How to use the BlueNRG-Tile Bluetooth LE enabled sensor node development kit

Introduction

The STEVAL-BCN002V1B Bluetooth LE enabled sensor node development kit features the STEVAL-BCN002V1 multi-sensor board based on BlueNRG-2 SoC Bluetooth Low Energy application processor. This sensor board has accelerometer, gyroscope, magnetometer, pressure, humidity, Time-of-Flight and microphone sensors, and is powered by a common CR2032 coin battery.

The sensor board communicates with a Bluetooth LE enabled smartphone running the ST BLE Sensor app, available on Google Play and iTunes stores.

The STEVAL-BCN002V1D adapter board is used to program and debug the sensor board. The adapter board is powered via USB.

Figure 1. STEVAL-BCN002V1B BlueTile kit

1. STEVAL-BCN002V1 "BlueTile" sensor node with inertial and environmental digital MEMS sensors, a digital MEMS microphone, a time-of-flight proximity sensor and a Bluetooth 5.0 wireless system-on-chip with a Cortex-M0 core

2. STEVAL-BCN002V1D host board to Flash and debug the sensor node

1 Safety Information

Any type of usage not specified by the manufacturer may compromise the protection mechanisms in the device.

1.1 Class 1 laser product

VL53L1X contains a laser emitter; the device is designed to limit the laser output within Class 1 laser safety limits under all conditions including single faults, in compliance with IEC 60825-1:2014 (third edition).

Recommended settings and operating conditions specified in VL53L1X datasheet and user manual MUST be respected.

The laser output MUST NOT be increased by any means and no optics should be to used focus the laser beam. Use of controls or adjustments or performance of procedures other than those specified in VL53L1X datasheet and user manual may result in hazardous radiation exposure.

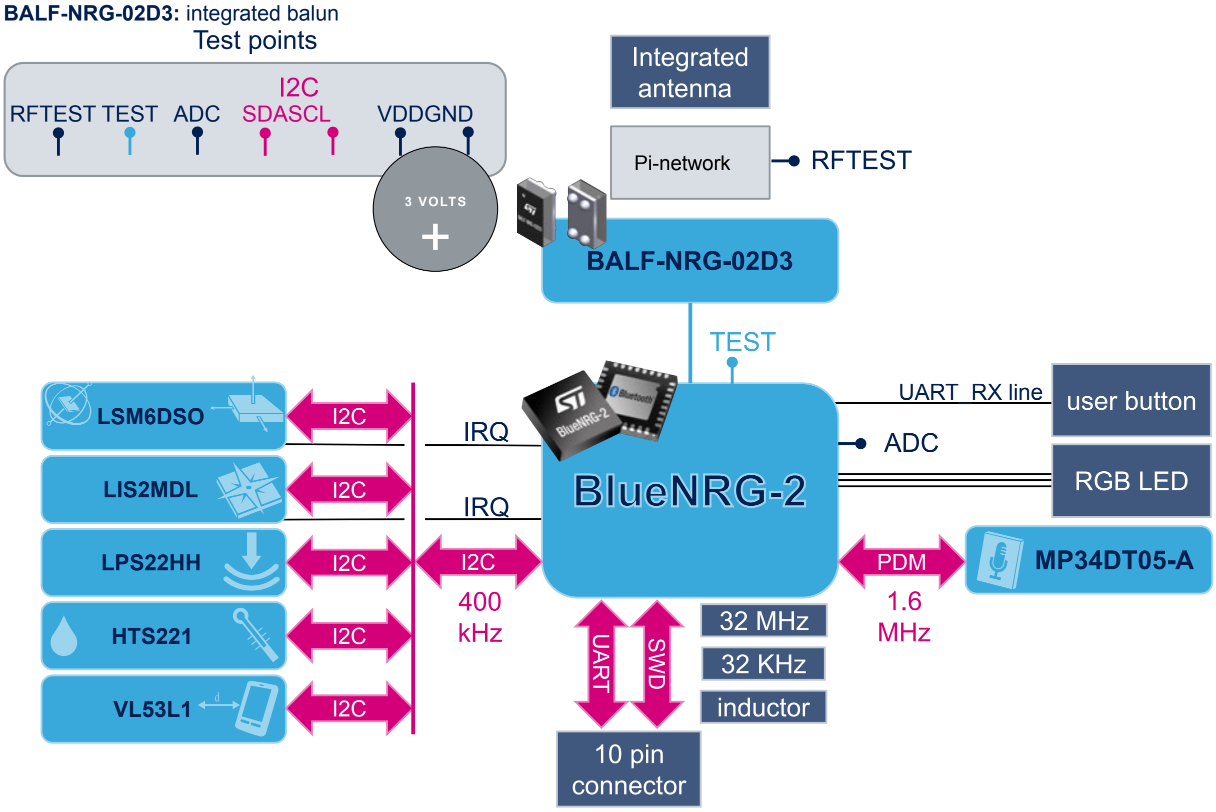
2 STEVAL-BCN002V1 BlueTile sensor node

BlueTile is a small form-factor reference design ready for you to extend and customize, as well as a development platform for BLE-enabled applications using the BlueNRG-2 SDK. It is also an evaluation tool to help you assess and evaluate the performance of the sensors and the capabilities of the BLE.

Thanks to its small and thin design, BlueTile can be used in the field for data collection activities to test and develop new algorithms.

Figure 2. STEVAL-BCN002V1 BlueTile block diagram

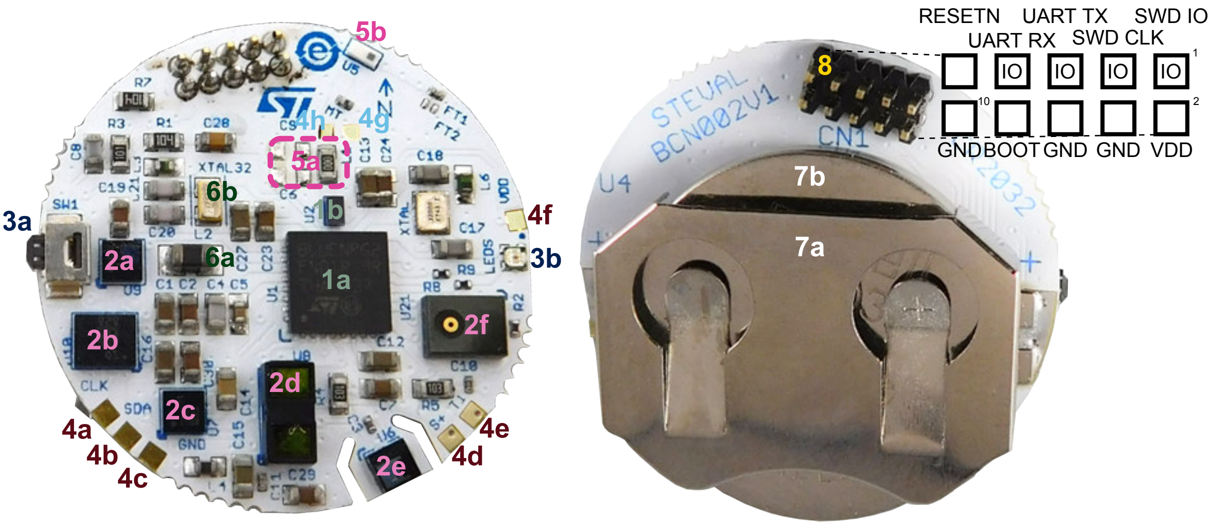
BlueNRG-2: Bluetooth 5.0 network and application processor
LSM6DSO: accelerometer and gyroscope
LIS2MDL: magnetometer
LPS22HH: barometer
HTS221: relative humidity and temperature sensor
VL53L1X: time-of-flight proximity sensor
MP34DT05-A: microphone
BALF-NRG-02D3: integrated balun



- The integrated SMD antenna needs clearance area and passives for proper tuning (FT1, FT2 and MT).
- The Pi-network is only intended for flexibility and for testing. It is not populated as the integrated balun provides the necessary matching.
- The 32kHz crystal allows lower power consumption BLE Sleep Mode.
- The inductor allows lower power consumption in BLE Active Mode.
- The STEVAL-BCN002V1 BlueTile sensor node is supplied with the default firmware (BLE_SensorDemo, available in the SDK) already loaded. The firmware enables the streaming of sensor data to the reference smartphone app (ST BlueMS, available on Android™ and iOS™ stores).

Figure 3. STEVAL-BCN002V1 sensor node front and rear components

1a. BlueNRG-2 Bluetooth 5.0 network and application processor **1b.** BALF-NRG-02D3 integrated balun and matching network
2a. LPS22HH ambient pressure sensor **2b.** LSM6DSO smart accelerometer and gyroscope **2c.** LIS2MDL magnetometer **2d.** VL53L1X proximity by time-of-flight **2e.** HTS221 relative humidity and temperature **2f.** MP34DT05-A top-port digital microphone
3a. User button **3b.** RGB LED
4a. I2C SCL **4b.** I2C SDA **4c.** GND **4d.** ADC **4e.** TEST **4f.** VDD **4g.** GND **4h.** RFTEST
5a. Π-network (not mounted) **5b.** SMD antenna
6a. Inductor to enable lowest power BLE active mode **6b.** 32kHz crystal to enable lowest power BLE sleep mode
7a. Battery holder **7b.** CR2032 battery (not included)
8. 10-pin connector
FCC ID: S9NSTEBCN2V1 IC ID: 8976C-STEBCN2V1



The BlueTile sensor node is supplied with the firmware already loaded. The default firmware includes two libraries:

1. MotionFX fusion library for orientation estimation (visualized with a rotating cube).
2. BlueVoice library to stream the voice captured by the MEMS microphone over the BLE connection (reproduced by the smartphone speaker, if not in vibration mode).

The STBLESensor app can be used to plot and log sensor data in real time on your smartphone.

RELATED LINKS

STBLE sensor documentation

2.1 System architecture

The BlueTile is powered by a coin-cell battery (CR2032). The voltage is not regulated because the sensors and the BlueNRG-2 can all operate at the voltage range of the battery. In any case, the BlueNRG-2 has its own embedded linear power regulator and switching mode power converter (DC-DC).

2.1.1 Power section for BlueNRG-2

The BlueNRG-2 in active mode can use the embedded linear voltage regulator (LDO) or the embedded DC-DC converter (DC-DC).

- LDO regulator [Active mode, CPU Flash and RAM on]:
  – RX 14.5 mA at 3 V, TX 17.2 mA when output power is +2 dBm
  – range is 12-28.8 mA when output is -14 to +8 dBm
- DC-DC converter [Active mode, CPU Flash and RAM on]:
  – RX 7.7 mA at 3 V, TX 9 mA at 3 V when output power is +2 dBm
  – range is 6.6-15.1 mA when output is -14 to +8 dBm

Note: The BlueTile sensor node includes the inductor needed by the DC-DC converter to allow lower power consumption in active mode.

In Sleep Mode, the BlueNRG-2 device can use its internal 32 kHz ring oscillator (RO) or the external 32 kHz crystal oscillator (XO) available on the BlueTile sensor node, which offers lower power consumption in sleep mode:

- Sleep Mode [32 kHz ring oscillator, 24 kB RAM retention]: 2.1 µA at 3 V
- Sleep Mode [32 kHz crystal oscillator, 24 kB RAM retention]: 0.9 µA at 3 V

2.1.2 Radio frequency section

The radio frequency section of the BlueTile includes the following elements:

1. A BALF-NRG-02D3 ultra-miniature balun which integrates matching network and harmonics filter.
2. A Pi-network which allows additional filtering and provides access points for testing.

Note: This network is not populated, as the integrated balun provides the necessary matching.

3. An SMD 2.4 GHz antenna, which requires a certain clearance area on the PCB and specific passives for precise tuning (FT1, FT2 and MT).

2.1.3 MEMS sensor section

The MEMS sensor section of the BlueTile sensor node includes inertial and environmental MEMS sensors connected with the BlueNRG-2 via an I2C bus operating at 400 kHz.

The MEMS microphone is connected with BlueNRG-2 through a dedicated line to transfer the PDM (Pulse Density Modulated) stream at 1.6 MHz, which is converted to PCM (Pulse Coded Modulation) by the integrated digital filter in the ADC block on the BlueNRG-2.

All sensors can generate interrupts, but only the interrupts from the LIS2MDL magnetometer and the LSM6DSO accelerometer and gyroscope are connected with the BlueNRG-2 through dedicated and independent lines.

