

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1 Pinout

The pinout of the FSP200 is shown in Figure 1.

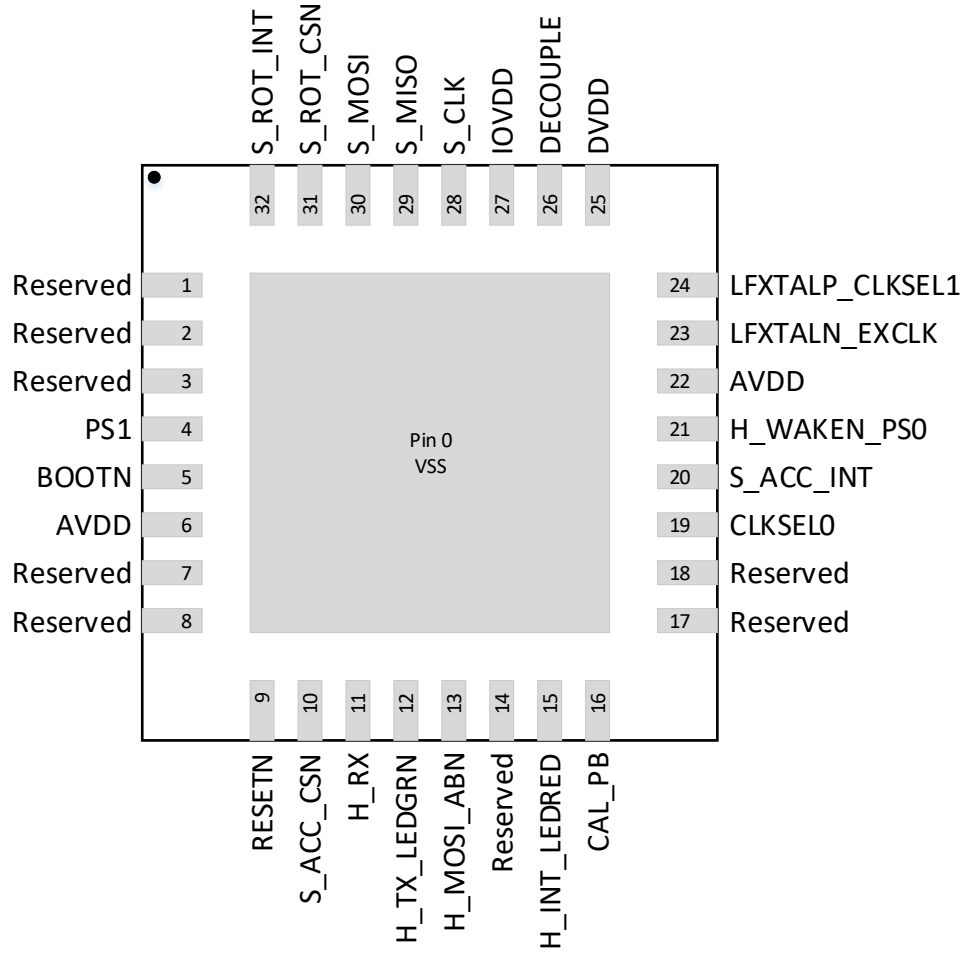


Figure 1: FSP200

A description of each pin is listed in Figure 2.

Pin	Name	Mode	Description
0	VREGVSS	Input	Ground
1	Reserved	NC	Reserved. Do Not Connect
2	Reserved	NC	Reserved. Do Not Connect
3	Reserved	NC	Reserved. Do Not Connect
4	PS1	Input ²	Protocol select 1.
5	BOOTN	Input	Boot mode select. Active low.
6	AVDD	Power	Analog power supply
7	Reserved	NC	Reserved. Do Not Connect
8	Reserved	NC	Reserved. Do Not Connect
9	RESETN	Input ¹	Reset.
10	S_ACC_CSN	Output	Sensor chip select – accelerometer
11	H_RX	Input	UART receive data
12	H_TX_LEDGRN	Output	Host UART transmit data or calibration status
13	H_MOSI_ABN	Input ¹	Autobaud enable (active low)
14	Reserved	NC	Reserved. Do Not Connect
15	H_INT_LEDRED	Output	Host interrupt (active low) or calibration status
16	CAL_PB	Input	Calibration push button. Active low. Connect to DVDD if not used.
17	Reserved	NC	Reserved. Do Not Connect
18	Reserved	NC	Reserved. Do Not Connect
19	CLKSEL0	Input	Clock select 0.
20	S_ACC_INT	Input	Sensor interrupt – accelerometer.
21	H_WAKEN_PS0	Input ¹	Protocol select 0. UART-SHTP mode wake input (active low).
22	AVDD	Power	Analog power supply
23	LFXTALN_EXTCLK	Input	32768 Hz crystal or external clock
24	LFXTALP_CLKSEL1	Input	32768 Hz crystal or clock select 1
25	DVDD	Power	Digital power supply
26	DECOUPLE	Power	Decouple output for decoupling capacitor
27	IOVDD	Power	Digital IO power supply
28	S_CLK	Output	Sensor SPI clock
29	S_MISO	Input	Sensor SPI MISO
30	S_MOSI	Output	Sensor SPI MOSI
31	S_ROT_CSN	Output	Sensor chip select – gyroscope
32	S_ROT_INT	Input	Sensor interrupt - gyroscope

Figure 2: FSP200 Pin Descriptions

Note 1: Internal pullup, 30-65 kΩ.

Note 2: Internal pulldown, 30-65 kΩ.

2 Host Interface

The FSP200 supports two host interfaces: UART-RVC and UART-SHTP. The host interface is selected following system reset using the PS1 and PS0 pins. The PS1 pin must always be set to the correct value. The H_WAKEN_PS0 pin must remain in the correct state until the FSP200 asserts H_INT_LEDRED and begins communications with the host for the first time. The selection settings are shown in Figure 3. Schematics showing typical connections for each interface are shown in the following sections. Sensor connections are omitted from these diagrams for clarity.

Source	PS1	PS0
UART-RVC-LOG	0	0
UART-RVC	0	1
UART-SHTP	1	0
Reserved	1	1

Figure 3: Host Interface Selection

2.1 UART-RVC

The UART-RVC interface is a simplified UART interface for use on robot vacuum cleaners (RVC). When configured in this mode the FSP200 transmits heading and sensor information at 100Hz over the UART TX pin. A typical connection diagram is shown in Figure 4.

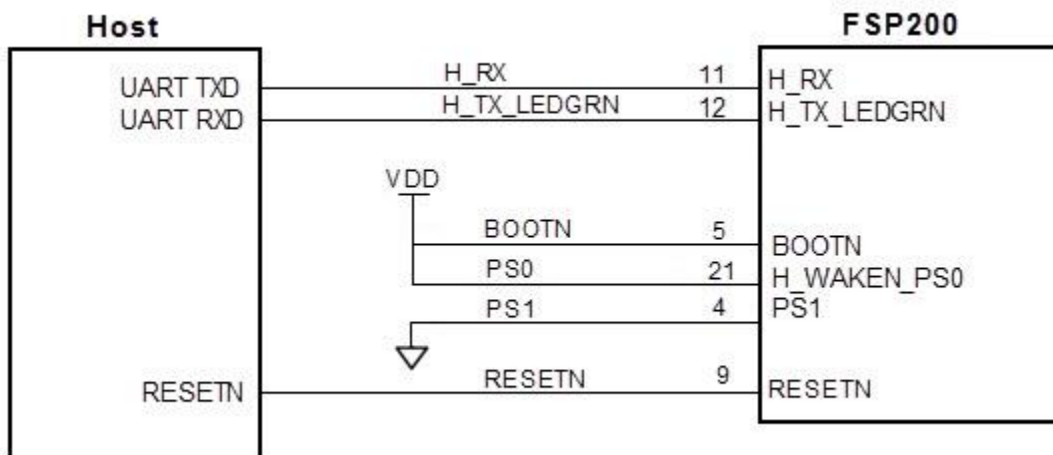


Figure 4: UART-RVC Connection Example

2.1.1 UART-RVC Operation

The UART operates at 115200 b/s, 8 data bits, 1 stop bit and no parity. The UART protocol relies on an idle line being 'high'. A transmission is started with the assertion of a start bit (pulling the line low), followed by the data, LSB first. After the data segment is sent (in this case 8-bits), the line is pulled high (the stop signal) for a minimum number of bits (1 for the FSP200) to indicate end of that segment.

