

## Overview

The FSM30X is a compact IMU module based on Hillcrest's BNO080 9-axis SiP. The FSM30X incorporates the BNO080, a 32.768 kHz crystal and passive components into a compact module form factor that can be quickly and easily integrated into a design. The FSM30X provides all the motion based outputs available on the BNO080. It does not support environmental sensors. The BNO080 datasheet is reference [3].

## Pinout

The pinout of the FSM30X is shown in Figure 1.

|   |             |              |      |
|---|-------------|--------------|------|
| 1 | ■ VDD       | NRST         | ■ 18 |
| 2 | ■ GND       | RSVR         | ■ 17 |
| 3 | ■ RSVR      | RSVR         | ■ 16 |
| 4 | ■ RSVR      | CSN          | ■ 15 |
| 5 | ■ HINTN     | SA0/MOSI     | ■ 14 |
| 6 | ■ BOOTN     | RSVR         | ■ 13 |
| 7 | ■ PS1       | SCL/SCK/RXD  | ■ 12 |
| 8 | ■ GND       | SDA/MISO/TXD | ■ 11 |
| 9 | ■ PS0/WAKEN | RSVR         | ■ 10 |

**Figure 1: FSM30X Module**

A description of each pin is listed in Figure 2. For pins with internal pullups/pulldowns the value of the pullup resistor is 34 k $\Omega$  and the value of the pulldown resistor is 6.2 k $\Omega$ .

| Pin Number | Name         | Mode          | Description   |
|------------|--------------|---------------|---|
| 1          | VDD          | Input         | Supply voltage (2.4V to 3.6V)   |
| 2          | GND          | Input         | Ground  |
| 3          | Reserved     | NC            | Reserved. Do Not Connect  |
| 4          | Reserved     | NC            | Reserved. Do Not Connect  |
| 5          | HINTN        | Output        | Host interrupt  |
| 6          | BOOTN        | Input         | Bootloader mode selection. Internal pullup.                                 |
| 7          | PS1          | Input         | Protocol select 1. Internal pulldown.                                       |
| 8          | GND          | Input         | Ground  |
| 9          | PS0_WAKEN    | Input         | Protocol select 0. SPI mode processor wake input. Internal pullup.          |
| 10         | Reserved     | NC            | Reserved. Do Not Connect  |
| 11         | SDA/MISO/TXD | Bidirectional | Host Interface I <sup>2</sup> C data, SPI data output or UART transmit data |
| 12         | SCL/SCK/RXD  | Bidirectional | Host Interface I <sup>2</sup> C clock, SPI clock or UART receive data       |
| 13         | Reserved     | NC            | Reserved. Do Not Connect  |
| 14         | SA0/MOSI     | Input         | Lower address bit of I2C device address. SPI data input. Internal pulldown. |
| 15         | CSN          | Input         | SPI chip select   |
| 16         | Reserved     | NC            | Reserved. Do Not Connect  |
| 17         | Reserved     | NC            | Reserved. Do Not Connect  |
| 18         | NRST         | Input         | Reset. Internal pullup.   |

**Figure 2: FSM30X Pin Descriptions**

### Host Interface Connectivity

The FSM30X supports all four of the host interfaces implemented by the BNO080. Schematics showing typical connections for each interface are shown in the following figures.