- The LIS2MDL magnetometer interrupt line is push-pull only and must have its own independent line. The interrupt pin of this sensor is connected with BlueNRG-2 to enable applications such as “reed-switch”, which is activated by an external magnet.
- The LSM6DSO smart accelerometer and gyroscope interrupt pin is an input at boot. It has an internal pull-down. If the pin is low at boot, the I2C interface is selected, otherwise the I3C interface is selected. The pin can be reconfigured as open-drain, but the external pull-up would cause additional power consumption. The interrupt pin of this sensor is connected to BlueNRG-2 to exploit the smart embedded processing functionality (single/double tap recognition, free-fall, wakeup, portrait/landscape, 6D/4D orientation detection; activity/inactivity, stationary/motion detection; pedometer, step detector and step counter; up to 16 finite state machines to process).
- The LPS22HH barometer interrupt pin exhibits the same behavior as the LSM6DSO interrupt pin: it is an input pin at boot and must be low to activate the I2C interface. It can be configured as push-pull or open-drain after boot. The interrupt pin of this sensor is not connected to BlueNRG-2.
- The HTS221 relative humidity and temperature interrupt pin is push-pull at boot and can be reconfigured as open-drain after boot. The interrupt pin of this sensor is not connected to BlueNRG-2.
- The VL53L1X time-of-flight proximity interrupt line is open-drain only and would require an external pull-up. The interrupt pin of this sensor is not connected to BlueNRG-2.

The dynamics of the environmental parameters are relatively slow, so interrupts are not necessary. The application only needs to wake up every few seconds and perform one-shot measurements with the LPS22HH barometer or HTS221 relative humidity and temperature sensor, and trigger an action if specific conditions are met.

It is also not convenient to keep the VL53L1X proximity time-of-flight sensor active, the power consumption or the latency would be too high. The power consumption of VL53L1X ranges from 0.5 mA for 1 Hz measurements, up to 7 mA for 10 Hz measurements.

2.1.4 Pinout descriptions

In the following figure, you can see 6 pads along the edge of the board:

- RFTEST (4h) and GND (4g) connected to the RF section for test purposes.
- TEST (4e) connected to the analog TEST output of BlueNRG-2 for test purposes.
- VDD (4f) and GND (4c), for test purposes or to power additional external components.
- ADC (4d) to accept analog input signals from additional external components.

- I2C SCL (4a) and I2C SDA (4b) to connect additional external components via I2C.

Figure 4. STEVAL-BCN002V1 sensor node front and rear components

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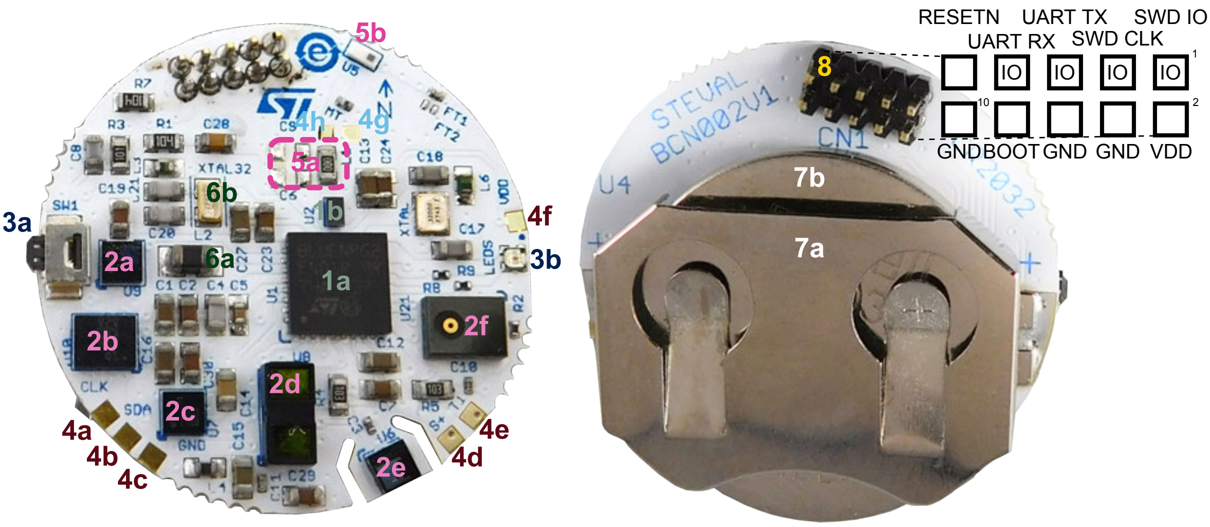


On the debug connector on the rear of the board, there are 10 pins:

- VDD (pin 2) and GND (pin 4, 6, 10) to accept power from the host motherboard.
- SWD IO (pin 1) and SWD CLK (pin 3) to Flash and debug through the host motherboard.
  – SWD pins can be used as digital GPIOs when the BlueTile is not connected to its host board.
- UART TX (pin 5) and UART RX (pin 7).
  – UART pins can be used as digital GPIOs when the BlueTile is not connected to its host board.
- BOOT (pin 8) and RESETN (pin 9) to control the boot and keep BlueNRG-2 under reset.
  – The boot pin can also be used as a digital GPIO when the BlueTile is not connected to its host board, but it needs to be pull-down at start-up.

2.2 Features of the BlueNRG-2 device

BlueNRG-2 integrates a Bluetooth Low Energy radio (BLE), an ARM® Cortex®-M0 core, 12+12 kB of RAM, 256 kB of Flash memory, SPI (max 1 MHz in slave mode, 8 MHz in master mode), two I2Cs (standard 100 kHz or fast 400 kHz), UART interfaces; two multi-function timers (MFT), a DMA controller, RTC and watchdog, and an ADC with PDM stream processor.

The public key cryptography (PKA) and random number generator (RNG) are reserved for the BLE protocol stack, but the user application can also read the RNG.

The ADC is 10-bit and features single or continuous acquisition at max. 1 MHz sampling frequency, two single ended or one differential signal (ADC1 and ADC2 pins), embedded channels for temperature and battery voltage sensing, embedded digital filter with down sampling. The embedded digital filter can be used to process the PDM stream from a digital MEMS microphone (1.6 MHz or 0.8 MHz) and convert it to audio PCM (8 kHz to 50 kHz when 1.6 MHz clock is used for the microphone).

BlueNRG-2 uses the embedded digital filter of the ADC peripheral for PDM to PCM conversion when reading the PDM output of the MEMS microphone MP34DT05-A.

The low-speed clock is used in low-power mode and can be supplied by the internal RC oscillator or by an external crystal (32 kHz ±50 ppm). The high-speed clock is supplied by a fast-starting internal RC oscillator (16 MHz) while the external crystal is starting up. The high-speed external crystal (16 or 32 MHz) is required to enable the BLE radio.

Only the 32 MHz XO can support the highest computational loads, allowing the Cortex-M0, the DMA and the APB tree to run at 32 MHz, while the rest of the clock tree runs at 16 MHz. When a 16 MHz XO is used, the Cortex-M0 and all the clock tree runs at 16 MHz.

2.2.1 BlueNRG-2 states

- Preactive:
  - After power-on-reset, all digital power supplies are stable.
  - Internal 16 MHz and 32 kHz RC oscillators are used.
  - Reachable from Reset, Standby and Sleep states.
  - Goes to Active state.
- Active:
  - The external high-frequency crystal is used (16 MHz ±50ppm or 32 MHz) to enable BLE communication.
  - Internal 16MHz RC oscillator is switched off
  - BlueNRG-2 uses a 32 MHz ±10ppm crystal (higher crystal accuracy = lower power consumption).
  - The radio can be activated for transmission (TX) or reception (RX). This is the state used by BlueNRG-2 when the user application is running or there is a BLE event to serve.
  - The programmed GPIO configuration is restored.
  - reachable only from Preactive only.
- Standby:
  - RAM retention is used (12 or 24 kB).
  - 5 different GPIOs can be used to wake-up: IO9, IO10, IO11 with an internal pull-up; IO12, IO13 which require an external drive).
  - BlueNRG-2 IO11 is connected to the user button, IO12 connected to the interrupt pin of LIS2MDL magnetometer, and IO13 connected to the interrupt pin of the LSM6DSO accelerometer and gyroscope.
  - Wake-up time is typically 200μs.
  - reachable from Active.
  - can go to Preactive.
- Sleep:
  - RAM retention is used (12 or 24 kB).
  - The low-frequency oscillator is switched on to serve periodic BLE connection events.
  - 5 different GPIOs can also be used to wake-up, as in Standby state.
  - This is the state used by the BlueNRG-2 tile to save power when the user application is not running and the device is waiting for a BLE event to serve.
  - The programmed GPIO configuration is not maintained (this may affect connected sensors; for example, see pin IO7 of BlueNRG-2 connected to XSHUT pin of VL53L1X).
  - Reachable from Active.
  - Can go to Preactive.

2.2.2 BLE firmware stack and memory map

Program memory, data memory, registers and I/O ports are organized in a linear 32-bit address space.

- The SRAM is divided in two banks:
  - 12 KB from 0x2000_0000 to 0x2000_2FFF (retention always-on).
  - 12 KB from 0x2000_3000 to 0x2000_5FFF (retention optional).
  - The FULL BLE stack needs 9.6 KB of SRAM.
  - The BASIC BLE stack needs 8.0 KB of SRAM.

- The Flash is 256 KB from 0x1004_0000 to 0x1007_FFFF
  - The FULL BLE stack needs 77 KB, leaving 179 KB for the user application. The FULL BLE stack supports concurrent peripheral and central roles (N=0,1,2 connections to other centrals and 8-N connections to other peripherals), LE secure connections, controller privacy, and extended data length.
  - The BASIC BLE stack needs 58 KB, leaving 198 KB for the user application. The BASIC BLE supports the peripheral role only (1 connection to a central), legacy security only, no controller privacy and no extended data length.
  - The OTA manager for over-the-air firmware updates adds 10 KB to the size of the BLE stack.

The OTA manager may be independent of the user application, or embedded in the user application:

- When the OTA manager is independent of the user application, the Flash is divided in two sections:
  1. A relatively small section for the OTA application; the size is the sum of the BLE stack size and the OTA manager size.
  2. A larger section for the user application.
- When the OTA manager is embedded in the user application, the Flash is divided in three sections:
  1. A section that holds the current application; the size is the sum of BLE stack size, OTA manager size and user application size.
  2. A section for the new updated application; the size is the same as the first section.
  3. A very small section for the reset application that decides decides which application to run after boot, depending on what is available and valid in the first two sections.

An independent OTA manager leaves more room for the user application, but there is no application to run if the update does not finish successfully.

An embedded OTA manager can still use the previous application if the update does terminate successfully, but the space available for the user application is less than half the size of the Flash.

Note: After a successful update, the new application can be copied over the old application, or the role of the first two sections can be exchanged.

2.3 Inertial MEMS sensors

Each sensor is made of a Micro Electro Mechanical system (MEMS) with a sensing element and a dedicated ASIC with analog acquisition chain, analog-to-digital converter (ADC), and digital signal processing (DSP) and control logic.

2.3.1 LSM6DSO 3D accelerometer and 3D gyroscope

2.3.1.1 LSM6DSO interrupts

The LSM6DSO delivers best-in-class motion sensing able to support more sophisticated functionality than simply orienting devices to portrait and landscape mode.

The following event-detection interrupts are supported:

- Free-fall event:
  - detected when acceleration data from all enabled axes are below threshold settings for a certain duration
- Wake-up event:
  - detected when the filtered data from any of the enabled axes are above threshold settings for a certain duration
  - choose between high-pass filtered data, slope detection filter (difference between consecutive samples, divided by two), low-pass filtered data plus an offset for each axis, or unfiltered data plus an offset.
- 6D/4D orientation event:
  - detected when an axis (positive or negative) is above the threshold setting, while the other two are below the threshold for a certain duration
  - 4D is a subset of 6D; the Z axis is not used.
  - choose between unfiltered data or low-pass filtered data

- Single/double tap event:
  - detected when the output of the slope detection filter exceeds the threshold setting and then returns below the same setting within a “shock” time interval
  - double tap event is detected when a first tap is detected and a second tap is detected after a “quiet” time interval, but before a maximum “duration” interval
  - for reliable detection, configure the device to use a high sampling rate, like 400 Hz.
  - if two or more enabled axes are over their respective thresholds, the axis with the highest priority setting is used
  - can be used to enable user interaction in addition to the button present on the BlueTile
- Activity/inactivity event:
  - uses the same data as the wake-up event
  - if inactivity is detected (data below the threshold setting for a certain time interval), the device automatically goes to Low-power Mode and reduces the accelerometer sampling rate down to 12.5 Hz to minimize power consumption
  - if a wake-up event is detected, the device automatically returns to the programmed accelerometer operating mode and sampling rate
  - can be configured to put the gyroscope in power-down or sleep mode when the accelerometer is in low-power mode
- Stationary/motion event
- a special activity/inactivity event in which event detection is the same, but the device does not change power mode or sampling rate

2.3.1.2 *LSM6DSO advanced functionality*

Certain digital processing blocks allow advanced functions and algorithms when the output data rate is 26 Hz or higher.