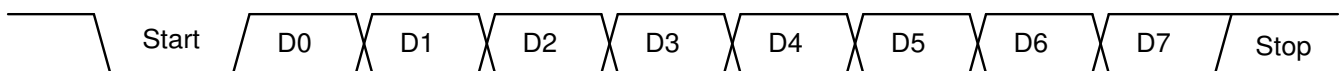


Figure 5: UART signaling

2.1.2 UART-RVC Protocol

The FSP200 transmits the following data at a rate of 100Hz.

Header	Index	Yaw		Pitch		Roll		X-axis accel		Y-axis accel		Z-axis accel		Interactive Calibration		Rsvd	Csum
0xAAAA		LSB	MSB	LSB	MSB	LSB	MSB	LSB	MSB	LSB	MSB	LSB	MSB	MI	MR	0	

Figure 6: FSP200 UART-RVC packet format

The 19-byte message has the following fields:

Header	Each report is prefixed with a 0xAAAA header
Index	A monotonically increasing 8-bit count is provided (0-255) per report
Yaw	The yaw is a measure of the rotation around the Z-axis since reset. The yaw has a range of +/- 180° and is provided in 0.01° increments, i.e. a report of 8734 is equivalent to 87.34°.
Pitch	The pitch is a measure of the rotation around the X-axis. The pitch has a range of +/- 90° and is provided in 0.01° increments, i.e. a report of 1072 is equivalent to 10.72°.
Roll	The roll is a measure of the rotation around the Y-axis. The roll has a range of +/- 180° and is provided in 0.01° increments, i.e. a report of 1072 is equivalent to 10.72°.
X-axis acceleration	The acceleration along the X-axis, presented in mg
Y-axis acceleration	The acceleration along the Y-axis, presented in mg
Z-axis acceleration	The acceleration along the Z-axis, presented in mg
MI	Motion Intent – this byte reflects the Motion Intent provided to the FSP200. 0 – FME_MOBILE_MOTION_INTENT_UNKNOWN – this is the initial state assumed by the sensor hub 1 – FME_MOBILE_MOTION_INTENT_STATIONARY_WITHOUT_VIBRATION 2 – FME_MOBILE_MOTION_INTENT_STATIONARY_WITH_VIBRATION 3 – FME_MOBILE_MOTION_INTENT_IN_MOTION 4:255 – Reserved
MR	Motion Request – the motion requested by the FSP200. 0 – FME_MOBILE_MOTION_REQUEST_NO_CONSTRAINT. The device may move as desired. 1 – FME_MOBILE_MOTION_REQUEST_STAY_STATIONARY_REQUIRED. The device should remain stationary to refine its calibration to a basic level. 2 – FME_MOBILE_MOTION_REQUEST_STAY_STATIONARY_OPTIONAL. The device should remain stationary to refine its calibration to a high-precision level. If high precision is not required, the device may resume motion. (DEPRECATED. Ignore this request) 3 – FME_MOBILE_MOTION_REQUEST_NON_URGENT_STATIONARY. The device should stop when convenient to improve its calibration. 4 – FME_MOBILE_MOTION_REQUEST_URGENT_STATIONARY. The device should stop as soon as possible to improve its calibration. 5 – FME_MOBILE_MOTION_REQUEST_TIMER_STATIONARY. The device should stop when convenient to check and possibly improve its calibration. 6:255 – Reserved
Reserved	The message is terminated with one reserved byte, currently set to zero
Checksum (Csum)	The Index, yaw, pitch, roll, acceleration and reserved data bytes are added to produce the 8-bit checksum.

To determine the actual orientation of the module, the rotations should be applied in the order yaw, pitch then roll.

An example complete message and checksum calculation is as follows:

Header		Index	Yaw		Pitch		Roll		X-axis accel		Y-axis accel		Z-axis accel		Interactive Calibration		Rsvd	Csum
AA	AA	DE	01	00	92	FF	25	08	8D	FE	EC	FF	D1	03	0	0	0	E7

Where:

Index = 0xDE = 222

Yaw = 00.01° (1 = 0x0001)

Pitch = -1.10° (-110 = 0xFF92)

Roll = 20.85° (2085 = 0x0825)

X-acceleration = -371 mg = -3.638 m/s² (-371 = 0xFE8D)

Y-acceleration = -20 mg = -0.196 m/s² (-20 = 0xFFEC)

Z-acceleration = 977 mg = 9.581 m/s² (977 = 0x03D1)

MI = 0, Motion Intent – unknown

MR = 0, Motion Request – no request

Checksum = 0xE7

2.1.3 UART-RVC-LOG

The UART-RVC-LOG interface is connected in the same manner as the UART-RVC interface and produces the same data in the same format. In addition, the UART-RVC-LOG interface outputs raw sensor data and other information that may assist with testing or debugging systems. See reference [9] for details.

2.2 UART-SHTP

The UART-SHTP is a high-speed low latency interface. The interface operates at either a fixed rate of 3 Mbps or at a discovered rate based on the first character received. A typical connection diagram is shown in Figure 7.

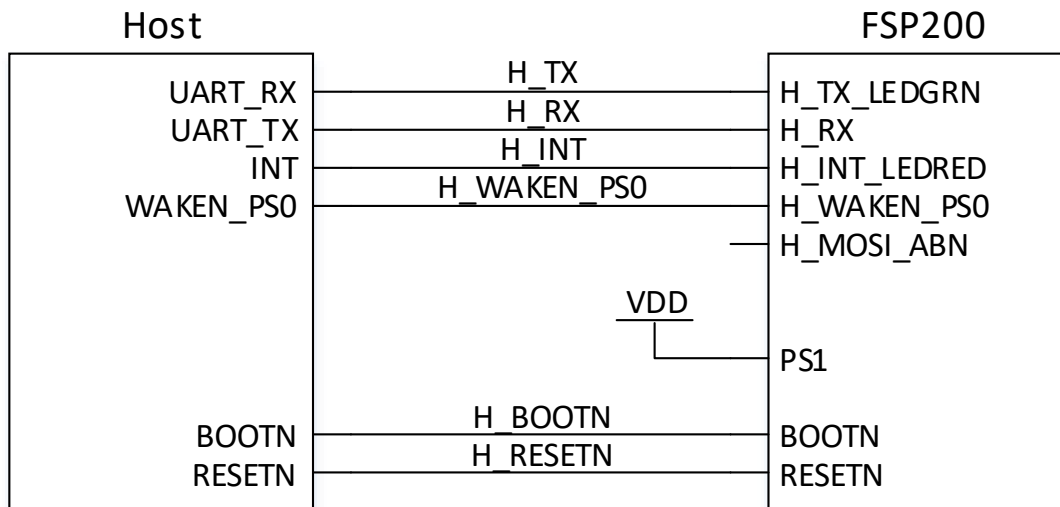


Figure 7: UART-SHTP Connection Example (3Mbps)

2.2.1 UART-SHTP Operation

The UART is configured for 3 Mb/s, 8 data bits, 1 stop bit and no parity. The UART protocol relies on an idle line being 'high'. A transmission is started with the assertion of a start bit (pulling the line low), followed by the data, LSB first. After the data segment is sent (in this case 8-bits), the line is pulled high (the stop signal) for a minimum number of bits (1 for the FSP200) to indicate end of that segment. Bytes sent from the host to the FSP200 must be separated by at least 100us. Bytes sent from the FSP200 to the host have no extra spacing.

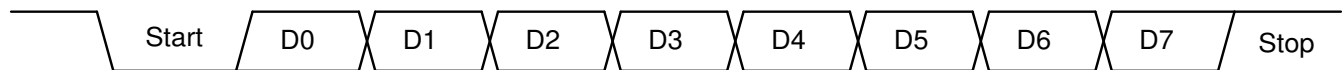


Figure 8: UART signaling

The FSP200 uses Hillcrest's SHTP protocol to communicate. The UART protocol makes use of framing bytes at the start and end of transmission. More details are available in [6].

2.2.2 UART-SHTP Autobaud

The UART-SHTP interface has an autobaud mode. To select autobaud mode, tie H_MOSI_ABN to ground. To set the baud rate:

- Reset the FSP200
- Wait for the first assertion of H_INT_LEDRED
- Transmit 0x55 at the desired baud rate

After the FSP200 receives the 0x55 character, it changes its baud rate to match the rate used by the host. When using autobaud mode the maximum rate is 2.375 Mbps and the minimum rate is 9600 bps.

2.2.3 UART-SHTP Startup and Power Management

Prior to taking the FSP200 out of reset, H_WAKEN_PS0 must be asserted low. It should remain low until the first interrupt is received, i.e. until H_INT_LEDRED is asserted low. After this H_WAKEN_PS0 should be deasserted high. Deasserting H_WAKEN_PS0 allows the FSP200 to enter its lowest power mode. See Figure 9.