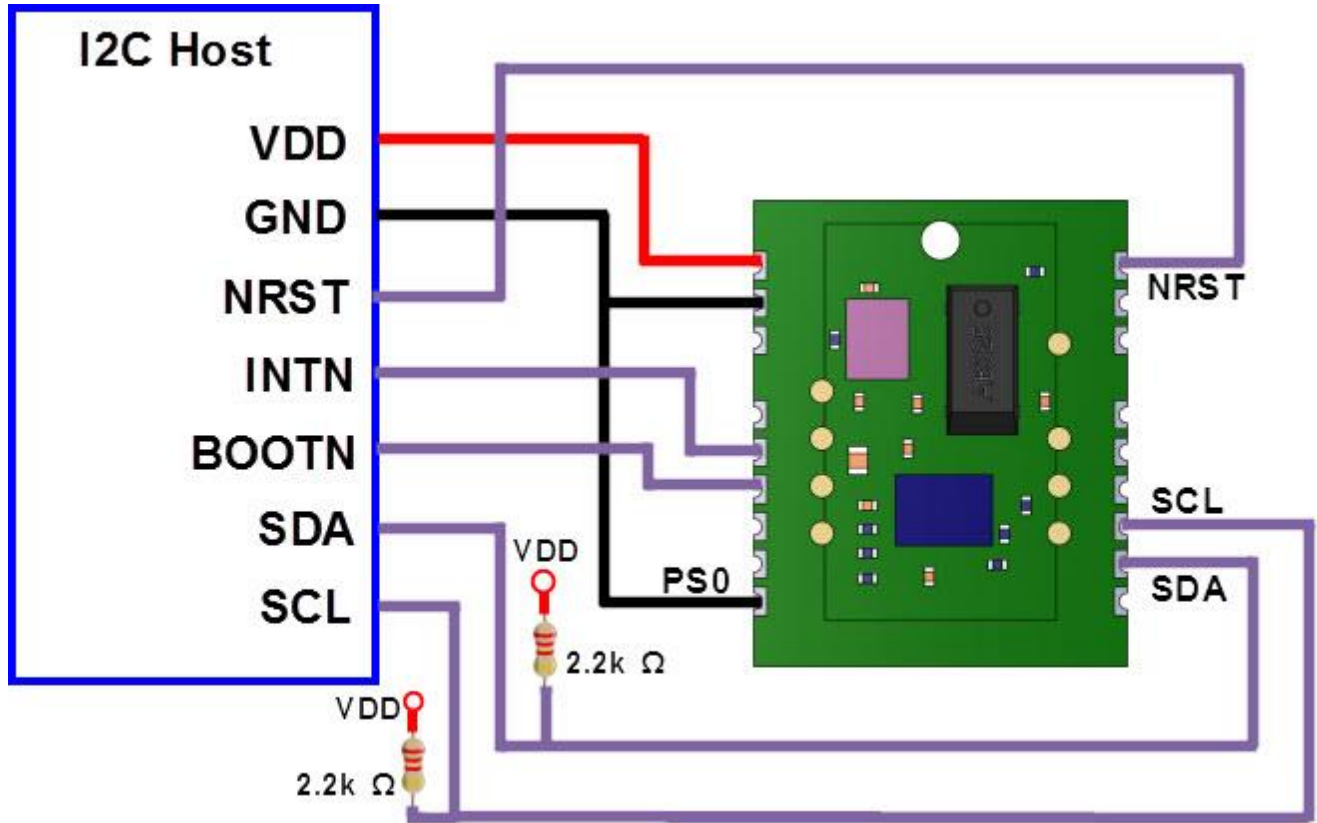


Figure 3: I2C Connection Example

As shown in Figure 3, the I2C bus requires pullup resistors. The value of these resistors should be in the range of 2.2 kΩ to 4.7 kΩ.