- Pedometer functions: step detector and step counter.
  - when a step is detected, an interrupt is generated and a corresponding counter is incremented by 1 (max value is 65535)
  - can also set the interrupt to only be triggered when at least one step is detected in a configurable time interval
  - de-bounce functionality to avoid false detections, where N consecutive steps are detected before the first interrupt is generated (default is N=10)
  - two additional blocks can facilitate the identification of false-positives:

only trigger when statistical data matches the walking pattern

adapt the embedded algorithm to slow pace walking patterns

- Significant motion detection: to signal a possible change in user location
  - based on the pedometer function, which is automatically enabled
  - interrupt is generated when the difference between the number of steps after initialization or reset is higher than the de-bounce threshold (default is 10).
  - function is reset after each interrupt
- Relative tilt detection
  - generates an interrupt when there a change in the tilt of the device exceeds 35 degrees
  - reference position is set when the detection logic is enabled and reset when the interrupt is generated
  - detection logic requires a 2-second settling time after it is enabled or re-initialized

2.3.1.3 *LSM6DSO finite state machines*

The LSM6DSO can run up to 16 simultaneous finite state machines (FSMs) that consist of a sequence of instructions or actions (parameter setting, interrupt generation, etc.), or a RESET-NEXT condition:

- if the RESET condition is satisfied, the FSM returns to the reset point
- if the NEXT condition is satisfied, the FSM moves to the next instruction
- otherwise, the RESET-NEXT conditions are re-tested.

FSM data may be accelerometer, gyroscope, integrated gyroscope or external sensor data, and can be decimated. A data vector consists of X, Y, Z values and a vector norm V (square root of sum of squares).

Each FSM has the following features:

- 3 different 8-bit masks to allow tests on positive and negative values of X, Y, Z and V.
- 3 different thresholds and 1 programmable hysteresis value that is automatically added to or subtracted from the selected threshold based on the test condition.
- 4 different counters/timers to manage event durations.

2.3.1.4 *LSM6DSO smart FIFO buffer*

The LSM6DSO accelerometer has a first-in first-out (FIFO) data buffer that can store up to 3 KB of data, or 512 words of 7 bytes each (1 tag byte plus 6 data bytes). The tag drives the decoding and includes a parity bit for validation, while the data can derive from any combination of accelerometer, gyroscope, up to 4 external sensors, embedded temperature sensor, timestamp counter and pedometer step counter. The data rates can be set independently for each source.

For the accelerometer, you can choose to store high-pass filtered data, slope detection filter data, low-pass filtered data or unfiltered data plus an optional offset (independent for each axis). The low and high-pass filters are configurable.

For the gyroscope, you can enable a first optional high-pass filter, and a second optional and programmable low-pass filter.

To maximize the amount of data stored in the FIFO, you can enable an adaptive lossless delta pulse-coded-modulation (DPCM) compression algorithm for the accelerometer and the gyroscope data. When the difference between consecutive data words is small, instead of sending a new data word (16 bits/axis), only the difference with respect to the previous is sent (8 bits = 2:1 compression or 5 bits/axis = 3:1 compression).

When DPCM compression is enabled, it is also possible to select when DPCM is reset by storing uncompressed data in the FIFO: never, every 8, 16 or 32 words. This is useful when the FIFO is used as a circular buffer (Continuous mode) and words may be overwritten, as the decoder can only work if previous data words can be traced back to an uncompressed data word for reference.

DPCM compression works on 3 data words (sampled at time t, t-1 and t-2) and introduces a latency of 2 data words. The compression factor depends on the difference between a data word and the previous data word.

- When DPCM is disabled, the compression buffer is flushed and the output is the non-compressed data word at time t-2, then data word at time t-1 and data words at current time t thereafter (tag “NC_T_2”, “NC_T_1”, and “NC”).
- When DPCM is enabled, the first output is the non-compressed data word at time t-2 (tag “NC_T_2”), used as the reference to start decoding. Subsequent outputs depend on D2 (difference between data word at t-2 and previous decoded word), D1 (difference between data word at t-1 and t-2), and D0 (difference between data word at t and t-1):
  - If any difference in D2 exceeds 128 LSB on any axis:
    - the uncompressed data word at time t-2 is written to the FIFO by storing the 16-bit signed value of each axis (low and high bytes for X, Y and Z: XL XH YL YH ZL ZH, for a total of 6 bytes)
    - tag NC_T_2
  - If any difference in D2 and D1 exceeds 16 LSB, but is within 128 LSB for all axes:
    - a 2:1 compression ratio is applied by storing the 8-bit signed difference to reconstruct 2 data values for each axis at time t-1 and t-2 (D1x D1y D1z, then D2x D2y D2z, for a total of 6 bytes)
    - tag 2xC
    - the data at time t-2 is derived by summing D2 to the previously decoded data word
    - the data at time t-1 is derived by summing D1 to the data at time t-2 just derived
  - If all differences in D2, D1 and D0 are within 16LSB for all axis:
    - a 3:1 compression ratio is applied by storing the 5-bit signed difference to derive 3 data values for each axis at time t, t-1 and t-2 (D0x D0y D0z and a dummy bit to make 16 bits, then D1x D1y D1z and a dummy bit, then D2x D2y D2z and a dummy bit, for a total of 6 bytes)
    - tag 3xC
    - the data at time t-2 is derived by summing D2 to the previous decoded data word
    - the data at time t-1 is derived by summing D1 to the data at time t-2 just derived
    - the data at time t is derived by summing D0 to the data at time t-1 just derived

Interrupts can be generated when the FIFO buffer stores a given number of samples (FIFO threshold level), or when it is full, or when it overflows (overrun). The FIFO can work in the following modes:

- Bypass Mode:
  - the FIFO buffer is disabled and cleared
- FIFO Mode:
  - the FIFO buffer collects data until it is full, then stops
- Continuous Mode:
  - the FIFO buffer collects data continuously
  - when it is full, the oldest samples are overwritten as in a circular buffer
  - FIFO full and FIFO threshold level interrupts allow the host microcontroller to read the data before it is overwritten
- Continuous-to-FIFO Mode:
  - the FIFO buffer collects data continuously but switches to FIFO Mode as soon as the selected interrupt occurs
  - this mode is especially useful to capture data before and after a specific event
- Bypass-to-Continuous Mode:
  - the FIFO buffer is disabled, but switches to Continuous Mode as soon as the selected interrupt occurs
  - this mode is useful to capture data after an event has occurred
- Bypass-to-FIFO Mode:
  - the FIFO buffer is disabled, but switches to FIFO mode as soon as the selected interrupt occurs
  - this mode is useful to capture data after an event has occurred
  - data collection stops once the FIFO is filled

2.3.2 LIS2MDL 3-axis magnetometer

2.3.2.1 *LIS2MDL dynamic range, resolution and accuracy*

The LIS2MDL is a 3D digital magnetometer with a ±50 Gauss dynamic magnetic field range (reduced to ±25 Gauss if the magnetic field is not aligned with one of the axes), which is well above Earth's magnetic field (which is typically in the range of 0.25 to 0.65 Gauss).

The output is 16 bits (1.5 mGauss/LSB ±7%), and the RMS noise level in High-performance Mode is 3 mGauss (2 LSB). The high resolution and accuracy allows e-compass orientation estimation and distance measurements from a reference magnet (in its simplest form, the magnetometer can emulate a magnetically activated Reed-switch).

The LIS2MDL magnetometer can perform a single-shot measurement and then return to Power-down Mode, or operate in Continuous Mode with a programmable sampling rate (10, 20, 50 or 100 Hz).

Single-shot measurements can be performed at max. 100 Hz in high-performance mode, or max. 150 Hz in low-power mode. In low-power mode, the power consumption is reduced to 25%, while in high-performance mode the RMS noise is halved. An optional low-pass filter can be activated to further reduce RMS noise, without increasing the power consumption, the bandwidth in this case is reduced from output data rate ODR/2 down to ODR/4.

2.3.2.2 *LIS2MDL intrinsic offset automatic cancellation*

The LIS2MDL is based on anisotropic magneto-resistive (AMR) technology, in which a set pulse is required to set an initial operating condition; a reset pulse may be used to enable the compensation of the intrinsic magnetic offset.

- If intrinsic offset compensation is disabled, there is no reset pulse. The set pulse can be generated at power-on only (Set_FREQ=1), or every 64 measurements (Set_FREQ=0).
- If intrinsic offset compensation is enabled, set and reset pulses are generated alternately on consecutive samples. After the set pulse, the measured output is the magnetic field H plus offset; after the reset pulse, the measured output is H minus offset.
  - In Continuous Mode, the device averages consecutive measurements to compensate for the offset, the output will be equal to the magnetic field H.
  - $output = \frac{[(H + offset) + (H - offset)]}{2} = H$
  - In Single-shot Mode, the host microcontroller averages two consecutive measurements. The averaged measurements must occur within a short time of each other for the compensation to be effective.

When intrinsic offset compensation is performed, the residual offset is in the range of ±60 mgauss, and the dependency on temperature is ±0.3 mgauss/°C.

2.3.2.3 *LIS2MDL extrinsic offset (hard iron) compensation*

Hard-iron compensation is a constant offset added to magnetic field measurements to compensate distortion caused by ferromagnetic materials or high currents. This offset can be computed by the host microcontroller by analysing the output of the magnetometer.

When it is available, this offset can be programmed in specific registers (OFFSET_X_REG_H/L, OFFSET_Y_REG_H/L, OFFSET_Z_REG_H/L) so that it is automatically subtracted by the LIS2MDL device.

RELATED LINKS

DT0059: Ellipsoid or sphere fitting for sensor calibration

MotionMC software library in the X-CUBE-MEMS1 Sensor and motion algorithm software expansion for STM32Cube

2.3.2.4 *LIS2MDL interrupt generation*

The LIS2MDL magnetometer sensor can be configured to generate an interrupt when output data (before or after the subtraction of hard-iron offset) exceeds a programmed threshold (INT_THS_H/L_REG) in the positive or negative direction.

Comparisons can be enabled independently for each axis (XIEN, YIEN, ZIEN flags):

- when the output data is above the positive threshold, the corresponding flag is set (P_TH_S_X/Y/Z)
- when the output data is below the negative threshold, the corresponding flag is set (N_TH_S_X/Y/Z).

A specific interrupt can be generated if there is a measurement range overflow at the internal ADC.

2.4 Environmental MEMS sensors

2.4.1 LPS22HH barometer

2.4.1.1 LPS22HH acquisition chain

The LPS22HH pressure sensor can perform a one-shot measurement and then return to Power-down Mode, or it can operate in Continuous Mode with a programmable sampling rate (1, 10, 25, 50, 75, 100 or 200 Hz).

Measurements can be taken in normal Low-noise Mode, or in Low-power Mode to minimize current consumption. When continuous mode is selected, Low-noise Mode is not available at 100 and 200 Hz. In all cases, an optional low-pass filter can be enabled with a programmable cutoff frequency to reduce the noise level (the bandwidth is reduced from output data rate ODR/2 down to ODR/9 or ODR/20).

The low-pass filter is reset when it is enabled. After reset, a specific settling time is required before the first accurate sample on the output is available (9 or 20 samples must be discarded, respectively).

Two programmable offsets can be subtracted from measured data:

- First, offset compensation (always): the offset measured with one-point calibration (OPC) can be stored in specific registers (RPDS) and then subtracted from subsequent measurements (OPC-compensated data = data – RPDS*256). The low-pass filter, if enabled, will filter OPC-compensated data. Filtered and unfiltered OPC-compensated data is stored in the FIFO.
- Second, auto-zero mode (optional): the offset-compensated (and possibly filtered) pressure measurements are stored in specific registers (REF_P) when auto-zero is enabled (AUTOZERO or AUTOREFP set to 1) and then subtracted from subsequent measurements (AZ-compensated data = data – REF_P). Filtered and unfiltered OPC-compensated data or AZ-compensated data is stored in output registers.

2.4.1.2 LPS22HH interrupt generation and FIFO buffer

The LPS22HH pressure sensor can be configured to generate interrupt events related to pressure acquisitions and FIFO status (watermark reached, full, overrun, etc.).

The interrupt can be generated when a new pressure or temperature sample is available, or when the AZ-compensated data exceeds a programmed threshold (THS_P) in the positive (PHE flag enables the comparison with +THS_P) or negative (PLE flag enables the comparison with –THS_P) direction. The following configurations are available:

1. AUTOZERO=0 and AUTOREFP=0: interrupt logic is disabled; filtered and unfiltered OPC-compensated data goes to FIFO and output registers.
2. AUTOZERO=1: interrupt logic is enabled; REF_P is set when interrupt is enabled; AZ-compensated data goes to the interrupt logic and to the output registers, while filtered and unfiltered OPC-compensated data goes to FIFO.
3. AUTOREFP=1: interrupt logic is enabled; REF_P is set when interrupt is enabled; AZ-compensated data goes to interrupt logic, while filtered and unfiltered OPC-compensated data goes to FIFO and output registers.