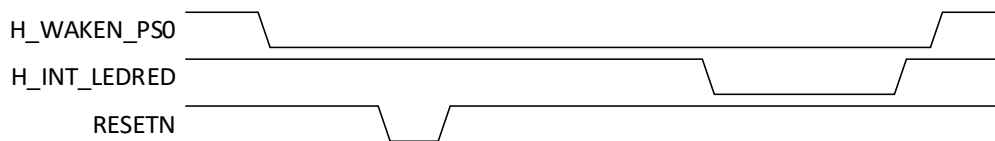


Figure 9: UART-SHTP Startup

When sending data to the FSP200, H_WAKEN_PS0 must be asserted low before transmission begins and must be deasserted high after transmission ends. The FSP200 uses the query and notification system described in reference [6]. A BSQ must be sent after H_WAKEN_PS0 is asserted low. The FSP200 responds with a BSN. If the FSP200 does not respond with a BSN after 10ms, send the BSQ again. After receiving the BSN, the host may send its message. See Figure 10. Deasserting H_WAKEN_PS0 after sending the message allows the FSP200 to enter its lowest power mode.

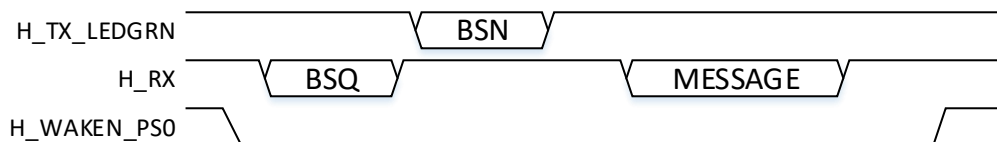


Figure 10: UART-SHTP Sending a message to the FSP200

3 Sensors

3.1 Overview

One accelerometer and one gyroscope must be connected to the FSP200. Connection diagrams for the supported sensors are shown in the following sections. Sensor specific information is also included in the following sections.

3.2 BMI055

A diagram showing how a BMI055 is connected to the FSP200 is shown below. Although V_{DDIO} and V_{DD} are connected together in the diagram, the lower limit for V_{DD} for the BMI055 is 2.4VDC. If the FSP200 is to be operated at less than 2.4 VDC, the BMI055 must be provided its own V_{DD} .

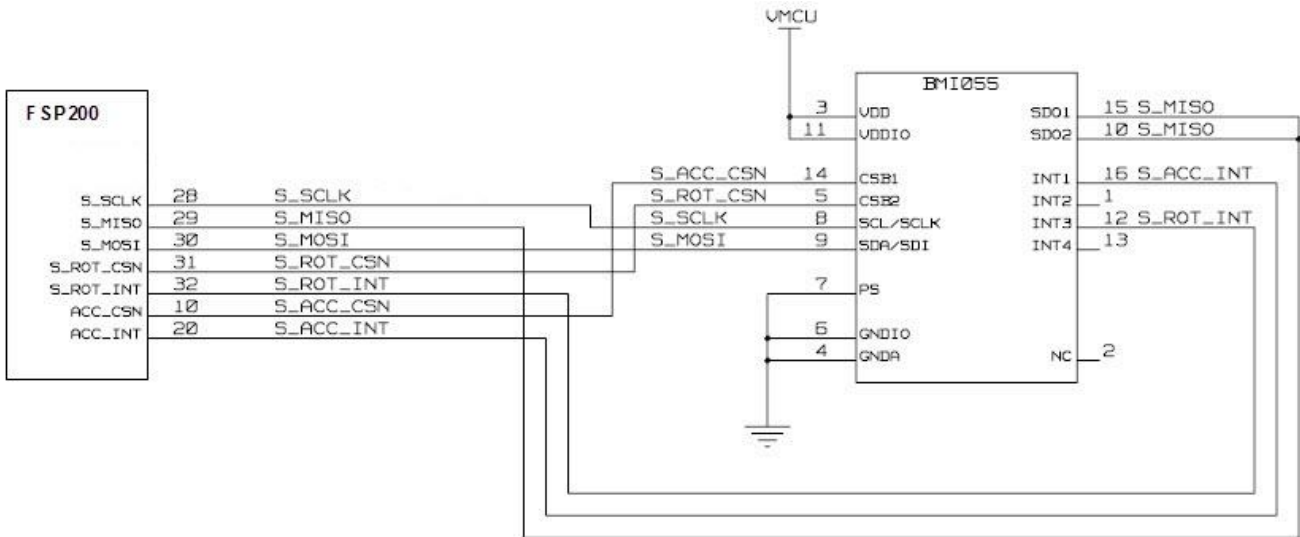


Figure 11: BMI055 SPI Connection Example

The BMI055 accelerometer and gyroscope are operated independently of one another. The accelerometer is operated at 15.62 Hz, 31.25 Hz, 62.5 Hz, 125 Hz, 250 Hz, 500 Hz or 1000 Hz. The gyroscope is operated at 100 Hz, 200 Hz, 400 Hz or 1000 Hz. Operation of the gyroscope at frequencies lower than 100 Hz is supported by running the sensor at 100 Hz and reporting only those samples needed to meet the requested frequency.

3.3 LSM6DSR

A diagram showing how an LSM6DSR is connected to the FSP200 is shown below.

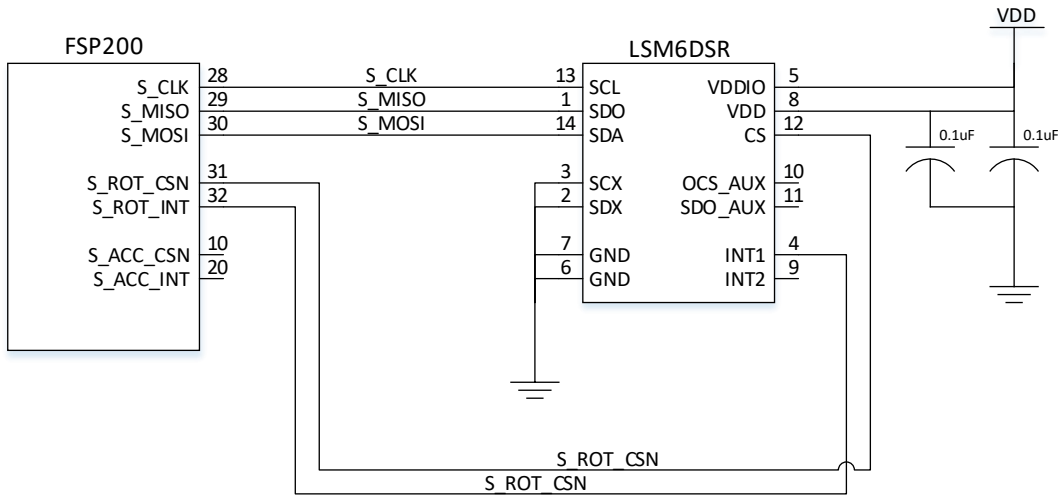


Figure 12: LSM6DSR SPI Connection Example

The LSM6DSR is operated at 13 Hz, 26 Hz, 52 Hz, 104 Hz, 208 Hz or 416 Hz. Operation at frequencies lower than 13 Hz is supported by running the sensor at 13 Hz and reporting only those samples needed to meet the requested frequency.

3.4 ICM42688P

A diagram showing how an ICM42688P is connected to the FSP200 is shown below.

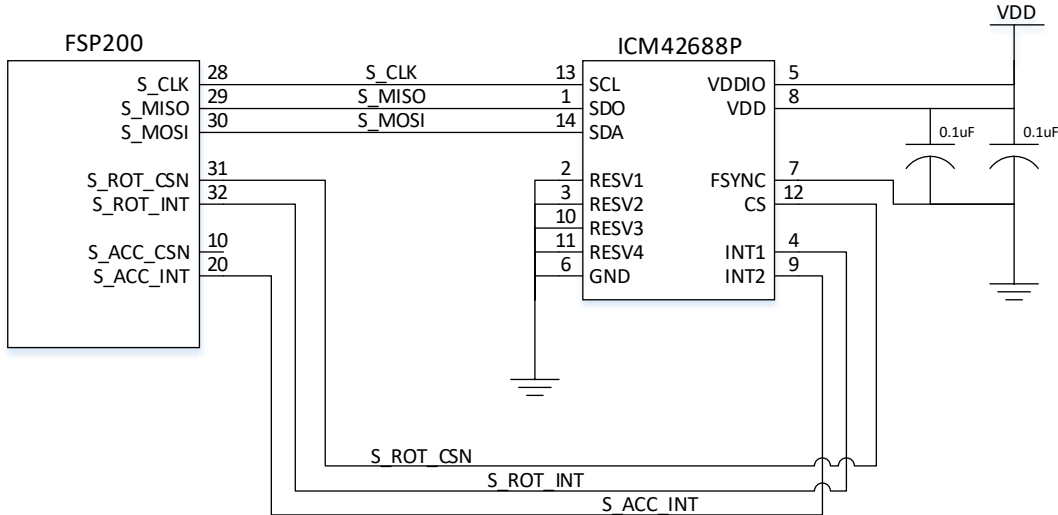


Figure 13: ICM42688P SPI Connection Example

The ICM42688P is operated at 100 Hz, 125 Hz, 250 Hz, 500 Hz or 1000 Hz. Operation at frequencies lower than 100 Hz is supported by running the sensor at 100 Hz and reporting only those samples needed to meet the requested frequency.