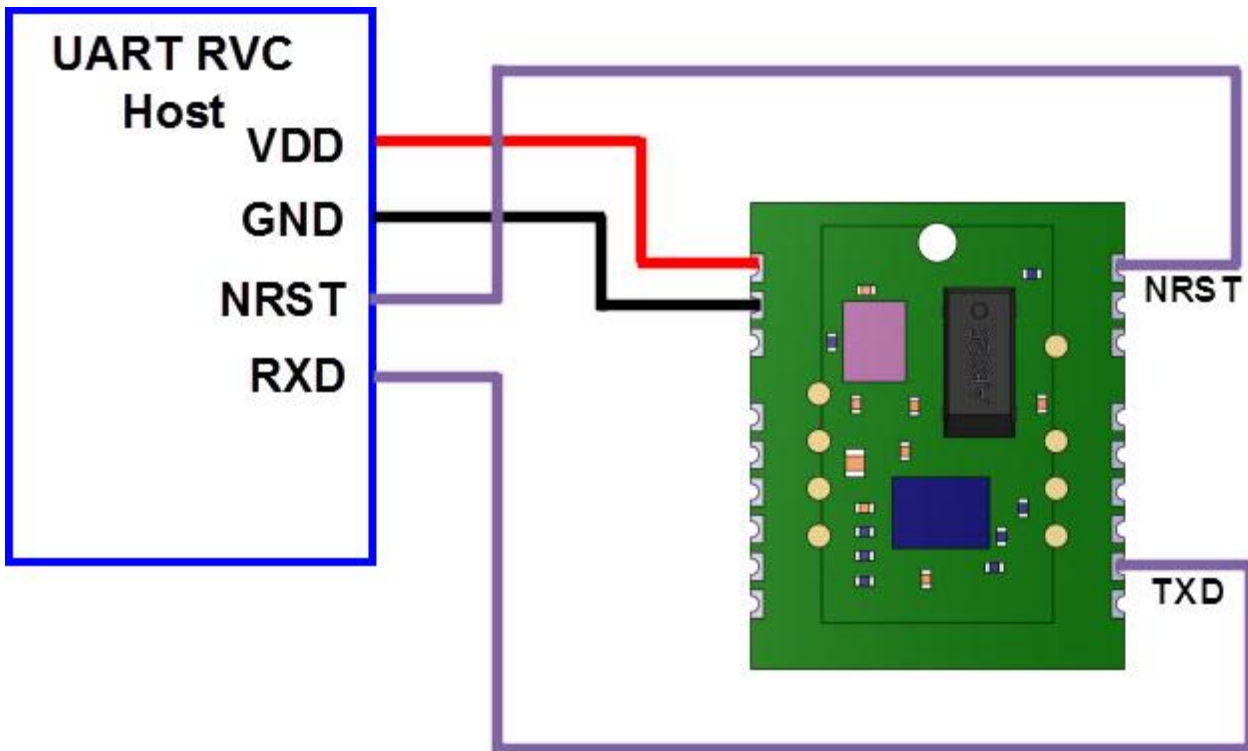


Figure 4: UART-RVC Connection Example

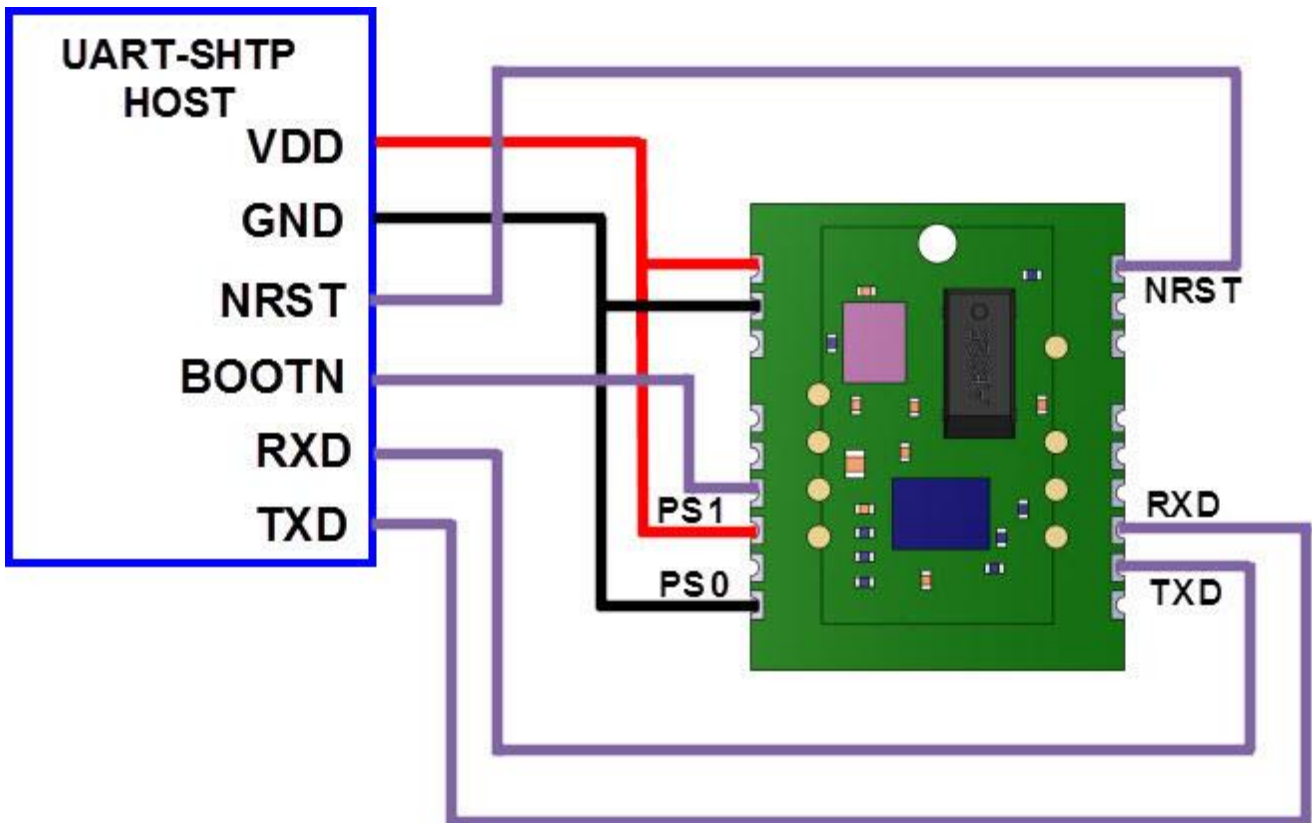


Figure 5: UART-SHTP Connection Example

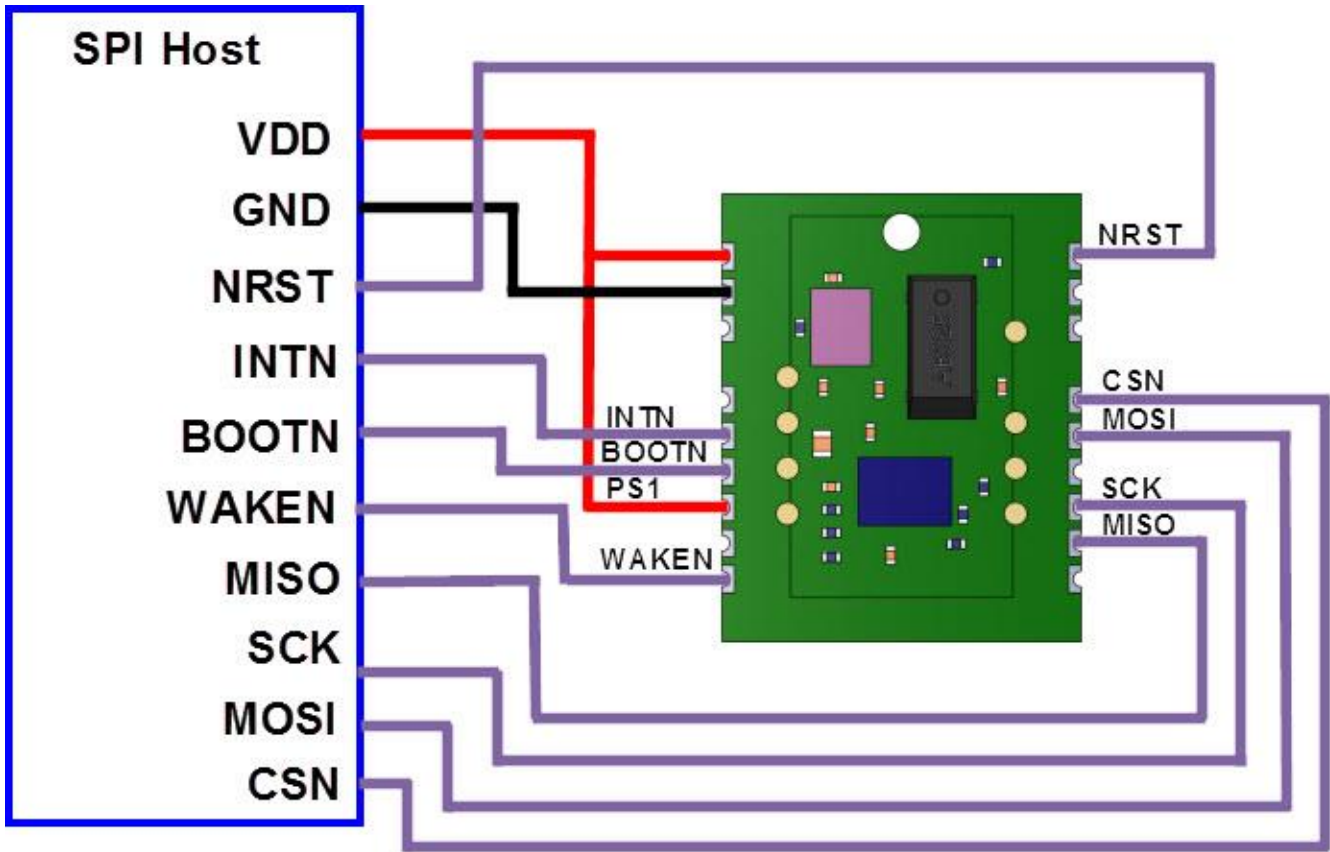


Figure 6: SPI Connection Example

### FSM30X Coordinate System

The coordinate system for the FSM30X is shown in Figure 7. It is a right-handed coordinate system. Positive rotations are counter-clockwise.

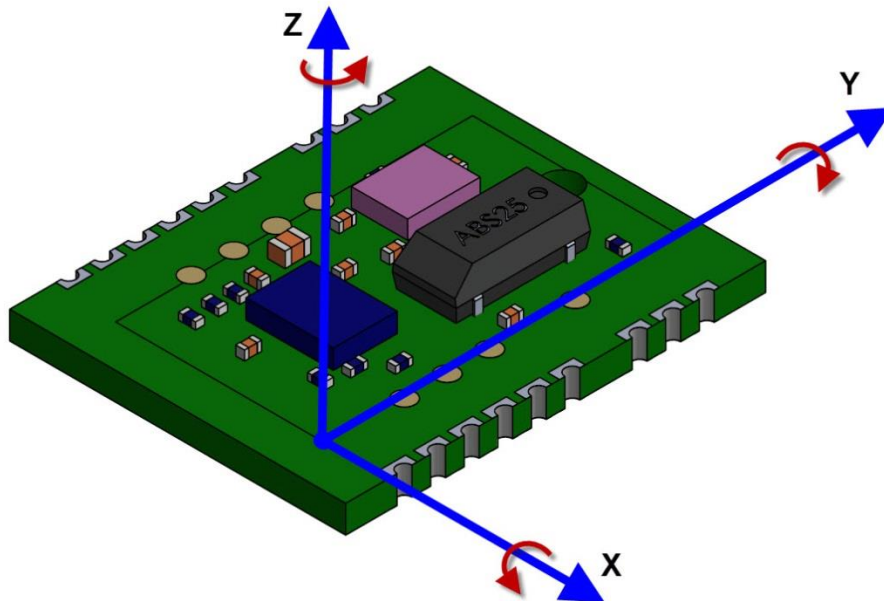


Figure 7: Coordinate System

## FSM30X Characteristics

This section describes the electrical and performance characteristics of the FSM30X. All the FSM30X I/O pins meet CMOS and TTL requirements.

Note that the electrical and mechanical sections of the specification reported here are reproduced from the Bosch Sensortec BMF055 datasheet. The data in this section is reported for convenience, the reader is encouraged to consult the BMF055 datasheet [1] to verify all parameters.

### 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    | $V_{DD}$                      |                              | -0.3 to 3.63 | V    |
| Voltage at any logic pin | $V_{non-supply}$              |                              | $V_{DD}+0.3$ | V    |
| Storage temperature      | $T_{rps}$                     |                              | -50 to +150  | °C   |
| Mechanical shock         | MechShock <sub>200µs</sub>    | Duration ≤ 200µs             | 10,000       | g    |
|                          | MechShock <sub>1ms</sub>      | Duration ≤ 1.0ms             | 2,000        | g    |
|                          | MechShock <sub>kreefall</sub> | Free fall onto hard surfaces | 1.8          | m    |
| ESD                      | ESD <sub>HBM</sub>            | HBM at any pin               | 2            | kV   |
|                          | ESD <sub>CDM</sub>            | CDM                          | 500          | V    |
|                          | ESD <sub>MM</sub>             | MM                           | 200          | V    |

Figure 8: FSM30X Maximum Ratings

### Recommended Operating Conditions

| Parameter             | Symbol   | Conditions | Min | Typ | Max | Unit |
|-----------------------|----------|------------|-----|-----|-----|------|
| Supply voltage        | $V_{DD}$ |            | 2.4 |     | 3.6 | V    |
| Operating temperature |          |            | -40 |     | 85  | °C   |