The FIFO buffer can store up to 128 pressure samples (24 bits each) and 128 temperature samples (16 bits each). FIFO depth can be limited by stopping at the programmable watermark level. The FIFO can work in the following modes:

- Bypass Mode:
  - the FIFO buffer is disabled and cleared
- FIFO Mode:
  - the FIFO buffer collects data until it is full or the watermark setting is reached, then stops
- Continuous (or Dynamic Stream) Mode:
  - the FIFO buffer collects data continuously
  - when it is full or the watermark setting is reached, the oldest samples are overwritten as in a circular buffer
  - FIFO full and FIFO threshold level interrupts allow the host microcontroller to read the data before it is overwritten

- Continuous (Dynamic Stream)-to-FIFO Mode:
  - the FIFO buffer collects data continuously but switches to FIFO Mode as soon as the selected interrupt occurs
  - this mode is especially useful to capture data before and after a specific event
- Bypass-to-Continuous (Dynamic Stream) Mode:
  - the FIFO buffer is disabled, but switches to Stream Mode as soon as the selected interrupt occurs
  - this mode is useful to capture data after an event has occurred
- Bypass-to-FIFO Mode:
  - the FIFO buffer is disabled, but switches to FIFO mode as soon as the selected interrupt occurs
  - this mode is useful to capture data after an event has occurred

2.4.2 HTS221 temperature sensor

2.4.2.1 *LPS22HH vs HTS221 ambient temperature measurement*

The temperature sensor in the LPS22HH device is designed to compensate for temperature effects in ambient pressure measurements, while the temperature sensor in the HTS221 device is designed and characterized for ambient temperature measurements.

The BlueTile takes ambient temperature data from the HTS221 because it is more accurate over a larger range than the LPS22HH. However, applications requiring a high data rate (above 12.5 Hz) can take data from the LPS22HH temperature sensor.

Table 1. Comparison of HTS221 and LPS22HH temperature sensor characteristics

Device	Temperature sensor operating range	Sensitivity	Temperature absolute accuracy	Data rate	Response time	Long term drift
HTS221	-40 to +120 °C	64 LSB/°C	±1°C (0 to 60 °C) ±0.5 °C (15 to 40 °C);	1, 7, 12.5 Hz	15 s (time to 63%).	0.05 °C/ year.
LPS22HH	-40 to +85 °C	100 LSB/°C	±1.5 °C (0 to 80 °C)	1, 10, 25, 50, 75, 100, 200 Hz.	-	-

2.4.2.2 *HTS221 acquisition chain*

While all the board components have an embedded temperature sensor to monitor the temperature of the silicon, the embedded HTS221 has the physical properties and accuracy necessary for the measurement of ambient temperature.

The raw output of the humidity acquisition chain is stored in two 8-bit registers (HUMIDITY_OUT_H and HUMIDITY_OUT _L), which are concatenated into a 16-bit two's complement value (H_OUT). The raw output is already temperature compensated and calibration coefficients to derive Relative Humidity (RH) from raw humidity data are stored in the device. Factory calibration is performed at two different humidity levels and one temperature.

The following sequence is used to calculate RH:

1. First true RH during calibration: $H0\_rH\_x2 \rightarrow setRH0 = \frac{H0\_rH\_x2}{2}$
2. Second true RH during calibration: $H1\_rH\_x2 \rightarrow setRH1 = \frac{H0\_rH\_x2}{2}$
3. First raw H output during calibration: $H0\_T0\_OUT \rightarrow setH0 = H0\_T0\_OUT$
4. Second raw H output during calib.: $H1\_T0\_OUT \rightarrow setH1 = H1\_T0\_OUT$
5. Current raw H output: $H\_OUT \rightarrow setH = H\_OUT$
6. Current RH% by linear interpolation: $RH = RH0 + (RH1 - RH0)*\frac{(H - H0)}{(H1 - H0)}$

The raw output of the temperature acquisition chain is stored in two 8-bit registers (TEMP_OUT_H and TEMP_OUT _L) which are concatenated into a 16-bit two's complement value (T_OUT). Calibration coefficients to derive the Temperature in °C from raw temperature data are stored in the device. Factory calibration is performed at two different temperatures.

Follow the sequence below to calculate the temperature in °C:

1. MSB of true temperatures during calibration: $T1T0MSB \rightarrow setMSB1 = T1T0MSB\&0x03, MSB0 = \frac{T1T0MSB}{4}$
2. First true T in Celsius deg. (two's comp): $T0\_°C\_x8 \rightarrow setT0°C = \frac{(T0\_°C\_x8 + MSB0*256)}{8}$
3. Second true T in Celsius deg. (two's comp): $T1\_°C\_x8 \rightarrow setT1°C = \frac{(T1\_°C\_x8 + MSB1*256)}{8}$
4. First raw T output during calibration: $T0\_OUT \rightarrow setT0 = T0\_OUT$
5. Second raw T output during calibration: $T1\_OUT \rightarrow setT1 = T1\_OUT$
6. Current raw T output during calibration: $T\_OUT \rightarrow setT = T\_OUT$
7. Current Temperature in °C: $T = T0deg + \frac{(T1deg - T0deg)*(T - T0)}{(T1 - T0)}$

2.4.2.3 *HTS221 system integration*

To get reliable and consistent measurements, the system design should maximize sensor exposure to the external environment while minimizing error sources.

- Mechanical design:
  – if there is one vent hole in the BlueTile housing, the hole diameter should be maximized and the dead volume enclosed should be minimized
  – two or multiple vent holes are preferable in order to create a laminar airflow and minimize the response time
  – avoid materials that absorb humidity
- Mechanical stress:
  – Avoid flexing or bending the BlueTile board
- Heat:
  – Heat convection or temperature gradients on the board may affect the sensor
  – Metal lines and planes, such as the ground plane, should be kept far from the sensor
  – Milled slits further increase decoupling
  – Insulation may be required to isolate the BlueTile from convective and conducted heat
- Light exposure may induce a change in temperature and humidity.

To accelerate sensor recovery time in case of condensation, the firmware running on the host microcontroller can be coded to switch the heating element on for a certain duration. Humidity and temperature data should not be read during the heating cycle.

The BlueTile is designed for ultra-low power operation and a long battery life (1 month to 1 year on a typical CR2032 coin battery, depending on the application). Power and heat generated on-board is therefore very limited. Possible sources of conducted heat such as the BlueNRG-2 and the LED are placed as far as possible from MEMS sensors to avoid any impact on measurements. Slits are also present to further isolate the HTS221 temperature sensor from neighboring components.

RELATED LINKS

AN4722: HTS221 digital humidity sensor: hardware guidelines for system integration

2.5 MP34DT05-A digital MEMS microphone

2.5.1 Features of the MEMS microphone

The MP34DT05-A omnidirectional top-port digital microphone has the following features:

- 122.5 dBSPL acoustic overload point (AOP), or 0 dBFS (100% of digital Full Scale(FS))
- -26dBFS ±3dB (5% of FS) sensitivity at 1 kHz and 94 dBSPL
- 64dB A-weighted SNR
- The equivalent input noise floor is 30 (94-64) dBSPL, or -90 (-26-64) dBFS (0.003% of FS).
- The total harmonic distortion plus noise THD+N:
  - 0.2% at 94 dBSPL
  - 0.7% at 110 dBSPL
  - 6% at 120 dBSPL
- The frequency response is generally flat from 100 Hz to 5 kHz, up to +0.5 dB at 20 kHz.

Appropriate frequency response is important to maximize the performance of beamforming applications that can determine the direction of incoming sounds and reject noise coming from certain directions

RELATED LINKS

AcousticBF software library in the X-CUBE-MEMSMIC1 Digital MEMS microphones acquisition and processing software expansion for STM32Cube

2.5.2 PDM to PCM conversion

The output of the digital MEMS microphone is a bit stream (1.6 MHz on the BlueTile), where frequency of ones is proportional to the sound pressure level: this is known as pulse-density modulation (PDM). However, audio is usually represented by words with at least 16 bits, at a rate equal or greater than twice the max. audio frequency, typically 16, 24 or 48 kHz: this is known as pulse-coded modulation (PCM).

The PDM-to-PCM conversion can be performed with low-pass filtering. In its simplest form, it is equivalent to averaging, or counting the number of ones over the sampling time of the PCM word.

In the BlueTile the conversion is performed by hardware in a dedicated block in the ADC peripheral in BlueNRG-2 device, but the conversion can also be performed by software.

RELATED LINKS

AN4957: How to synchronize the DFSDMs filters and how to program the pulse skipper on the STM32F413/423 line devices

AN3998: PDM audio software decoding on STM32 microcontrollers

PDM2PCM software library in the X-CUBE-MEMSMIC1 Digital MEMS microphones acquisition and processing software expansion for STM32Cube

2.6 VL53L1X Time-of-Flight sensor

2.6.1 Features of the Time-of-Flight sensor

The VL53L1X is a state-of-the-art laser-ranging sensor in a miniaturized package, with a 940 nm Class 1 vertical-cavity surface-emitting laser (VCSEL), a receiving 16x16 array of single-photon-avalanche-detectors (SPAD), physical infrared filters and optics to achieve the best ranging performance.

The VL53L1X measures the time it takes for photons emitted by the laser to be reflected back to the sensor.

The field-of-view (FoV) is programmable from 15 to 27 degrees, which sets the region of interest (ROI) in the SPAD array from 4x4 to 16x16 detectors, respectively. The position of the ROI in the array can also be set, in order to orient the FoV cone in a specific direction.

The sensor returns the following data:

- ranging distance in mm
- the return signal rate and the ambient signal rate (kilo-count-per-second (kcps) per SPAD)
- range status

2.6.2 Calibration for best performance

For best performance, run the calibration functions at least once after assembly is completed. Calibration data is stored in the host microcontroller and loaded in the VL53L1X on each startup.

If you call one or more calibration functions, you must observe the sequence below:

- RefSPAD calibration:
  - Optimizes device dynamics and accuracy.
  - Especially recommended if a protective glass cover is used on top of the device.
  - SPAD cells are classified as non-attenuated, attenuated by 5 or attenuated by 10.
  - SPAD are then selected to avoid internal signal saturation.
  - This part-to-part value is computed during the final test at ST and stored in the non-volatile memory (NVM); it is automatically loaded after boot.
- Offset calibration:
  - Should always be performed after assembly.
  - Compensates for part-to-part variations, reflow effects, and cover glass effects.
- Crosstalk calibration:
  - Performed whenever there is a protective cover glass on top of the device, which may reflect laser light back to the sensor.
  - Crosstalk can be compensated internally by the VL53L1X .

2.6.3 Ranging Mode configuration, distance and accuracy

The sensor performs ranging continuously and autonomously with a programmable inter-measurement period. If the interrupt pin is connected, the host receives an interrupt whenever a new measurement is available. The inter-measurement period must be longer than the selected timing budget plus 4 ms.

The measurement timing budget can be set from 20 to 1000 ms. Increasing the timing budget increases the maximum distance and reduces the repeatability error (standard deviation of measurements), but power consumption also increases:

- 20 ms is the minimum timing budget, can be used only in Short Distance Mode
- 33 ms is the timing budget that can be used for all distance modes
- 140 ms is the minimum timing budget which allows maximum distance of 4 m in Long Distance Mode (dark ambient light and a 54% gray target).

The minimum accurate ranging distance is 40 mm, while the maximum ranging distance depends on several factors such as the ambient light (the lower the better), the reflectance of the target (the higher the better), on the timing budget (the higher the better), on the selected ROI (the larger the better) and on the selected ranging mode:

- Short Distance Mode:
  - ranging distance up to 1.3 m
  - independent of ambient light and target reflectance

- Medium Distance Mode:
  - ranging distance up to 2.9 m in the dark
  - limited to 0.7 m in strong ambient light (200 kcps/SPAD, direct illumination on the sensor in a sunny day, infrared component removed by glass)
- Long Distance Mode:
- ranging distance from 1.7 to 3.6 m max. in the dark for targets with 17 to 88% reflectance
- limited to 0.7 m in strong ambient light
- longest ranging distance is 4 m when timing budget is at least 140 ms

The ranging error is the sum of the accuracy and the repeatability error, and is typically between ±20mm in the dark, and ±25mm in strong ambient light:

The software driver provided by ST uses two parameters to qualify the ranging measurement:

- VL531L1X_CHECKENABLE_SIGMA_FINAL_RANGE:
  - standard deviation in mm, default is 15mm
  - decrease to reduce repeatability error, but maximum ranging distance is also reduced
- VL53L1X_CHECKENABLE_SIGNAL_RATE_FINAL_RANGE:
  - rate of photons reflected by target in Mcps, default is 1 Mcps
  - increase to reduce repeatability error, but maximum ranging distance is also reduced

2.6.4 Power up and boot sequence

In the BlueTile, the XSHUT pin connected to the host BlueNRG-2 (IO7 pin) is used to power off the sensor between measurements. The maximum boot time is 1.2 ms.