4 Clock Configuration

The FSP200 supports either an external crystal or an external digital clock signal. The accuracy of the clock should be 50 ppm or better. Settings for the CLKSEL signals are shown in Figure 14.

Source	CLKSEL0	CLKSEL1
External Crystal Clock	0	Connect to Crystal
External Digital Clock	1	1
Reserved	1	0

Figure 14: Clock Selection

5 Coordinate System

The coordinate system for the FSP200 is determined by the placement and orientation of the connected sensor. If the sensor must be installed in an orientation different from the desired coordinate system, the system orientation record can be modified to align the coordinate system as desired. See reference [8] for details. The default orientations are shown below. All views are top views with the Z-axis pointing up. The default coordinate system is East/North/Up (ENU).

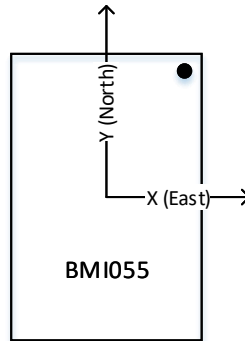


Figure 15: BMI055 Orientation and ENU Coordinate System

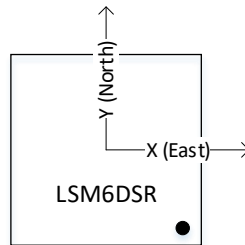


Figure 16: LSM6DSR Orientation and ENU Coordinate System

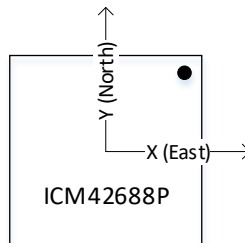


Figure 17: ICM42688P Orientation and ENU Coordinate System

6 Startup Messages

6.0 UART-RVC mode

When the FSP200 is configured for UART-RVC mode it starts up and sends a string resembling the following:

```
%Hillcrest Labs 10004095
%SW Ver 3.9.x
%(c) 2017 Hillcrest Laboratories, Inc.
```

This message informs the user that the FSP200 has exited reset and provides version information.

Following this message the FSP200 will issue data packets according to section 2.1.2.

6.1 UART-SHTP mode

The FSP200 starts up with all sensors disabled, waiting for the application processor (AP) to configure it.

6.1.1 Establishing Contact

After power up or reset the FSP200 will assert the interrupt (HOST_INTN) indicating that the reset routine has completed and that the FSP200 is ready for communication. A read from the FSP200 will return the initial SHTP advertisement packet. This packet details the SHTP channel assignments and packet length parameters (see [8] and [6]). Following the SHTP advertisement packet, the individual applications built in to the FSP200 will send a packet indicating they have left the reset state:

- The executable will issue a reset message on SHTP channel 1
- SH-2 will issue an unsolicited initialization message on SHTP channel 2

Beyond these initial messages the FSP200 will wait for configuration by the host.

7 Configuration

The FSP200 stores configuration parameters in flash. It uses the SH-2 records and FRS read and write messages. See [8] for details of the messages and records. Figure 18 lists the records used by the FSP200.

Record ID	Description
0x7979	Static calibration – AGM
0x4D4D	Nominal calibration – AGM
0x1F1F	Dynamic calibration
0xD3E2	MotionEngine power management
0x2D3E	System orientation
0x2D41	Primary accelerometer orientation
0x2D46	Gyroscope orientation
0xD7D7	Maximum fusion period
0x4B4B	Serial number
0x74B4	User record
0xD403	MotionEngine Time Source Selection
0xA1A4	Simple Calibration Configuration
0xA1A5	Nominal Simple Calibration Configuration

Figure 18: Existing FRS Records

8 Operation

When using the UART-SHTP host interface, operation of the FSP200 can be controlled by the host. The FSP200 follows the report and command definitions defined in [8]. The FSP200 supports a subset of those reports and commands while defining several new reports and commands of its own. In some cases, various fields in existing reports may not be used. These variations from [8] are explained in the following sections.

8.1 Application Reports and Commands

Figure 19 lists the reports used by the FSP200.

SHTP Channel	Direction	Report ID	Description
SH-2 Control	W	0xFE	Get Feature Request
SH-2 Control	W	0xFD	Set Feature Command
SH-2 Control	R	0xFC	Get Feature Response
Normal	R	0xFB	Base Timestamp Reference
SH-2 Control	W	0xF9	Product ID Request
SH-2 Control	R	0xF8	Product ID Response
SH-2 Control	W	0xF7	FRS Write Request
SH-2 Control	W	0xF6	FRS Write Data
SH-2 Control	R	0xF5	FRS Write Response
SH-2 Control	W	0xF4	FRS Read Request
SH-2 Control	R	0xF3	FRS Read Response
SH-2 Control	W	0xF2	Command Request
SH-2 Control	R	0xF1	Command Response
Normal	R	0x01	Accelerometer
Normal	R	0x02	Gyroscope
Normal	R	0x04	Linear Acceleration
Normal	R	0x06	Gravity
Normal	R	0x07	Uncalibrated Gyroscope
Normal	R	0x08	Game Rotation Vector
Normal	R	0x14	Raw Accelerometer
Normal	R	0x15	Raw Gyroscope
Normal	R	0x2B	Motion Request

Figure 19: Reports Used by the FSP200

The batch interval field in set feature command and get feature response is not used by the FSP200. In the set feature command, this field should be set to zero. In the set feature response, the FSP200 sets this field to zero.

Although the FSP200 does not support batching, the base timestamp reference report is still used. Using this report allows the timestamp interpretation for the FSP200 and other products using the SH-2 reports to be done identically.

Figure 20 lists the commands used by the FSP200.

Id	Name	Description
1	Errors	Command and Response to access error queue.
2	Counter	Command and Response to access counters.
3	Tare	Command and Response to operate on tare
4	Initialize	Reinitialize sensor hub components.
6	DCD	Command to save DCD.
7	ME CAL	Command and Response to configure ME Calibration.
8	Reserved	Deprecated.
9	DCD Save	Command to configure periodic saving of DCD.
10	Oscillator	Command to retrieve the oscillator type used in the clock system.
11	Clear DCD and Reset	Command to clear the in-memory DCD state and perform a chip reset.
12	Simple Cal	Command to control the simple calibration process.
14	Interactive Cal	Command to control interactive calibration.

Figure 20: Commands Used by the FSP200

For the Tare command, only tare now for the game rotation vector is supported.

8.2 Bootloader Reports and Commands

Commands for retrieving bootloader status and issuing bootloader commands from the application are documented in reference [8].

8.3 Persist Dynamic Calibration Data

The FSP200 stores updated Dynamic Calibration Data (DCD) to RAM frequently (every 5 seconds). At non-power-up reset, the hub will persist the last-stored DCD from RAM to FRS. To clear the DCD from RAM before system reset, use the Clear-DCD and Reset command (Figure 20).

For SHTP applications, the last stored DCD can be saved to FRS during operation through specific commands; the Save DCD request and the Configure Periodic DCD Save command (Figure 20).

9 Firmware Upgrade

9.1 Overview

The FSP200 supports in field firmware upgrades. Upgrades are performed by placing the FSP200 in bootloader mode and then performing a DFU operation. The FSP200 may be placed in bootloader mode by holding BOOTN low during reset or by issuing a “Reset to Bootloader” message, described below. When in bootloader mode, the FSP200 uses SHTP to communicate with the host. The SHTP advertisement for the bootloader is listed in Figure 21. The bootloader uses only one channel, control, for communications.

Tag	Tag Name	Value
1	GUID	10
8	AppName	Bootloader
6	NormalChannel	1
9	ChannelName	control

Figure 21: Bootloader SHTP Advertisement

9.2 Messages

The messages used to communicate with the bootloader are described below. Some messages may also be used with the SH-2 application get information about the bootloader or trigger a bootloader operation.