Figure 9: FSM30X Operating Conditions

### Electrical Characteristics

| Parameter                               | Symbol         | Conditions                        | Min  | Typ  | Max  | Unit     |
|---|----------------|-----------------------------------|------|------|------|----------|
| Input high voltage                      | $V_{IH}$       | $V_{DD}=2.4-2.7V$                 | 0.7  |      |      | $V_{DD}$ |
|   |                | $V_{DD}=2.7-3.6V$                 | 0.55 |      |      | $V_{DD}$ |
| Input low voltage                       | $V_{IL}$       | $V_{DD}=2.4-2.7V$                 |      |      | 0.25 | $V_{DD}$ |
|   |                | $V_{DD}=2.7-3.6V$                 |      |      | 0.3  | $V_{DD}$ |
| Output high voltage                     | $V_{OH}$       | $V_{DD} > 3V$ , $I_{OH}=10mA$     | 0.8  | 0.9  |      | $V_{DD}$ |
| Output low voltage                      | $V_{OL}$       | $V_{DD} > 3V$ , $I_{OL}=20mA$     |      | 0.1  | 0.2  | V        |
| POR Voltage threshold on VDD-IN rising  | $V_{DD\_POT+}$ | $V_{DD}$ falls at 1V/ms or slower |      | 1.45 |      | V        |
| POR Voltage threshold on VDD-IN falling | $V_{DD\_POT-}$ |                                   |      | 0.99 |      | V        |

Figure 10: FSM30X Electrical Characteristics

### Mechanical Characteristics

The sensors within the FSM30X are specified by Bosch Sensortec. The mechanical and electrical details of the raw sensors are specified in the BMF055 datasheet [1].

## Performance Characteristics

### FSM300

Each FSM300 module is calibrated for Z-axis gyro scale. This calibration improves the heading performance of the UART-RVC output. Figure 11 captures the performance of the FSM300's heading performance.

| Parameter                        | Performance Metric               | Typical            | Max                   |
|----------------------------------|----------------------------------|--------------------|-----------------------|
| Roll/Yaw                         | Resolution                       | 0.01°              |                       |
|                                  | Range                            | +/- 180°           |                       |
| Pitch                            | Resolution                       | 0.01°              |                       |
|                                  | Range                            | +/- 90°            |                       |
| Accelerometer                    | Range                            | +/- 2g             |                       |
|                                  | Resolution                       | 1 mg               |                       |
|                                  | Scale error                      | 1%                 | 4%                    |
|                                  | Zero-g offset                    | 20 mg              |                       |
| Gyroscope                        | Range                            | +/- 2000 °/s       |                       |
|                                  | Resolution                       | 0.1 °/s            |                       |
|                                  | Z-axis scale error @25°C         | 0.3%               | 1%                    |
|                                  | X/Y-axis scale error @25°C       | 1%                 | 3%                    |
|                                  | Scale error over temperature     | 0.03 %/°C          | 0.07 %/°C             |
|                                  | Z-axis gyro ZRO after stationary | 0.01 °/s           |                       |
| Z-axis gyro ZRO over temperature | 0.0017 °/s/°C                    | 0.0043 °/s/°C      |                       |
| Startup time                     | UART reports from reset          | 125ms              |                       |
| Composite Sensor                 | Measurement                      | Performance Metric | Typical               |
| Rotation Vector                  | Dynamic                          | Rotation Error     | 3.5°                  |
|                                  | Static                           | Rotation Error     | 1.0°                  |
| Gaming Rotation Vector           | Dynamic                          | Non-heading Error  | 2.5°                  |
|                                  | Static                           | Non-heading Error  | 1.0°                  |
|                                  | Dynamic                          | Heading Drift      | 0.5°/min              |
| Geomagnetic Rotation Vector      | Dynamic                          | Rotation Error     | 4.5°                  |
|                                  | Static                           | Rotation Error     | 1.0°                  |
| Gravity                          | Static                           | Angle Error        | 1.0°                  |
| Linear Acceleration              | Dynamic                          | Accuracy           | 0.35 m/s <sup>2</sup> |
| Magnetometer                     | Dynamic                          | Accuracy           | 1.4uT                 |

**Figure 11: FSM300 UART-RVC Performance**

The gyro ZRO is the zero-rate offset and is the constant offset that is reported by the gyro when at rest. ZRO is constantly evaluated and corrected. The heading error estimate will vary in the short term based on gyro scale (or sensitivity) error and in the long term by the gyro ZRO.

For planar motions that only rotate about the Z-axis, the heading error can be determined from the following:

Heading Error Estimate = ScaleError \* NonCancellingRotations + ZROError \* time.

A cancelling rotation is a rotation in one direction followed by an opposite rotation. The result of the two rotations is that they cancel the effect of the scale error, hence any error attributable to scale is a function of the number of rotations in one direction being greater than in the opposite direction.