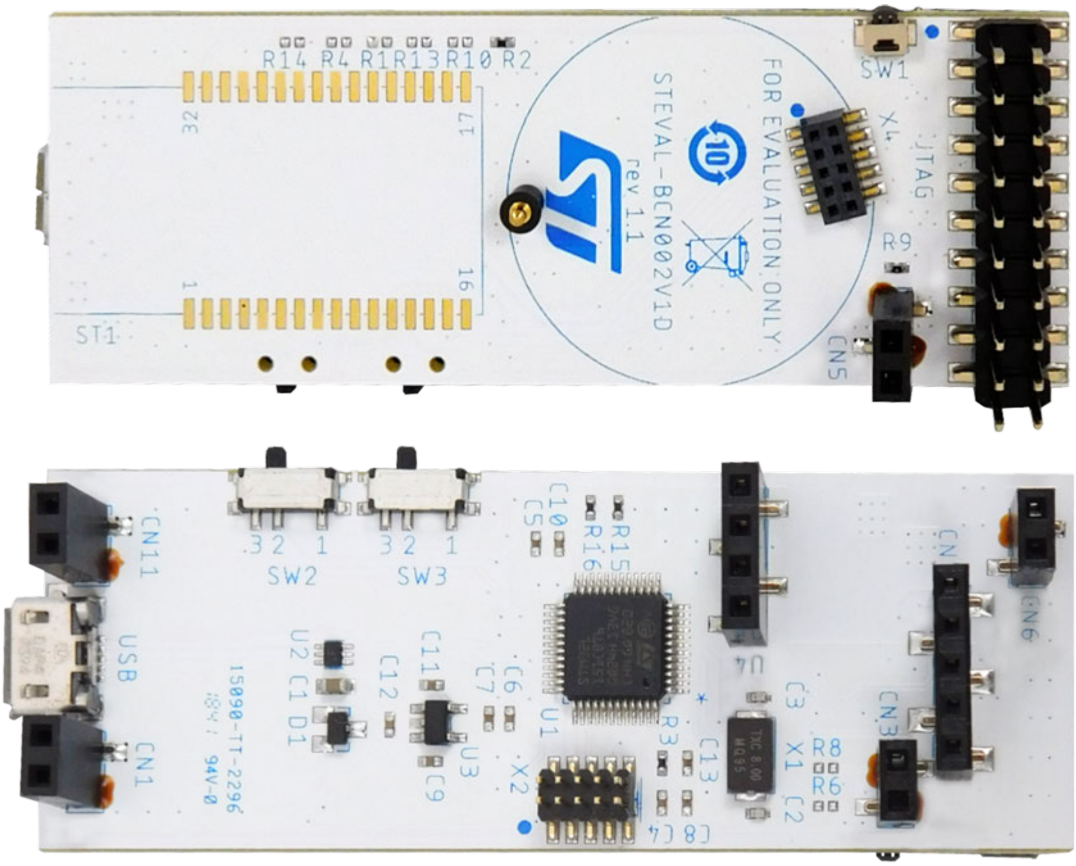
Note: When the sensor is powered off, the configuration is lost. The sensor must be re-configured on each wake-up.

To minimize power consumption, the application firmware may skip the configuration step after wake-up and use the default (long ranging mode, 30 ms timing budget). The application may also perform an early readout, not waiting for the data ready flag, and immediately shut down the sensors. This reduces power consumption but also limits accuracy. The minimum ranging distance in this case is around 70 mm.

3 STEVAL-BCN002V1D host board for programming and debugging

The STEVAL-BCN002V1D is used to Flash and debug the STEVAL-BCN002V1 BlueTile sensor node.

Figure 5. STEVAL-BCN002V1D top and bottom

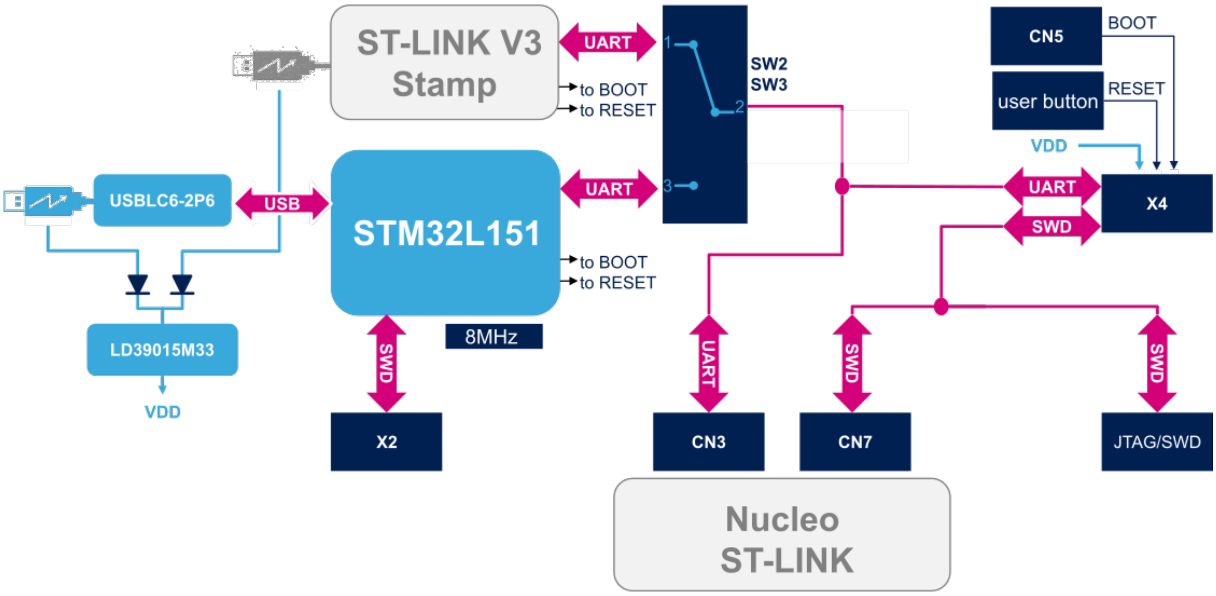


During Flashing and debugging, remove the battery as the BlueNRG-2 device on the BlueTile is powered by the host board, which receives its supply voltage through its USB connector or on the USB connector of the ST-LINK V3 Stamp if you are using it.

The BOOT and RESET pin of the BlueNRG-2 on the BlueTile are controlled by the STM32L1 on the host board, or by the ST-LINK V3 Stamp if used, or by the user (user button and connector CN5).

Figure 6. **STEVAL-BCN002V1D block diagram**

USBLC6-2P6: ESD protection
LD39015M33: LDO 3V3 - outputs to VDD
STM32L151: Cortex-M3 microcontroller
X2: 10-pin connector to JTAG/SWD of external ST-LINK
CN3: 2-pin connector to UART of Nucleo ST-LINK
CN5: 2-pin connector - force to VDD
CN7: 5-pin connector to JTAG/SWD of Nucleo ST-LINK
JTAG/SWD: 20-pin connector to JTAG/SWD of external ST-LINK
User button: force to GND
SW2 for UART RX/ SW3 for UART TX:
- 1-2 for ST-LINK V3
- 2-3 for STM32L1
X4: 10-pin connector - outputs to BlueNRG-2 device on the BlueTile board



The BlueNRG-2 is programmed through the UART from the STM32L1 on the host board, or from the ST-LINK V3 Stamp module if used.

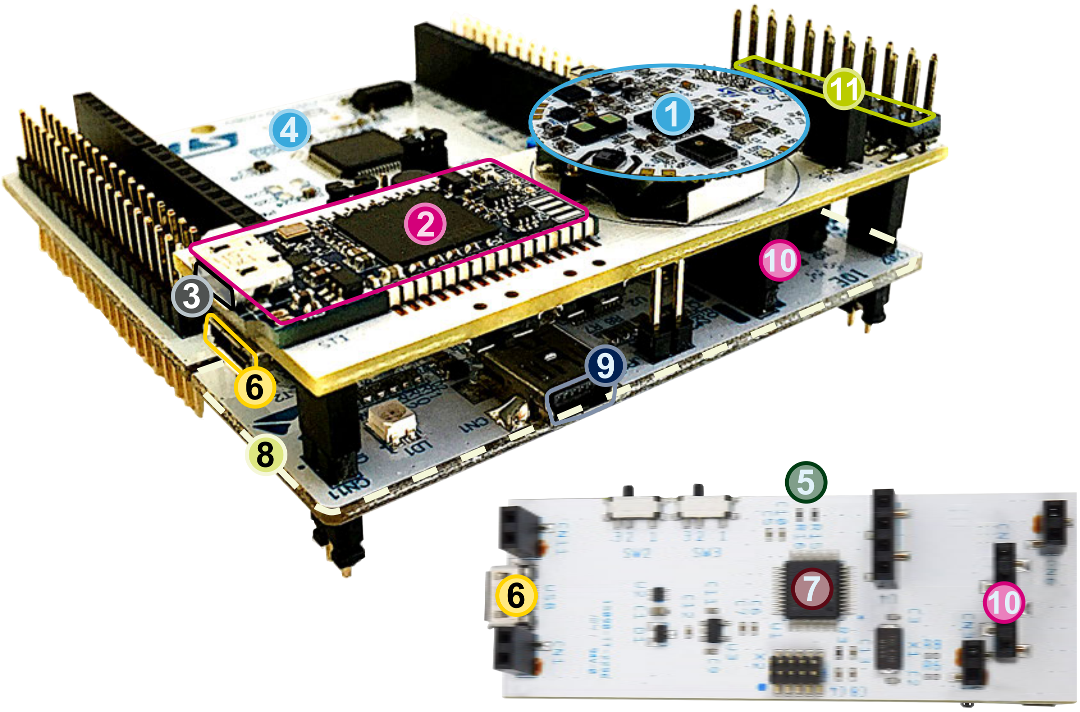
Switches SW2 and SW3 must be in the following positions:

- 2-3 when the STM32L1 of the host board is used
- 1-2 when ST-LINK V3 is used

The BlueNRG-2 can also be programmed and debugged using the SWD of the Nucleo ST-LINK, or the SWD of an external ST-LINK or other debugger.

Figure 7. Configuration with STEVAL-BCN002V1 sensor node and STEVAL-BCN002V1D host board plugged onto a NUCLEO ST-LINK

1. STEVAL-BCN002V1 BlueTile sensor node
2. ST-LINK Stamp V3
3. ST-LINK Stamp V3 USB port (also power source for the microcontroller)
4. STM32 Nucleo development board
5. STEVAL-BCN002V1D host board (bottom side)
6. STEVAL-BCN002V1D USB port (also power source for host board microcontroller)
7. STM32L151 host board microcontroller
8. Nucleo ST-LINK (the rest of the Nucleo board may be detached)
9. Nucleo ST-LINK USB port
10. 5 pin JTAG/SWD for Nucleo ST-LINK (connected)
11. 20 pin JTAG/SWD for external ST-LINK V2 (not connected)

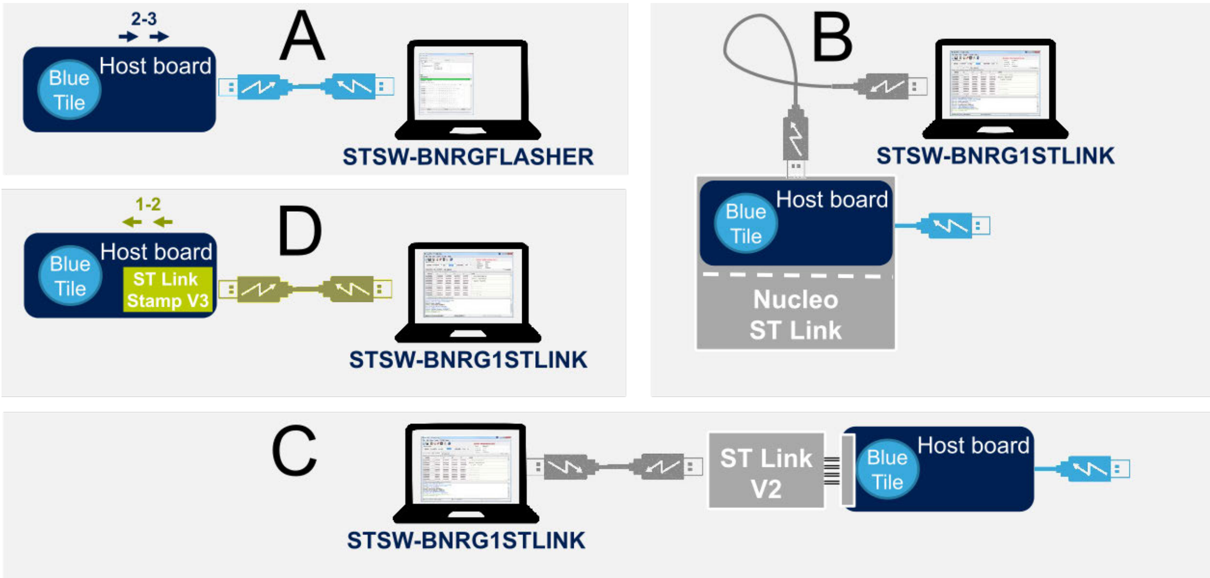


To Flash and debug the STEVAL-BCN002V1 BlueTile sensor node, the following software must be installed on your computer:

- STSW-STM32102 STM32 Virtual COM port driver (VCOM); (not needed for Windows 10).
- STSW-BNRGFLASHER utility to Flash the STEVAL-BCN002V1 or the STSW-BNRG1STLINK (or other IDE) utility to Flash and debug using an ST-LINK.