9.2.1 Message Types

The bootloader message types are listed below. All messages are supported by the bootloader. A subset of these messages is supported by the application.

Application Channel	Bootloader Channel	Direction	Report ID	Description
SH-2 Control	Bootloader Control	W	0xE1	Bootloader Product ID Request
SH-2 Control	Bootloader Control	R	0xE2	Bootloader Product ID Response
SH-2 Control	Bootloader Control	W	0xE3	Bootloader Operating Mode Request
	Bootloader Control	R	0xE4	Bootloader Operating Mode Response
SH-2 Control	Bootloader Control	W	0xE5	Bootloader Status Request
SH-2 Control	Bootloader Control	R	0xE6	Bootloader Status Response
	Bootloader Control	W	0xE7	Bootloader DFU Write Request
	Bootloader Control	R	0xE8	Bootloader DFU Write Response

Figure 22: Bootloader Report ID List

9.2.2 Message Descriptions

9.2.2.1 Bootloader Product ID Request

The bootloader product ID request is used to request product ID information from the FSP200 bootloader.

Byte	Description
0	Report ID = 0xE1
1	Reserved

Figure 23: Bootloader Product ID Request

9.2.2.2 Bootloader Product ID Response

The bootloader product ID response returns product ID information about the FSP200 bootloader.

Byte	Description
0	Report ID = 0xE2
1	Reserved
2	Reserved
3	Reserved
4	SW Part Number LSB
5	SW Part Number ...
6	SW Part Number ...
7	SW Part Number MSB
8	SW Version Patch LSB
9	SW Version Patch MSB
10	SW Version Minor
11	SW Version Major
12	SW Build Number LSB
13	SW Build Number ...
14	SW Build Number ...
15	SW Build Number MSB

Figure 24: Bootloader Product ID Response

SW Part Number: 32-bit value representing the software part number
 SW Version: software version major (8 bits). minor (8 bits). patch (16 bits)
 SW Build Number: 32-bit software build number

9.2.2.3 Bootloader Operating Mode Request

The bootloader operating mode request is used to request various operating modes of the FSP200 bootloader.

Byte	Description
0	Report ID = 0xE3
1	Bootloader Operating Mode ID

Figure 25: Bootloader Operating Mode Request

Operating Mode ID: 0 – Reset to bootloader Mode
 1 – Upgrade Application Mode; upgrade the application image in flash.
 2 – Validate Image Mode; validate an application image without updating the flash
 3 – Launch Application; launch the application image in flash.

9.2.2.4 Bootloader Operating Mode Response

The bootloader operating mode response reports the ID and the result of the operating mode last requested.

Byte	Description
0	Report ID = 0xE4
1	Bootloader Operating Mode ID
2	Status (0 – success, 1 – error)
3	Reserved

Figure 26: Bootloader Operating Mode Response

9.2.2.5 Bootloader Status Request

The bootloader status request is used to acquire the status of the FSP200 bootloader.

Byte	Description
0	Report ID = 0xE5
1	Reserved

Figure 27: Bootloader Status Request

9.2.2.6 Bootloader Status Response

The bootloader status response reports the status of the bootloader. The application and the bootloader would send status response messages in response to status request messages. The bootloader would also send status responses to the host when errors occurred.

The bootloader operating mode ID field shows the operating mode last requested; while the status code reports the status and the result of the current bootloader operation.

Byte	Description
0	Report ID = 0xE6
1	Bootloader Operating Mode ID (Section 8.2.2.3)
2	Reserved
3	Reserved
4	Bootloader Status LSB (Figure 29)
5	Bootloader Status ...
6	Bootloader Status ...
7	Bootloader Status MSB
8	Bootloader Error Codes LSB (Figure 30)
9	Bootloader Error Codes ...
10	Bootloader Error Codes ...
11	Bootloader Error Codes MSB

Figure 28: Bootloader Status Response

Bitmask	Status Code
0x00000000	No status update
0x00000001	Launch application
0x00000002	Launch bootloader
0x00000004	Upgrade operation started
0x00000008	Validate operation started
0x00000010	Internal application valid
0x00000020	Internal application invalid
0x00000040	DFU image valid
0x00000080	DFU image invalid
0x40000000	Error occurred. Refer to Error Code field for details.
0x80000000	Source of DFU status. 1 – Bootloader; 0 - Application

Figure 29: Bootloader Status Flags

Value	Error
0x00	No error
0x01	Unexpected command received
0x02	Invalid internal application
0x03	Flash erase error
0x04	Flash write error
0x05	Flash lock error
0x06	Flash overflow
0x07	Invalid DFU image type
0x08	Invalid DFU image size
0x09	Invalid DFU image version
0x0A	Incompatible hardware
0x0B	Reserved
0x0C	Reserved
0x0D	DFU image length mismatch
0x0E	Invalid application size in DFU image
0x0F	Invalid application CRC in DFU image
0x10	Invalid DFU image CRC
0x11	Invalid data payload length in request message
0x12	Invalid data offset in request message

Figure 30: Bootloader Error Codes

9.2.2.7 Bootloader DFU Write Request

The bootloader DFU write request is used to send the payload of the DFU image to the bootloader.

Byte	Description
0	Report ID = 0xE7
1	Length
2	Word Offset LSB
3	Word Offset MSB
4	Data0 LSB
5	Data0 ...
6	Data0 ...
7	Data0 MSB
8
N-3	Data# LSB
N-2	Data# ...
N-1	Data# ...
N	Data# MSB

Figure 31: Bootloader DFU Write Request

- Length:** Length of the DFU image payload in words. The maximum size of the payload is 16 words.
- Word Offset:** Offset, in 32-bit words, from the beginning of the DFU image indicating where in the file the data is to be written
- Data#:** 32-bit words of DFU image

9.2.2.8 Bootloader DFU Write Response

The bootloader DFU write response reports the status of the DFU write request.

Byte	Description
0	Report ID = 0xE8
1	Status (0 – success, 1 – error)
2	Word Offset LSB
3	Word Offset MSB

Figure 32: Bootloader DFU Write Response

9.3 Procedure

9.3.1 Enter Bootloader Mode

There are two ways to place the FSP200 in bootloader mode: hold the BOOTN signal low during system reset or issue a “Reset to Bootloader” operating mode request followed by a system reset. A bootloader status response message is sent shortly after startup to report the status of the device. The source bit in the status field of the status response message should be set to indicate that the device is running the bootloader.

9.3.2 Enter Device Firmware Upgrade Mode

9.3.2.1 Entering from Bootloader Mode

The FSP200 may be placed in upgrade application mode from bootloader mode by issuing an “Upgrade” operating mode request. The device issues an operating mode response to acknowledge the request. Once the device has switched to device firmware upgrade mode, a status response message is sent to report the status of the device.

9.3.2.2 Entering from Application Mode

The FSP200 may switch from the application to any one of the bootloader operating modes directly without explicitly switching to the bootloader first. The host application can issue an operating mode request to the application. The request is stored in RAM and processed during the next system reset.

9.3.3 Transfer Device Firmware Image

Device firmware image is transferred to the device in chunks through a sequence of Bootloader DFU write requests. The maximum size of firmware image payload for each request is 16 words.

After the device is placed in device firmware upgrade mode, the host software sends the device firmware image through DFU write requests. The bootloader issues a DFU write response message, reporting any errors, immediately after processing each DFU write request. Any DFU write request received before the bootloader responds to the previous write request is dropped.

When the end of the device firmware image is detected, the bootloader validates the newly programmed application image in flash and reports the status through a bootloader status response message.

If any error occurs while processing the device firmware image, the bootloader terminates the firmware upgrade process and notifies the host with a status response message. Any further write request are ignored.

The host may use the operating mode request to reset/switch the bootloader operating mode after the upgrade process is complete or terminated.

10 Characteristics

This section describes the electrical and performance characteristics of the FSP200. All the FSP200 I/O pins meet CMOS and TTL requirements.

10.1 Absolute Maximum Electrical Ratings

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

Parameter	Symbol	Conditions	Rating	Unit
Voltage at supply pin	V_{DD}		0 to 3.8	V
Voltage at any logic pin	V_{DIGPIN}		$V_{DD}+0.3$	V
Storage temperature	T_{STG}		-50 to +150	°C
Junction temperature	T_J		-40 to +105	°C

Figure 33: FSP200 Maximum Ratings

10.2 Recommended Operating Conditions

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Analog supply voltage	V_{AVDD}		1.85	3.3	3.8	V
Digital supply voltage	V_{DVDD}		1.62	3.3	V_{AVDD}	V
IO supply voltage	V_{IOVDD}		1.62	3.3	V_{AVDD}	V
Operating temperature			-40	-	85	°C

Figure 34: FSP200 Operating Conditions

10.3 Electrical Characteristics

The electrical characteristics of the FSP200 are listed below.