### FSM305

Each FSM305 module is calibrated for 3D motion. This calibration improves performance across all outputs. Figure 12 captures the performance of the FSM305 when using an external clock or crystal.

| Composite Sensor            | Measurement | Performance Metric | Typical               |
|-----------------------------|-------------|--------------------|-----------------------|
| Rotation Vector             | Dynamic     | Rotation Error     | 3.0°                  |
|                             | Static      | Rotation Error     | 1.0°                  |
| Gaming Rotation Vector      | Dynamic     | Non-heading Error  | 2.3°                  |
|                             | Static      | Non-heading Error  | 1.0°                  |
|                             | Dynamic     | Heading Drift      | 0.5°/min              |
| Geomagnetic Rotation Vector | Dynamic     | Rotation Error     | 3.5°                  |
|                             | Static      | Rotation Error     | 1.0°                  |
| Gravity                     | Static      | Angle Error        | 1.0°                  |
| Linear Acceleration         | Dynamic     | Accuracy           | 0.3 m/s <sup>2</sup>  |
| Accelerometer               | Dynamic     | Accuracy           | 0.12 m/s <sup>2</sup> |
| Gyroscope                   | Dynamic     | Accuracy           | 2.0°/s                |
| Magnetometer                | Dynamic     | Accuracy           | 1.4uT                 |

**Figure 12: FSM305 Performance**

The results above were generated by simulation. 210 physical devices were characterized and each of these models was subjected to simulated motion and the variation from truth catalogued. The rotation vector and geomagnetic rotation vector are highly dependent on the environmental conditions (specifically the magnetic field). In practice the rotation vector is typically accurate to 5° and the geomagnetic rotation vector to 10°.

## Power Consumption

The power consumption of the FSM30X 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.



| Function                    | Sensor Rate(Hz) | Current (mA) | Power (mW) |
|-----------------------------|-----------------|--------------|------------|
| Idle Power (reset)          | —               | 0.479        | 1.437      |
| UART-RVC mode               | 100             | 19.230       | 57.690     |
| Rotation vector             | 100             | 11.431       | 34.293     |
| Rotation vector             | 400             | 15.372       | 46.116     |
| Game rotation vector        | 100             | 11.411       | 34.233     |
| Geomagnetic rotation vector | 100             | 7.973        | 23.920     |
| Accelerometer               | 125             | 2.196        | 6.587      |
| Accelerometer               | 500             | 7.197        | 21.592     |
| Gyroscope                   | 100             | 11.094       | 33.283     |
| Gyroscope                   | 400             | 14.965       | 44.894     |
| Magnetometer                | 100             | 6.805        | 20.414     |
| Gyro rotation vector        | 400             | 15.377       | 46.130     |
| Gyro rotation vector        | 1000            | 16.268       | 48.805     |
| Significant motion          | On              | 0.900        | 2.700      |
| Step detector               | On              | 0.976        | 2.929      |
| Tap detector                | On              | 0.619        | 1.853      |
| Shake detector              | On              | 0.855        | 2.566      |
| Stability classifier        | 100             | 11.127       | 33.380     |
| Stability detector          | On              | 0.632        | 1.895      |

**Figure 13: Power Consumption**

# Packaging Information

## Package Outline

The FSM30X is available in an 18-pin PCB module (20mm x 25mm) Units are in mm [inch]

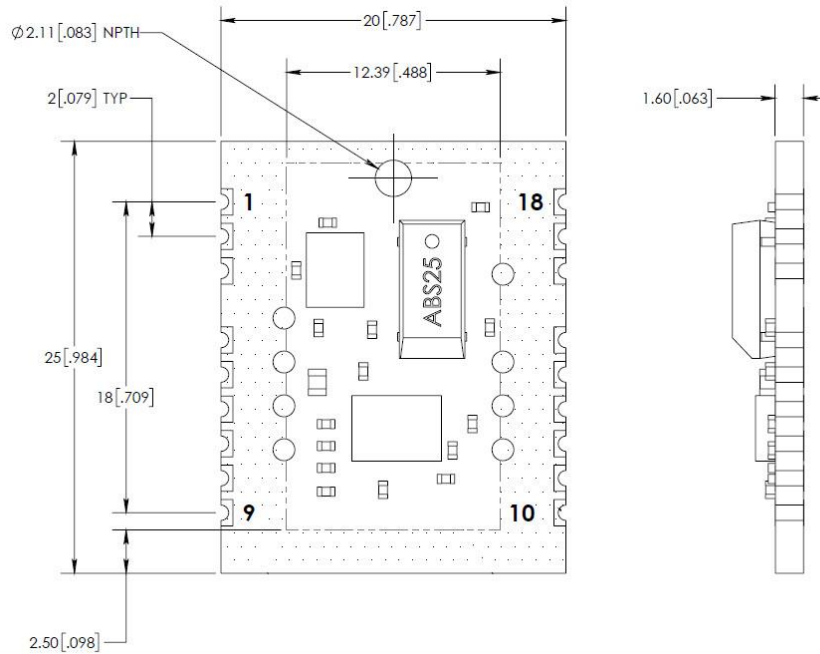


Figure 14: 18 pin module package outline (Top and Side View)