Figure 8. **Different ways to Flash and debug using the BlueTile host board and optional ST-LINK**

Option A: host board only
- SW2 and SW3 in positions 2-3
- Flasher in UART Mode
- GUI: STSW-BNRGFLASHER
Option B: host board and Nucleo ST-LINK
- SW2 and SW3 in positions 1-2
- GUI: STSW-BNRG1STLINK or any IDE
Option C: host board and standalone ST-LINK/V2 debugger/programmer (or other JTAG/SWD debugger)
- GUI: STSW-BNRG1STLINK or any IDE
- USB connection on host board powers BlueTile board
Option D: host board with soldered ST-LINK V3 module
- GUI: STSW-BNRG1STLINK or any IDE
- USB connection on host board powers BlueTile board



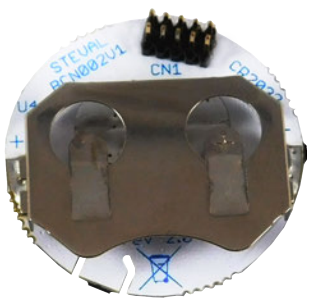
3.1 How to Flash using the STEVAL-BCN002V1D host board only

This configuration is the simplest and most straightforward way to Flash the BlueTile.

Note: No debugging is possible in this configuration.

Step 1. Remove the battery from the STEVAL-BCN002V1 BlueTile sensor board.

Figure 9. **STEVAL-BCN002V1 sensor node bottom with battery removed**



Step 2. Plug CN1 on the BlueTile sensor board onto the matching connector on the host board.
Do not plug the sensor node onto the host board with the battery inserted.

Figure 10. Connectors to mount the sensor node on the host board

Step 3. Set switches SW2 and SW3 to position 2-3.
This connects the BlueNRG-2 to the STM32L151 microcontroller on the host board.

Step 4. Plug the USB of the host board to the computer.
This powers the target microcontroller and establishes the UART VCOM communication.

Step 5. Run the STSW-BNRGFLASHER utility.
The utility exploits the STM32L151 microcontroller on the host board.

Figure 11. Configuration for Flash only

1. Flasher in UART Mode
2. STEVAL-BCN002V1D host board
3. SW2 and SW3 in position 2-3
4. STEVAL-BCN002V1 sensor node

3.2 How to Flash and debug using the STEVAL-BCN002V1D host board and the NUCLEO ST-LINK V2

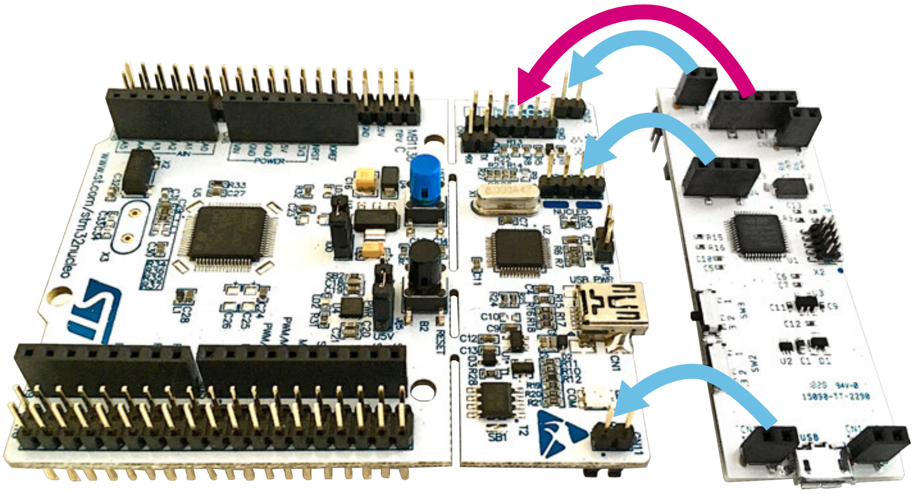
This method represents a straightforward and inexpensive way to Flash and debug with a Nucleo board and any IDE

Step 1. Remove the battery from the STEVAL-BCN002V1 BlueTile sensor board.

Step 2. Plug CN1 on the BlueTile sensor board onto the matching connector on the host board.

Step 3. Plug the host board onto the Nucleo ST-LINK.
- Red arrow: 5-pin SWD connecto
- Blue arrows: alignment connectors

Figure 12. Connectors to mount the host board on the Nucleo ST-LINK debugger



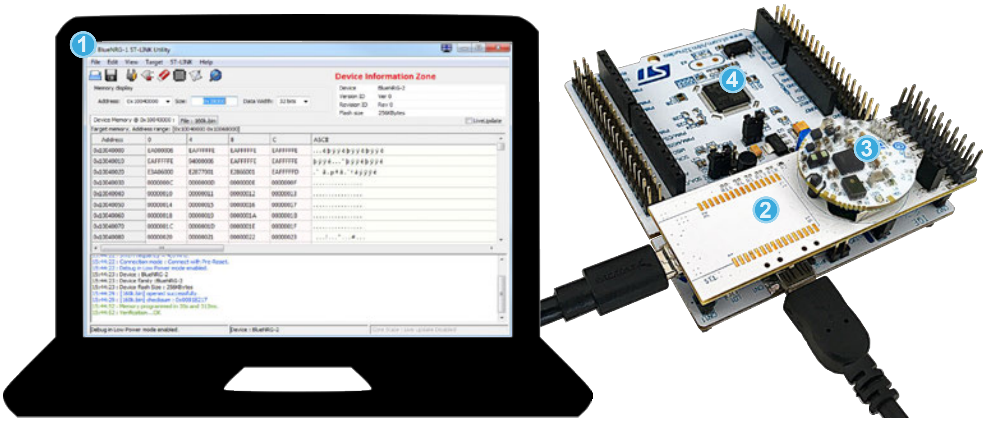
Step 4. Plug the USB of the host board.
This powers the target microcontroller.

Step 5. Plug the USB of the NUCLEO ST-Link to the computer.
This establishes the UART VCOM communication.

Step 6. Run the STSW-BNRG1STLINK utility.
The utility exploits the microcontroller on the NUCLEO ST-LINK.
Any other IDE can be used instead of the utility.

Figure 13. Configuration to Flash and debug with Nucleo ST-LINK programmer/debugger

1. STSW-BNRG1STLINK or any other IDE
2. STEVAL-BCN002V1D host board
3. STEVAL-BCN002V1 sensor node
4. STM32 Nucleo board



3.3 How to Flash and debug using the STEVAL-BCN002V1 host board and the ST-LINK/V2 debugger/programmer

This method allows you to Flash and debug with any JTAG/SWD in-circuit debugger.

Step 1. Remove the battery from the STEVAL-BCN002V1 BlueTile sensor board.

Step 2. Plug CN1 on the BlueTile sensor board onto the matching connector on the host board.

Step 3. Plug the 20-pin JTAG/SWD connector on the host board to your ST-LINK/V2 in-circuit programmer/debugger.

Step 4. Plug the USB of the host board.
This powers the target microcontroller.

Step 5. Plug the USB of the external ST-LINK/V2 to your computer.
This establishes the UART VCOM communication.

Step 6. Run the STSW-BNRG1STLINK utility.
The utility exploits the microcontroller on the external ST-LINK programmer/debugger.
Any other IDE can be used instead of the utility.

3.4 How to Flash and debug using the STEVAL-BCN002V1 host board with ST-LINK Stamp V3 module

This method requires the ST-LINK Stamp V3 module to be soldered onto the host board.

Step 1. Remove the battery from the STEVAL-BCN002V1 BlueTile sensor board.

Step 2. Plug CN1 on the BlueTile sensor board onto the matching connector on the host board with soldered ST-LINK Stamp V3 module.

Step 3. Set switches SW2 and SW3 to position 1-2.
This connects the BlueNRG-2 to the microcontroller on the ST-Link Stamp V3.

Step 4. Plug the USB of the ST-LINK V3 to your computer.
This powers the target microcontroller and establishes the UART VCOM communication.

Step 5. Run the STSW-BNRG1STLINK utility.
The utility exploits the microcontroller on the ST-LINK Stamp V3 module.
Any other IDE can be used instead of the utility.

RELATED LINKS

UM2406: The BlueNRG-1, BlueNRG-2 Flasher SW package

AN4820: BlueNRG-1 and BlueNRG-2 low power modes

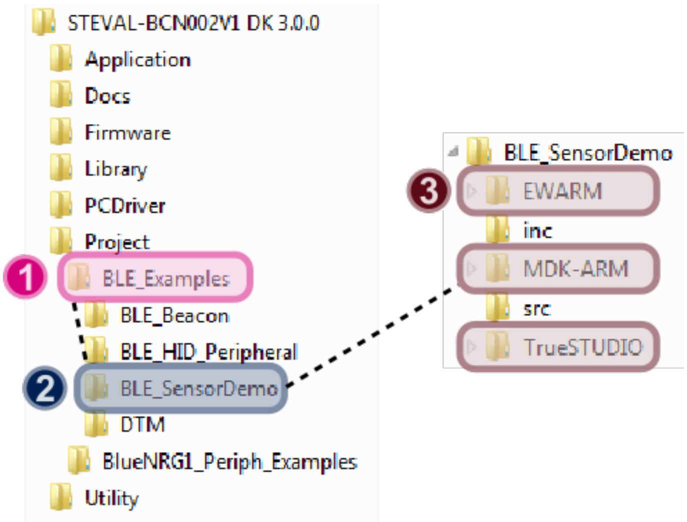
4 Application firmware

The BlueTile is offered together with a software development kit (SDK) with documentation with examples on how to use the BlueNRG-2 radio stack and hardware peripherals, PC utilities to easily configure the examples provided and test all BlueNRG-2 functionalities, and few sample applications:

- BLE_Beacon to advertise programmable data
- BLE_HID_Peripheral to emulate a wireless keyboard or mouse
- BLE_SensorDemo (default BlueTile firmware) to enable the streaming of sensor data to the STBLESensor app
- DTM to enable the real-time interaction between a dedicated graphical user interface (STSW-BNRGUI) and the BlueNRG-2 wireless system-on-chip

Figure 14. SDK directory structure with examples and IDE project files

1. Expand the BLE_Examples folder
2. Choose an appropriate demo application (BLE_SensorDemo is the default demo firmware)
3. Open the project file for your preferred IDE



The BLE_SensorDemo is structured as follows:

- Initialization of the BlueNRG-2 system (Clock, GPIO, Peripherals), the Bluetooth low-energy stack, and MEMS sensors.
- An infinite main loop which calls:
  – the Bluetooth low-energy stack tick function for processing BLE events, usually to change the state of the system
  – user tick function (User_AppTick) executes specific actions based on the state of the system

User actions are usually executed on a regular basis at specific intervals. After the action is executed, the BlueNRG-2 can be set to Sleep Mode with active timers (SLEEPMODE_WAKETIMER is used) to minimize the power consumption and wake up at the right moment, or it can be kept in Active Mode but with the CPU halted (SLEEPMODE_CPU_HALT) to keep GPIOs configured and peripherals active.

In BLE_SensorDemo, the state of the system corresponds to which notification from the server (BlueTile sensor node) to the client (the remote app running on the smartphone) is enable. The following notifications and states can be enabled:

- Environmental data from LPS22HH barometer and HTS221 relative humidity and temperature sensor
  – When enabled, this notification is performed every 100 ms (10 Hz).

- Inertial data from LSM6DSO accelerometer and gyroscope, and LIS2MDL magnetometer. Inertial data is processed on-board by the embedded MotionFX fusion library dedicated to orientation estimation, the output quaternion is also notified.
  – When enabled, these notifications are perfromed every 40 ms (25 Hz).
- Inertial data with fusion, as in the previous item, but VL53L1X time-of-flight ranging data is also added.
  – When enabled, these notifications are performed every 40m s (25 Hz).
- Audio data from MP34DT05-A microphone. Audio data is processed on-board by the embedded BlueVoice library dedicated to DPCM encoding at 32 kbps.
  – When enabled, notifications are sent every 10 ms (100 Hz).
- Accelerometer events data from LSM6DSO accelerometer: events are detected by the built-in logic in the MEMS sensors. The host BlueNRG-2 does not process accelerometer data to perform event detection.
  – This notification only occurs when the enabled event is detected.
- LED control: the app sends commands to the BlueTile in order to control the LED status.
  – The write occurs when the user taps the corresponding button on the app.