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Input high voltage	V_{IH}		$0.7 * V_{IOVDD}$	-	-	V
Input low voltage	V_{IL}		-	-	$0.3 * V_{IOVDD}$	V
Output high voltage	V_{OH}	$V_{IOVDD} > 3V, I_{OH}=3mA$	$0.8 * V_{IOVDD}$	-	-	V
Output low voltage	V_{OL}	$V_{IOVDD} > 3V, I_{OL}=3mA$			$0.2 * V_{IOVDD}$	V
POR Voltage threshold on VDD-IN rising	$V_{DVDDBOD}$	V_{DVDD} falling		1.62		V
POR Voltage threshold on VDD-IN falling	$V_{DVDDBOD}$	V_{DVDD} rising		1.35		V
Input leakage current	I_{LEAK}	GPIO except LFXO, GPIO $\leq V_{IOVDD}, T_{amb} \leq 85\text{ °C}$	-	0.1	30	nA
		LFXO, GPIO $\leq V_{IOVDD}, T_{amb} \leq 85\text{ °C}$	-	0.1	50	nA
CAL_PB asserted	t_{LOW}		50			nS
Crystal frequency	f_{LFXO}			32768		Hz
Crystal ESR	ESR_{LFXO}		-	-	70	kΩ
Crystal load capacitance	C_{LFXO_CL}		6	-	18	pF
Crystal start-up time	t_{LFXO}	ESR = 70 kΩ, $C_L = 7\text{ pF}$		308		ms

Figure 35: FSP200 Electrical Characteristics

10.4 Power Consumption

The power consumption of the FSP200 is dependent on the configuration of the device including the sample rates of various sensors and even the environment in which the device is being used. The table below provides typical

power consumption numbers for typical configurations. Measurements were taken with VDD at 3.0V. The clock source is an external crystal.

Function	Sensor Rate(Hz)	Current (mA)	Power (mW)
Idle Power (reset)	—	0.052	0.156
UART-RVC mode	100	2.313	6.939
Game Rotation vector	100	0.721	2.164
Game Rotation vector	400	1.830	5.491
Accelerometer	100	0.386	1.158
Accelerometer	400	0.951	2.851
Gyroscope	100	0.639	1.916
Gyroscope	400	1.472	4.414

Figure 36: FSP200 Power Consumption

10.5 Performance Characteristics

The performance of the FSP200 using the BMI055 sensor is as shown in Figure 37. For optimum performance, the gyroscope Z-axis must be calibrated for scale using simple calibration. See section 10.5.1.

Parameter	Performance Metric	Typical
Roll/Yaw	Resolution	0.01°
	Range	± 180 °
Pitch	Resolution	0.01°
	Range	± 90 °
Accelerometer	Range	± 8g
	Resolution	4 mg (12-bit)
	Noise density	150 µg/√Hz
	Scale error	1%
	Zero-g offset initial	70 mg
	Zero-g offset after dynamic calibration	20 mg
Gyroscope	Range	± 2000 °/s
	Resolution	0.06 °/s (16-bit)
	Noise density	0.014 °/s/√Hz
	Scale error @25°C uncalibrated	1%
	Z-axis scale error calibrated	0.3%
	Scale error over aging	0.7%
	Scale error over temperature	0.03 %/°C
	Offset after dynamic calibration	0.006 °/s
Startup time	UART reports from reset	1.2 s
Composite Sensor	Performance Metric	Typical
Gaming Rotation Vector	Non-heading Error - dynamic	2.5°
	Non-heading Error - static	1.0°
	Heading Drift – dynamic	0.16°/min(10°/hr) ¹
Gravity	Angle Error - static	1.0°
Linear Acceleration	Accuracy - dynamic	0.35 m/s ²

Figure 37: FSP200 Calibrated Performance Using BMI055

¹ After learning over temperature range of 22 °C to 45 °C and using interactive calibration.

The performance of the LSM6DSR is shown in Figure 38. For optimum performance, the gyroscope Z-axis must be calibrated for scale using simple calibration. See section 10.5.1.

Parameter	Performance Metric	Typical
Roll/Yaw	Resolution	0.01°
	Range	± 180°
Pitch	Resolution	0.01°
	Range	± 90°
Accelerometer	Range	± 8g
	Resolution	0.244 mg (16-bit)
	Noise density	60 µg/√Hz
	Scale error	1%
	Zero-g offset initial	40 mg
	Zero-g offset after dynamic calibration	20 mg
Gyroscope	Range	± 2000 °/s
	Resolution	0.07 °/s (16-bit)
	Noise density	0.007 °/s/√Hz
	Scale error @25°C uncalibrated	1%
	Z-axis scale error calibrated	0.2%
	Scale error over temperature	0.007 %/°C
	Offset after dynamic calibration	0.007 °/s
Startup time	UART reports from reset	1.3 s
Composite Sensor	Performance Metric	Typical
Gaming Rotation Vector	Non-heading Error - dynamic	2.5°
	Non-heading Error - static	1.0°
	Heading Drift - dynamic	0.2°/min ¹
Gravity	Angle Error - static	1.0°
Linear Acceleration	Accuracy - dynamic	0.35 m/s ²

Figure 38: FSP200 Calibrated Performance Using LSM6DSR

¹ After learning over temperature range of 22 °C to 45 °C and using interactive calibration.

The performance of the ICM42688P is shown in Figure 39. For optimum performance, the gyroscope Z-axis must be calibrated for scale using simple calibration. See section 10.5.1.

Parameter	Performance Metric	Typical
Roll/Yaw	Resolution	0.01°
	Range	± 180°
Pitch	Resolution	0.01°
	Range	± 90°
Accelerometer	Range	± 8g
	Resolution	0.25 mg (16-bit)
	Noise density	70 µg/√Hz
	Scale error	1%
	Zero-g offset initial	40 mg
	Zero-g offset after dynamic calibration	20 mg
Gyroscope	Range	± 2000 °/s
	Resolution	0.06 °/s (16-bit)
	Noise density	0.0028 °/s/√Hz
	Scale error @25°C uncalibrated	0.5%
	Z-axis scale error calibrated	0.2%
	Scale error over aging	0.3%
	Scale error over temperature	0.0066%
	Offset after dynamic calibration	0.025 °/s
Startup time	UART reports from reset	1.2 s
Composite Sensor	Performance Metric	Typical
Gaming Rotation Vector	Non-heading Error - dynamic	2.5°
	Non-heading Error - static	1.0°
	Heading Drift - dynamic	0.6°/min ¹
Gravity	Angle Error - static	1.0°
Linear Acceleration	Accuracy - dynamic	0.35 m/s ²

Figure 39: FSP200 Calibrated Performance Using ICM42688P

¹ After learning over temperature range of 22 °C to 45 °C and using interactive calibration.

10.5.1 Calibration

The FSP200 has a special mode, called simple calibration, allowing for Z-axis calibration. This mode may be entered via SHTP commands or it may be entered using the CAL_PB input signal. The progress and status of the calibration are reported via SHTP commands and the H_TX_LEDGRN and H_INT_LEDRED signals. See [5] for details.