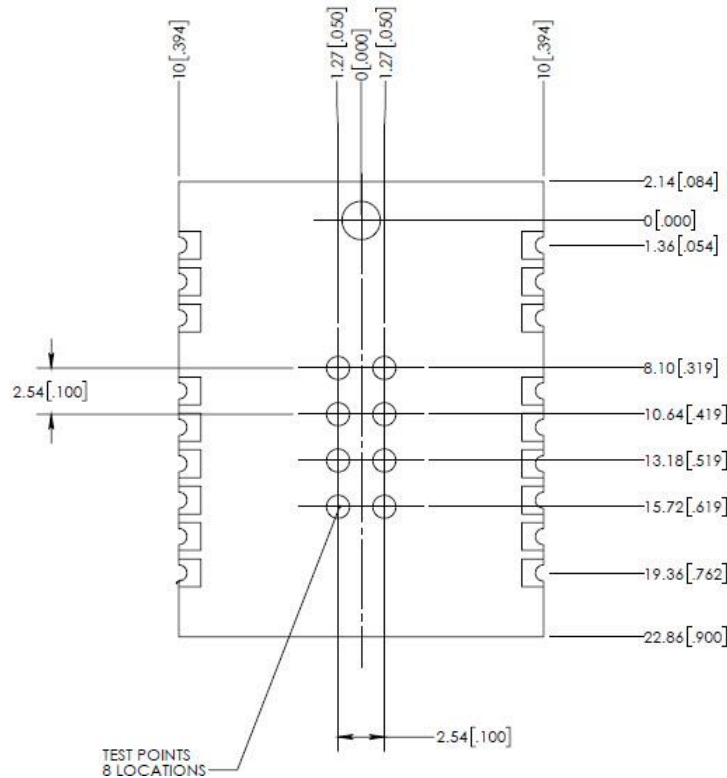
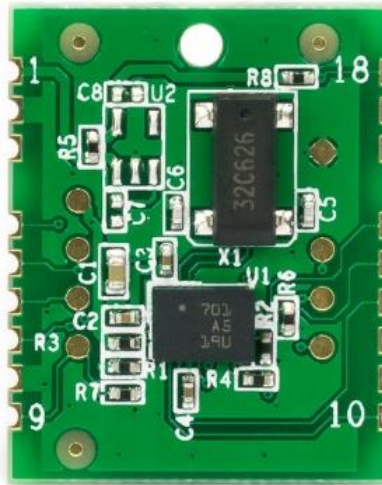


Figure 15: 18 pin module package outline (Bottom View)

## Marking

The module pin identifiers are marked at each corner pin location.



| Symbol | Name              | Remark    |
|--------|-------------------|-----------|
| 1      | Pin 1 identifier  | VDD       |
| 9      | Pin 9 identifier  | PS0_WAKEN |
| 10     | Pin 10 identifier | RESERVED  |
| 18     | Pin 18 identifier | NRST      |

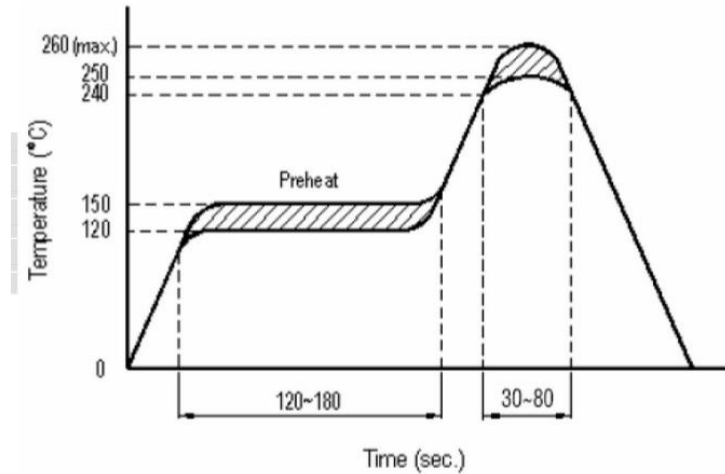
**Figure 16: Module pin identifiers markings**

## Soldering Guidelines

The moisture sensitivity level of the BNO080 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 recommended solder reflow profile is shown below.



**Figure 17: Recommended solder reflow profile**

## Handling Instructions

Micromechanical sensors are designed to sense acceleration with high accuracy even at low amplitudes and contain highly sensitive structures inside the sensor element. The MEMS sensor can tolerate mechanical shocks up to several thousand g's. However, these limits might be exceeded in conditions with extreme shock loads such as e.g. hammer blow on or next to the sensor, dropping of the sensor onto hard surfaces etc.

We recommend avoiding g-forces beyond the specified limits during transport, handling and mounting of the sensors in a defined and qualified installation process.

This device has built-in protections against high electrostatic discharges or electric fields (e.g. 2kV HBM); however, anti-static precautions should be taken as for any other CMOS component. Unless otherwise specified, proper operation can only occur when all terminal voltages are kept within the supply voltage range. Unused inputs must always be tied to a defined logic voltage level.

For more details on recommended handling, soldering and mounting please contact Hillcrest Labs and ask for the "Handling, soldering and mounting instructions" document [2]

## Environmental Safety

The BNO080 sensor meets the requirements of the EC restriction of hazardous substances (RoHS and RoHS2) directive, see also:

- Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

## Halogen content

The BNO080 is halogen-free. For more details on the analysis results please contact Hillcrest Labs.