Table 2. Power consumption of BlueTile devices

Device	Active phase	Inactive phase (power not gated by MCU)
BlueNRG-2	1.9 mA (Active mode)	0.9 µA (Sleep mode)
LSM6DSO	280 µA (LowP, 50Hz)	3 µA (power-down)
LIS2MDL	475 µA (HighP, 50Hz, NoCanc)	1.5 µA (power-down)
HTS221	0.8 µA (AvgH=4, AvgT=2, 1Hz)	0.5 µA (power-down)
LPS22HH	4 µA (LowP, one-shot 1Hz)	0.9 µA (power-down)
MP34DT05-A	650 µA (normal)	5 µA (power-down)
VL53L1X	<7 mA (<40 ms budget)	5 µA (power-down)
LED	1 mA	0 mA

RELATED LINKS

UM2058: BlueNRG GUI SW package

UM2109: BlueNRG-1 ST-LINK Utility software description

5 Typical system performance

The current consumption of the BlueNRG-2 can be accurately predicted under different conditions using the STSW-BNRG001 PC application.

Below are few examples of estimated power conditions similar to those used in the BLE_SensorDemo reference firmware:

- Advertise at +8 dBm, 30 bytes every 1000 ms: 30 µA
- Advertise at +8 dBm, 30 bytes every 250 ms: 115 µA
- Connected as slave, +8 dBm, 2x 20 bytes every 10 ms (100 Hz): 1510 µA
- Connected as slave, +8 dBm, 1x 20 bytes every 40 ms (25 Hz): 220 µA
- Connected as slave, +8 dBm, 1x 20 bytes every 100 ms (10 Hz): 90 µA

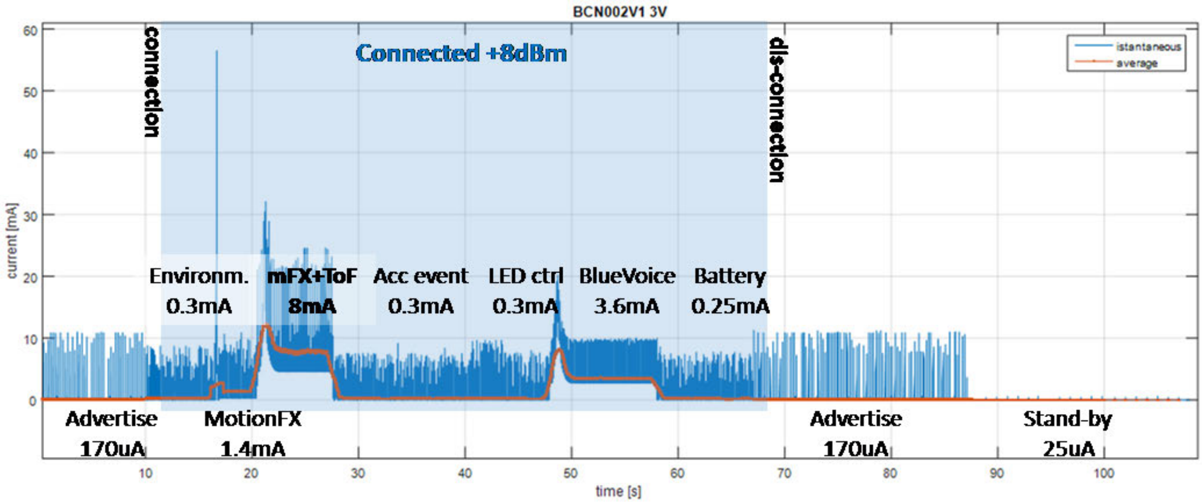
Note: This estimate does not include MEMS sensor consumption and data readout and processing consumption.

The estimate does not include MEMS sensor consumption and data readout and processing consumption. For sensors, the power consumption in the active phase depends on the configuration (low-power or high-performance, output data rate, internal filter setting, etc).

The following figure shows the average power consumption of the BlueTile, when the BlueTile is running the reference firmware (BLE_SensorDemo) and it is connected to the ST BlueMS app running on the smartphone.

Figure 15. Average current consumption of BlueTile BCN002V1 when connected to ST BlueMS app on the smartphone.

Mode: Standby | freq.: n/a | consumption: 25 µA
Mode: Advertise | freq.: 0.25 Hz | consumption: 170 µA
Mode: Battery data | freq.: 1 Hz | consumption: 0.3 mA
Mode: Environmental data | freq.: 10 Hz | consumption: 0.3 mA
Mode: Accelerometer events | freq.: sporadic | consumption: 0.3 mA
Mode: LED control (1mA 43% duty when on) | freq.: sporadic | consumption: 0.3 mA
Mode: Inertial data and MotionFX fusion | freq.: 25 Hz | consumption: 1.4 mA
Mode: BlueVoice 32kbps | freq.: 100 Hz | consumption: 3.6 mA
Mode: Inertial and Fusion with Time-of-Flight | freq.: 25 Hz | consumption: 8 mA



RELATED LINKS

4 Application firmware on page 28

6 Schematic diagrams

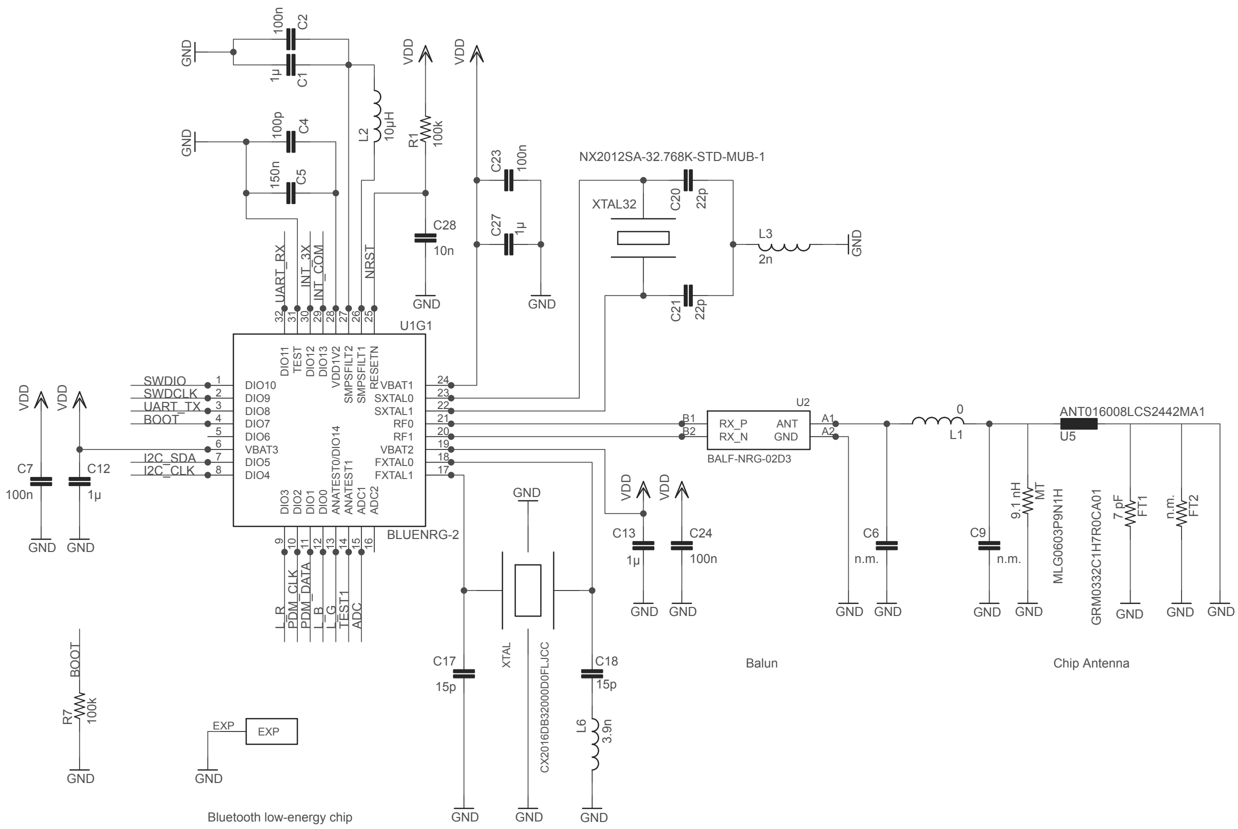


Figure 16. STEVAL-BCN002V1 schematic (1 of 3)

Figure 17. STEVAL-BCN002V1 schematic (2 of 3)

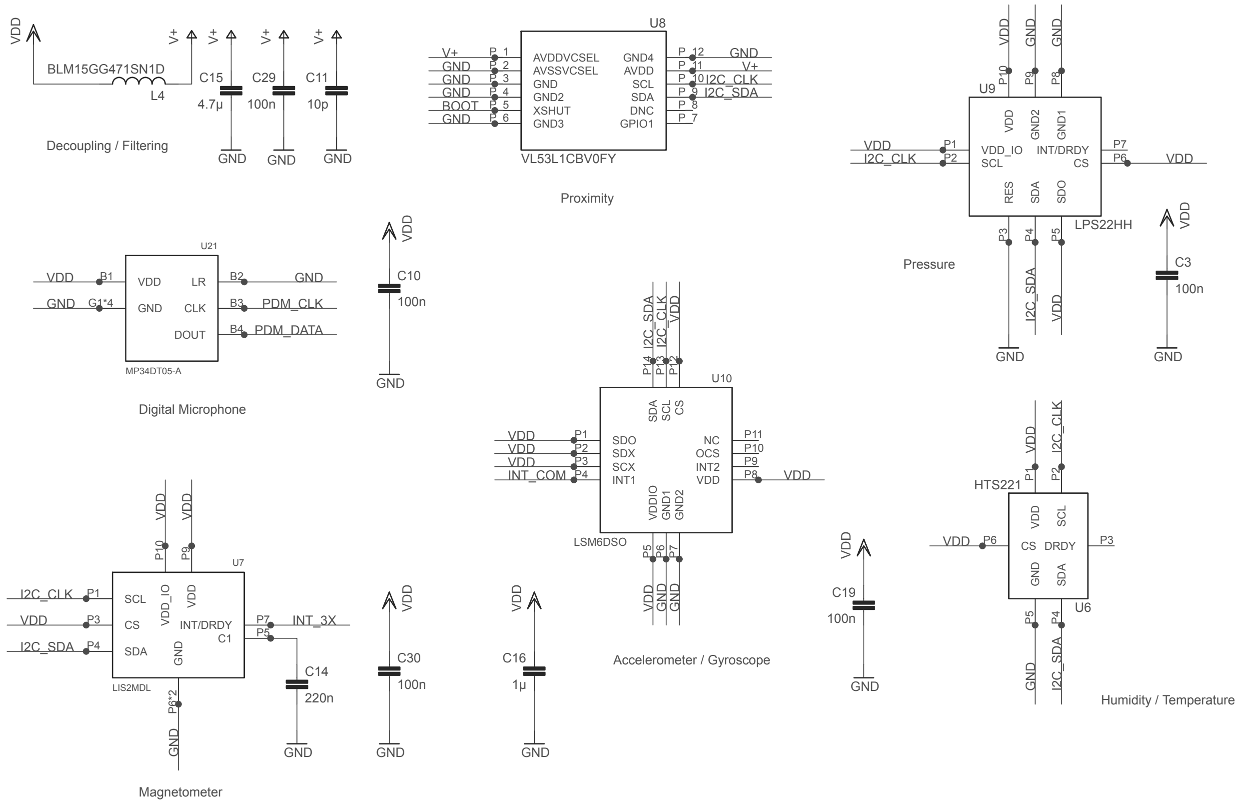
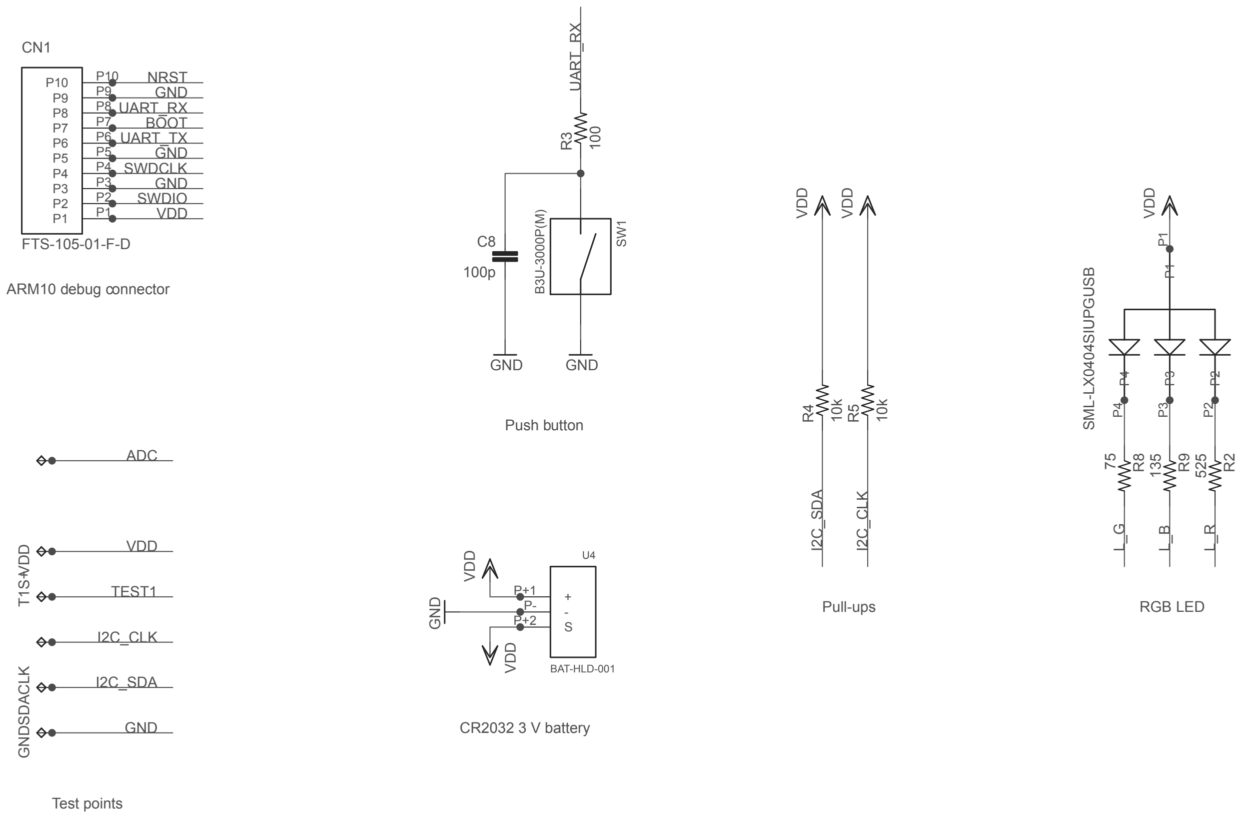