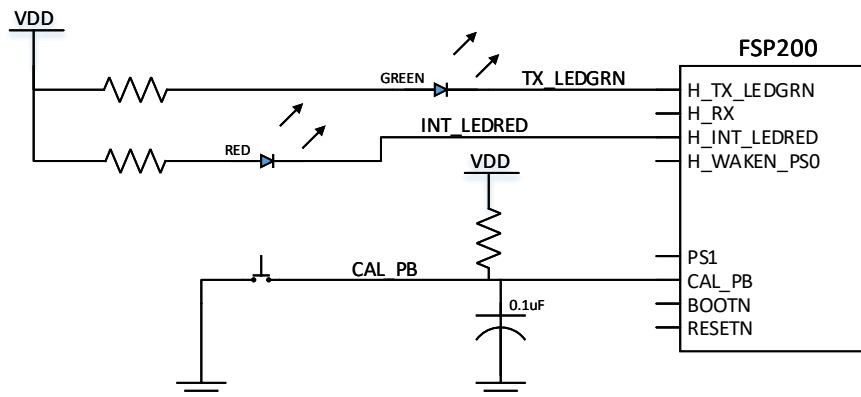


Figure 40: FSP200 Calibration Hardware Example

11 Packaging Information

11.1 QFN32 Package Dimensions

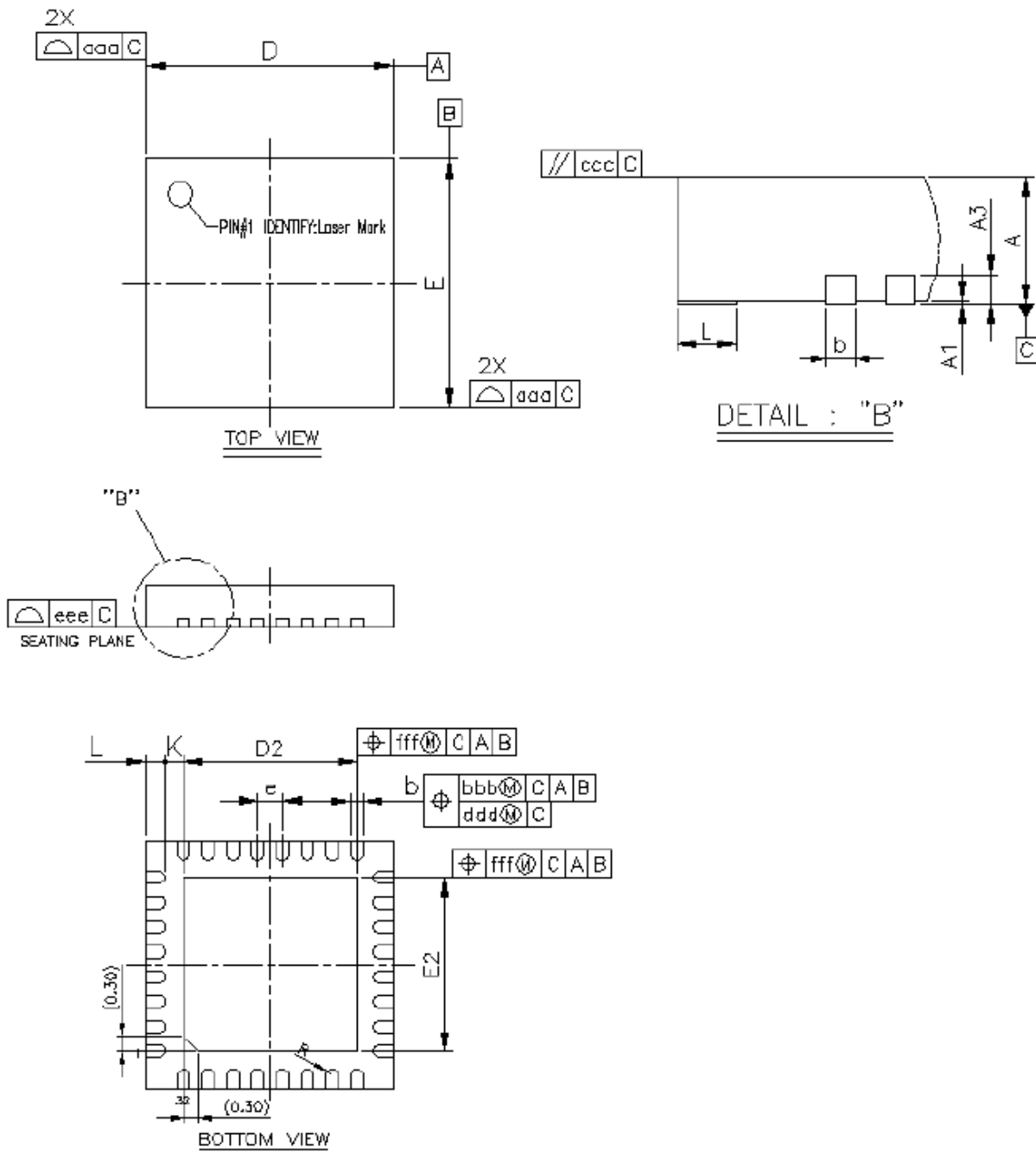


Figure 41: QFN32 Package Drawing

Dimension	Min	Typ	Max
A	0.80	0.85	0.90
A1	0.00	0.02	0.05
A3	0.20 REF		
b	0.18	0.25	0.30
D/E	4.90	5.00	5.10
D2/E2	3.40	3.50	3.60
E	0.50 BSC		
L	0.30	0.40	0.50
K	0.20	—	—
R	0.09	—	0.14
aaa	0.15		
bbb	0.10		
ccc	0.10		
ddd	0.05		
eee	0.08		
fff	0.10		
Note:			
<ol style="list-style-type: none"> 1. All dimensions shown are in millimeters (mm) unless otherwise noted. 2. Dimensioning and Tolerancing per ANSI Y14.5M-1994. 3. This drawing conforms to the JEDEC Solid State Outline MO-220, Variation VKKD-4. 4. Recommended card reflow profile is per the JEDEC/IPC J-STD-020 specification for Small Body Components. 			

Figure 42: QFN32 Package Dimensions

11.2 QFN32 PCB Land Pattern

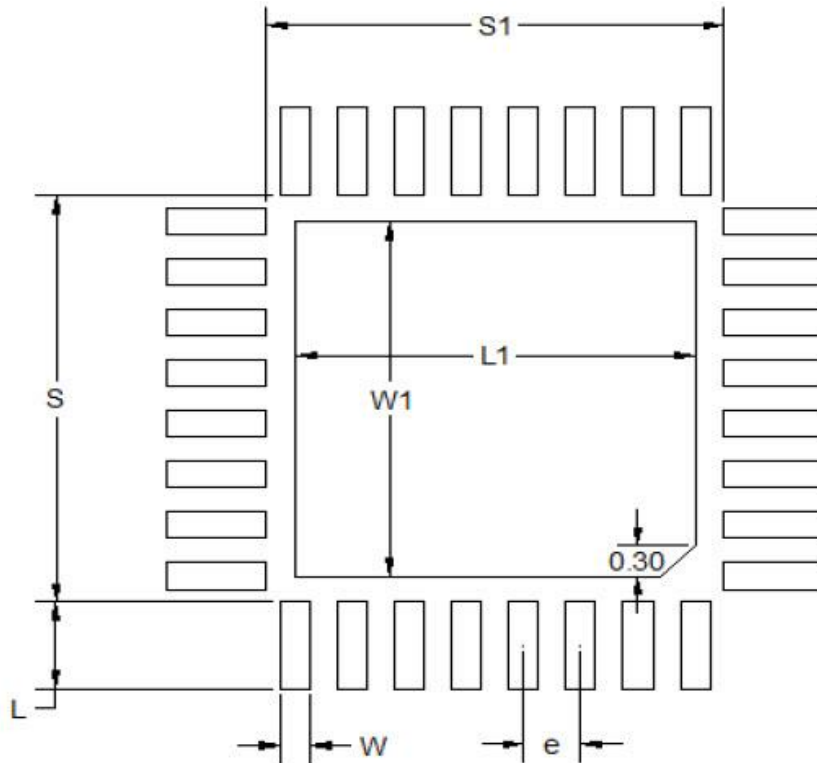


Figure 43: QFN32 PCB Land Pattern Drawing

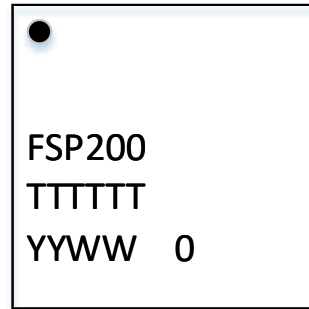
Dimension	Typ
S1	4.01
S	4.01
L1	3.50
W1	3.50
e	0.50
W	0.26
L	0.86

Note:

1. All dimensions shown are in millimeters (mm) unless otherwise noted.
2. This Land Pattern Design is based on the IPC-7351 guidelines.
3. All metal pads are to be non-solder mask defined (NSMD). Clearance between the solder mask and the metal pad is to be 60 μm minimum, all the way around the pad.
4. A stainless steel, laser-cut and electro-polished stencil with trapezoidal walls should be used to assure good solder paste release.
5. The stencil thickness should be 0.125 mm (5 mils).
6. The ratio of stencil aperture to land pad size can be 1:1 for all perimeter pads.
7. A 3x3 array of 0.85 mm square openings on a 1.00 mm pitch can be used for the center ground pad.
8. A No-Clean, Type-3 solder paste is recommended.
9. The recommended card reflow profile is per the JEDEC/IPC J-STD-020 specification for Small Body Components.