# FSM30X Schematic

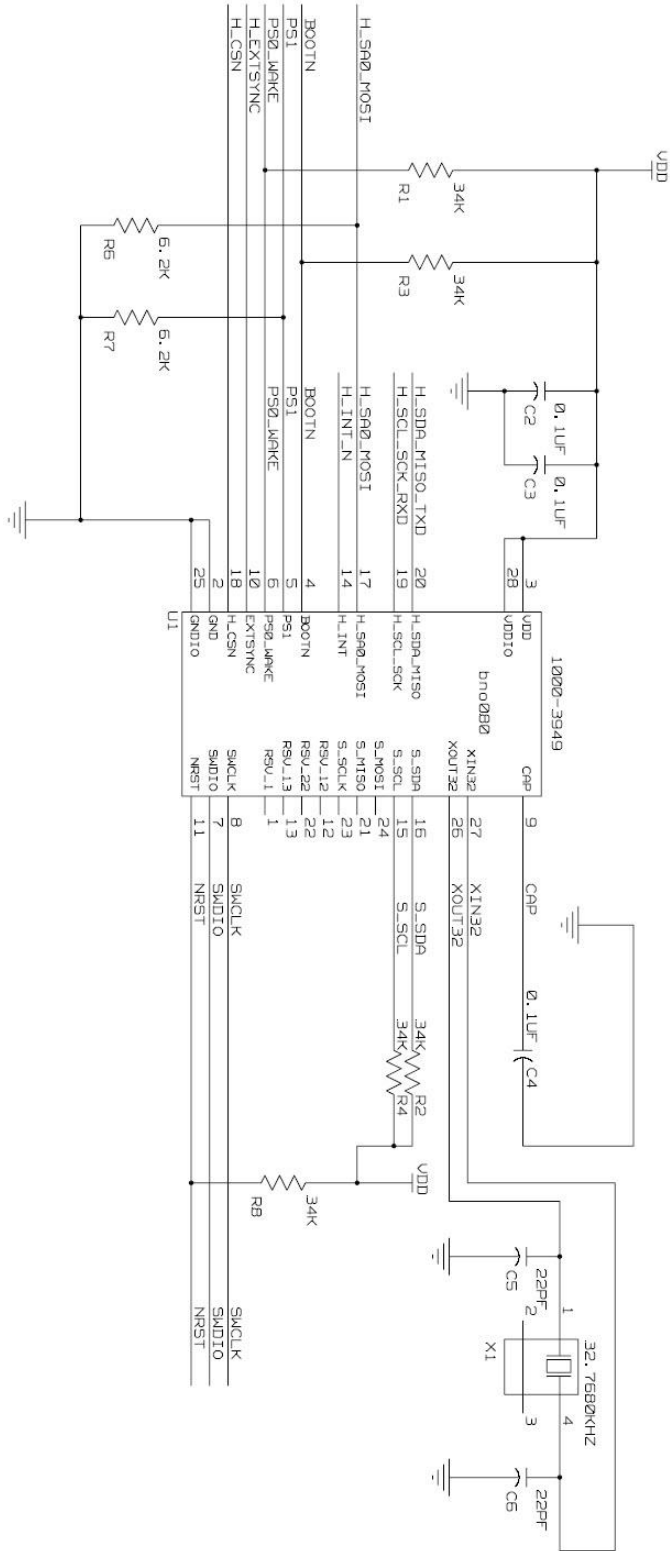


Figure 18: FSM30X Schematic

## Bill of Materials

| Qty | Title  | Detail                | Ref          | Mfr             | Mfr P/N            |
|-----|--|-----------------------|--------------|-----------------|--------------------|
| 1   | Crystal, 12.5pF, SMT                                 | 32.7680KHz::1uW:20ppm | X1           | Citizen         | CM200S32.768KDZFTR |
| 1   | Resistor   | 0'::1/16W:5%          | R5           | Yageo Corp      | RC0402JR-070RL     |
| 3   | Ceramic Capacitor                                    | 0.1uF:10V::10%        | C2-C4        | Taiyo Yuden Co. | LMK105BJ104KV-F    |
| 2   | Ceramic Capacitor                                    | 22pF:50V::5%          | C5,C6        | Yageo Corp      | CC0402JRNPO9BN220  |
| 1   | Ceramic Capacitor                                    | 10uF:6.3V::20%        | C1           | TDK             | C1608X5R0J106M     |
| 1   | Tri Axis Gyro, Tri Axis Acc,<br>Tri Axis Mag, BNO080 | :2.4-3.6V::           | U1           | Hillcrest Labs  | BNO080             |
| 5   | Resistor   | 34K::1/16W:1%         | R1-<br>R4,R8 | Yageo Corp      | RC0402FR-0734KL    |
| 2   | Resistor   | 6.2K::1/16W:1%        | R6,R7        | Yageo Corp      | RC0402FR-076K2L    |

## Version History

| Version | Changes   | Date          |
|---------|---|---------------|
| 1.2     | Add recommended solder profile (figure 17)  | June 26, 2017 |
| 1.1     | Add UART-RVC and stability classifier power consumption. Replaced picture in Figure 16. Update performance tables. Updated pull down resistor values. | June 23, 2017 |
| 1.0     | Initial release   | May 19, 2017  |

## References

1. BMF055 datasheet, Bosch Sensortec. [https://ae-bst.resource.bosch.com/media/\\_tech/media/datasheets/BST\\_BMF055\\_DS000\\_01.pdf](https://ae-bst.resource.bosch.com/media/_tech/media/datasheets/BST_BMF055_DS000_01.pdf)
2. BNO055 handling, soldering & mounting instructions. [https://ae-bst.resource.bosch.com/media/\\_tech/media/others/BST-BNO055-HS000-00.pdf](https://ae-bst.resource.bosch.com/media/_tech/media/others/BST-BNO055-HS000-00.pdf)
3. 1000-3927 – BNO080 Datasheet, Hillcrest Labs.



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