Figure 18. STEVAL-BCN002V1 schematic (3 of 3)



7 Bill of materials

Table 3. **STEVAL-BCN002V1 bill of materials**

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
1	1	U1		Bluetooth® low energy wireless system-on-chip	ST	BLUENRG-232
2	1	U9		Low-Power Pressure sensor	ST	LPS22HH
3	1	U6		Capacitive digital sensor for humidity and temperature	ST	HTS221
4	1	U7		Digital output magnetic sensor	ST	LIS2MDL
5	1	U10		iNEMO inertial module	ST	LSM6DSO
6	1	U8		Time-of-Flight (ToF) ranging sensor	ST	VL53L1CBV0FY
7	1	U2	50 Ω nominal input	Conjugate match balun	ST	BALF-NRG-02D3
8	1	U21		MEMS audio sensor	ST	MP34DT05TR-A
9	1	XTAL	32.0000 MHz 8 pF SMD	Crystal	AVX Corp/ Kyocera Corp	CX2016DB32000D0FLJCC
10	1	XTAL32	32.7680 KHz 12.5 pF SMD	Crystal	NDK America, Inc.	NX2012SA-32.768K-STD-MUB-1
11	1	U4	20 mm - coin	Battery holder	Linx Technologies Inc.	BAT-HLD-001
12	5	C1, C12, C13, C16, C27	1 µF 10 V ±10%	MLCC - SMD/SMT 0603 X5R	Murata	GRM188R61A105KA61D
13	2	C17, C18	15 pF 5 V ±5%	MLCC - SMD/SMT 0603 C0G	TDK	C1608NP01H150J080AA
14	7	C2, C7, C19, C23, C24, C29, C30	0.1 µF 16 V ±10%	MLCC - SMD/SMT 0603 X7R	Walsin Technologies	0603B104K250CT
15	1	C5	0.15 µF 10 V ±10%	MLCC - SMD/SMT X5	Murata	GRM155R61A154KE19J
16	1	L1	0 Ω	Resistor SMD R0603	Walsin Technologies	WR06X000 PTL
17	1	L2	10 µH	Fixed Inductors Power Supply Choke	Murata	LQM21FN100M70L
18	1	C28	0.01 µF 16 V ±10%	MLCC - SMD/SMT 0603 X7R	Walsin Technologies	0603B103K500CT
19	2	C4, C8	100 pF 50 V±5	MLCC - SMD/SMT 0603 C0G	TDK	C1608COG1H101JT
20	2	R4, R5	10 k ±10%	Resistor SMD R0603	Walsin Technologies	WR06X1002FTL
22	2	C6, C9		Do not mount		
23	1	U5	2.4 GHz	BT WLAN Zigbee Antenna chip		ANT016008LCS2442MA1
24	1	FT2		Do not mount		

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
25	1	FT1	7 pF 50 V COG 0201	Ceramic capacitor	Murata	GRM0335C1H7R0CA01
26	1	MT	9.1 nH 250 mA 900 mΩ ±3% 0201	Fixed inductor	TDK	MLG0603P9N1HT000
27	1	R2	510 Ω 5% 1/20 W ±5% SMD 0201	Resistor	Panasonic	ERJ-1GEJ511C
28	1	C14	0.22 µF 50 V ±10% X5R 0603	Ceramic capacitor	Walsin Technologies	0603B224K250CT
29	2	C20, C21	22 pF 50 V NP0 ±5% 20603	Ceramic capacitors	Viking	MC03JTN800220
31	1	L6	3.9 nH 900 mA 90 mΩ ±0.3 nH	Fixed inductor	Murata	LQG15WZ3N9S02D
32	2	R1, R7	100 k ±10% SMD R0603	Resistor	Yageo	RC0603JR-07100KL
33	1	L4	470 Ω 0402 1LN	Ferrite bead	Murata	BLM15GG471SN1D
34	1	R3	100 Ω 1/16 W ± 5% SMD 0603	Resistor	Walsin Technologies	WR06X101JTL
35	1	L3	2 nH 900 mA 120 mΩ SMD	Fixed inductor	Murata	LQG15HN2N0S02D
36	1	C15	4.7 µF 10 V ±10% X5R 0603	Ceramic capacitor	Murata	GRM188R61A475KE15D
37	1	R9	130 Ω 1/20 W ± 1% SMD 0201	Resistor	Panasonic	ERJ-1GEF1300C
38	1	R8	75 Ω 1/20 W ±1% SMD 0201	Resistor	Panasonic	ERJ-1GEF75R0C
39	1	CN1	.050 X .050 C.L.	Low profile header strip	Samtec Inc.	FTS-105-01-F-D
40	1	LEDS	RGB clear 0404 SMD	LED	Lumex Opto	SML-LX0404SIUPGUSB
41	1	SW1	0.05 A 12 V SPST-NO	Tactile switch	Omron Electronics	B3U-3000PM
42	2	C3, C10	0.1 µF 10 V ±10% X5R 0201	Ceramic capacitor	Murata	GRM033R61A104KE15D
43	1	C11	10 pF 50 V ±5% C0G/NP0 0201	Ceramic capacitor	Murata	GRM0335C1H100JA01D

8 Board limitations and operating ranges

LSM6DSO, LIS2MDL, LPS22HH and HTS221 MEMS sensors:

- Mechanical stress on the package (e.g., caused by PCB bending) may affect the measurement accuracy of all sensors.
- Conducted heat may affect measurement accuracy, especially for the environmental sensor HTS221.

Operating conditions for normal operation:

- Temperature between -20 and +85 °C; but care must be taken to ensure battery performance below 0 degrees and above 45 degrees.
- Ambient pressure between 260 and 1260 hPa; extreme values or fast variations may cause mechanical stress in the sensor package and affect measurement accuracy.
- Relative humidity between 0 and 100%; the use of the heating element in HTS221 may be required to restore sensor operation in case of condensation
- The board is not protected against condensation of water.
- FCC part 15 Subpart C verification conditions: indoor environment, temperature up to 45 °C, humidity range between 20% and 80%.

8.1 Temperature, pressure and humidity considerations

A suitable battery must be selected for operation at low/high temperatures, ambient pressure and relative humidity, as it represents the main limiter for temperature, humidity and ambient pressure ranges.

The operating ambient pressure ranges from 260 to 1260 hPa, but the LSM6DSO accelerometer sensor may be sensitive to extreme changes in ambient pressure.

The operating ambient relative humidity ranges from 0 to 100% rH, but the BlueTile board is not protected against condensation, so a suitable water-resistant coating should be applied to the board and its components:

Note: Depending on the chemistry, typical batteries have very limited or no functionality at or below 0 °C. Moreover, rechargeable batteries cannot operate above +45 °C.

8.1.1 Operating ranges for each component

- BALF-NRG-02D3 ultra-miniature balun and integrated harmonic filter:
  - -40 to +105 °C.
- BlueNRG-2 low-energy wireless system-on-chip in QFN32 package:
  - -40 to +105 °C.
- LSM6DSO accelerometer and gyroscope:
  - -40 to +85 °C
  - Max shock 20000 g for 0.2 s.
- LIS2MDL magnetometer:
  - -40 to +85 °C:
  - magnetic dynamic range ±50 Gauss when magnetic field is aligned with any axis
  - ±25 Gauss when it is not aligned
  - Automatic recovery is activated when larger fields are removed, and recovery is complete if larger field do not exceed 1200 Gauss
  - If 1200 Gauss limit is exceeded, there will be a residual magnetization of ±100mGauss for X and Y, ±500mGauss for Z axis.
  - Residual magnetization can be estimated and compensated for, as in hard-iron effects.
  - Max field 10000 Gauss.
- LPS22HH ambient pressure sensor in HLGA-10L package:
  - -40 to +85 °C
  - 260 to 1260 hPa ambient pressure
  - Max pressure 2 MPa

- HTS221 relative humidity and temperature sensor in HLGA-6L package:
  - -40 to +120 °C
  - 0 to 100% rH ambient relative humidity
  - Max. temperature +125 °C
- MP34DT05-A digital microphone:
  - -40 to +85 °C.
- VL53L1X time-of-flight ranging sensor:
  - -20 to +85 °C
  - moisture sensitivity level 3 (MSL) as described in IPC/JEDEC JSTD-020-C.
- CR2032 typical Lithium/Manganese-Dioxide battery:
  - 220mAh nominal capacity and 3V open-circuit voltage at room temperature.
  - At -20 Celsius, open-circuit voltage is reduced from 3V to 2.2-2.7V for 1k-100kΩ loads
  - Capacity is reduced from 220mAh down to 45-175mAh for 1k-100kΩ loads.
  - The battery cannot sustain peak currents at low temperatures.

9 Compliance Information

9.1 Part 15.19

This device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) this device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

9.2 Part 15.21

Any changes or modifications to this equipment not expressly approved by STMicroelectronics may cause harmful interference and void the user’s authority to operate this equipment.

9.3 Part 15.105

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interferences by one or more of the following measures:
- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and the receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

9.4 Compliance Statement

This device complies with Industry Canada licence-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation.

9.5 Japanese RF certification

This radio equipment is certified in accordance with the provisions of Article 38-24 of the Radio Law.
- Classification of the specified radio equipment: 2.4 GHz advanced low power data communication
- Type of emission, frequency and antenna power: FID 2402 ~ 2480 MHz 0.005 W
- Certification number: 006·000773

10 References

The following reference material is all freely available on www.st.com:

- AN5192: LSM6DSO always-on 3D accelerometer and 3D gyroscope
- AN5069: LIS2MDL ultra-low-power high-performance 3D magnetometer
- TN0018: surface mounting guidelines for MEMS sensors in LGA package (LSM6DSO, LIS2MDL)
- AN5209: LPS22HH MEMS nano pressure sensor
- AN4722: HTS221 digital humidity sensor: hardware guidelines for system integration
- TN1219: HTS221 digital humidity sensor reference design implementation
- TN1218: Interpreting humidity and temperature readings in the HTS221 digital humidity sensor
- TN1198: surface mount guidelines for MEMS sensors in HLGA packages (LPS22HH, HTS221, MP34DT05-A)
- AN4428: best practices in the manufacturing process of MEMS microphones
- AN4427:: gasket design for optimal acoustic performance in MEMS microphones
- AN4426: tutorial for MEMS microphones
- AN5191: using the programmable region of interest (ROI) with the VL53L1X
- UM2356: VL53L1X API user manual
- UM2058: BlueNRG GUI SW package (documentation for STSW-BNRGUI, GUI to interact in real-time with BlueNRG-2)
- UM2109: BlueNRG-1 ST-Link utility software package (documentation for STSW-BNRG1STLINK, GUI to flash BlueNRG-2 using an ST-Link)
- UM2406: The BlueNRG-1, BlueNRG-2 Flasher SW package (documentation for STSW-BNRGFLASHER, GUI to flash BlueNRG-2)
- UM2379: The BlueNRG-1, BlueNRG-2 radio driver (documentation for a proprietary 2.4GHz radio stack)
- PM0257: BlueNRG-1, BlueNRG-2 BLE stack v2.x programming guidelines (documentation for Bluetooth low-energy radio stack)

Revision history

Table 4. **Document revision history**

Date	Version	Changes
12-Nov-2018	1	Initial release.
17-Sep-2019	2	Added Section 9.5 Japanese RF certification.
04-Jun-2020	3	Updated Section 7 Bill of materials.

Contents

List of figures

List of tables