Figure 44: QFN32 PCB Land Dimensions

11.3 Marking



TTTTTT – manufacturing code

YY – the last two digits of the assembly year

WW – the two digit work week when the device was assembled

0 - reserved

Figure 45: FSP200 QFN32 Package Marking

11.4 Soldering Guidelines

The moisture sensitivity level of the FSP200 sensors corresponds to JEDEC Level 1, see also

- IPC/JEDEC J-STD-020C "Joint Industry Standard: Moisture/Reflow Sensitivity Classification for non-hermetic Solid State Surface Mount Devices"
- IPC/JEDEC J-STD-033A "Joint Industry Standard: Handling, Packing, Shipping and Use of Moisture/Reflow Sensitive Surface Mount Devices"

The sensor fulfils the lead-free soldering requirements of the above-mentioned IPC/JEDEC standard, i.e. reflow soldering with a peak temperature up to 260°C.

11.5 Compliance

11.5.1 RoHS

The FSP200 is compliant with the European Union Directive 2015/863/EU for the Restriction of the use of Hazardous Substances in Electrical and Electronic Equipment (RoHS2) and China's Administrative Measure on the Control of Pollution Caused by Electronic Information Products (China RoHS).

No Lead (Pb), Cadmium (Cd), Mercury (Hg), Hexavalent Chromium (Cr+6), PBB, PBDE, DEHP, BBP, DBP, or DIMP is intentionally added to this device. Any trace impurities of these substances contained in the part are below the RoHS specified threshold levels:

Cr+6, Hg, Pb, PBB's, PBDE's, DEHP, BBP, DBP, DIBP < 1000ppm

Cd < 100ppm

11.5.2 Halogen

The FSP200 is Halogen-Free. No Bromine (Br) or Chlorine (Cl) based flame retardants have been intentionally added to this device, their individual levels are < 900 ppm, and the total impurity level of these elements is < 1500 ppm.

Therefore:

Br < 900 ppm

Cl < 900 ppm

Br + Cl < 1500 ppm

11.5.3 PFOS/PFOA Compliant

The FSP200 is compliant with the European Marketing and Use Directive 2006/122/EC for the restriction of the use of PFOS (PerFluoroOctane Sulfonate). No PFOS is intentionally added to this device and any trace of impurity of PFOS contained in this part is below the specified threshold level:

PFOS < 1000 ppm (Measured at Homogenous Material Level)

In addition, this device does not intentionally add PFOA (PerFluoro-Octanoic Acid). Threshold levels for PFOA have not yet been established as the use of this substance is not currently restricted. However, several worldwide environmental bodies are considering future restrictions on the use of PFOA.

11.5.4 REACH Compliant

The FSP200 is REACH compliant (Declaration for Substances of Very High Concern) Regulation (EC) No 1907/2006, SVHC list 174 substances updated 7 JUL 2017. Contact Hillcrest Labs for full report.

12 FSP200 Example Design

12.1 Schematic

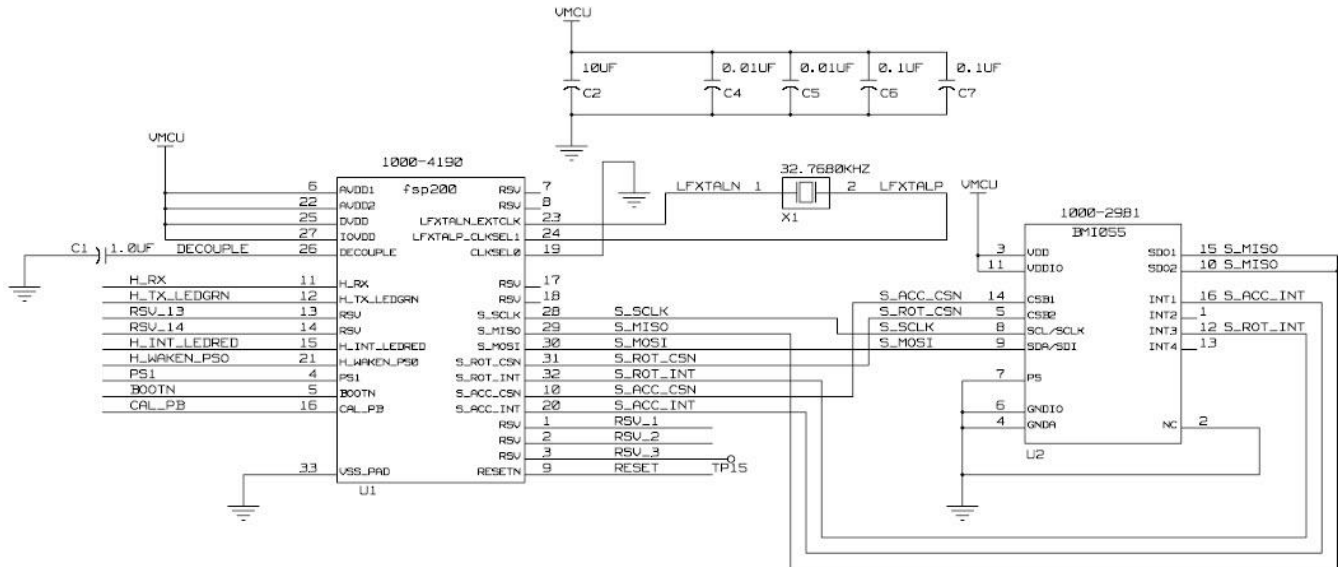


Figure 46: FSP200 Example Schematic

12.2 Bill of Materials

Item	P/N	Qty	Title	Detail	Reference(m)	Mfr	Mfr P/N
1	1000-0409	2	Ceramic Capacitor	0.01uF:25V::10%	C4,C5	Yageo Corporation	CC0402KRX7R8BB103
2	1000-0452	2	Ceramic Capacitor	0.1uF:10V::10%	C6,C7	Taiyo Yuden Co., Ltd	LMK105BJ104KV-F
3	1000-2410	1	Ceramic Capacitor	10uF:6.3V::20%	C2	TDK	C1608X5R0J106M
4	1000-2981	1	Tri Axis Gyro, Tri Axis Accelerometer, BMI055	:2.4-3.6V::	U2	Bosch	BMI055
5	1000-3384	1	Ceramic Capacitor	1.0uF:10V::10%	C1	TDK	C1005X5R1A105K050BB
6	1000-4140	1	Crystal, 12.5pF, SMT	32.7680KHz:::1uW:20ppm	X1	Abracon Corporation	ABS06-32.768KHZ-T
7	1000-4174	0	Schematic, FSP200, BMI055, Ref Module				
8	1000-4175	1	PCB, FSP200, BMI055, Ref Module				
9	1000-4176	0	Assy Drawing, FSP200, BMI055, Ref Module				
10	1000-4190	1	FSP200	6 axis IMU processor	U1	Hillcrest Laboratories, Inc.	FSP200

Figure 47: FSP200 Example BOM

13 Version History

Version	Changes	Date
1.5	Correct pitch and roll axes in section 2.1.2. Update document to include ICM42688P. Add section 6 "Startup Messages". Correct SW version fields in Figure 24. Correct report ID in Figure 31 and Figure 32.	September 16, 2022
1.4	Update logos and formatting.	September 23, 2019
1.3	Add basic information about UART-RVC-LOG mode. Remove negative sign for Z-acceleration in section 2.1.2. Replace BMI160 with LSM6DSR. Add interactive calibration reports and commands to section 8.1.	May 20, 2019
1.2	Clarified which pins have internal pullups/pulldowns. Added autobaud feature.	July 17, 2018
1.1	Fixed minor typographical errors. Update directions in Figure 19. Update heading drift specifications.	April 10, 2018
1.0	Removed ARVR stabilized GRV. Specified sensor orientations. Added Simple Calibration Configuration records to Figure 18. Updated sensor startup times in section 10.5.	December 11, 2017
0.2	Preliminary release	October 20, 2017

14 References

1. BMI055 datasheet, Bosch Sensortec.
2. LSM6DSR datasheet, STMicroelectronics.
3. ICM42688P datasheet, InvenSense.
4. 1000-4154 Application Note: FSP200 Tare, Hillcrest Labs.
5. 1000-4155 Application Note: FSP200 Simple Calibration, Hillcrest Labs.
6. 1000-3535 Sensor Hub Transport Protocol, Hillcrest Labs.
7. 1000-3600 SH-2 SHTP Reference Manual, Hillcrest Labs.
8. 1000-3625 SH-2 Reference Manual, Hillcrest Labs.
9. 1000-4269 Application Note: FSP200 RVC Data Logging, Hillcrest Labs.

15 Notices

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