Eoxys Systems

XENO+ NB-IOT ML Module  
datasheet

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| --- | --- | --- |
| **Revision History** | | |
| Version | Date | Description of change |
| 1.0 | 29-May-2023 | Initial version |

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# Overview

XENO+ NB-IOT ML Module is a solderable module and used for building intelligent and secure IoT devices for applications such as smart metering, smart lighting, smart tracking, and industrial automation. The XENO+ NB-IOT ML Module integrates LTE Cat NB1/NB2 modem and Multi GNSS GPS modem with NDP120 Neural Decision Processor. This integration brings together AI and deep learning capabilities with cellular connectivity, unlocking unparalleled opportunities for innovation in the IoT ecosystem. By leveraging the intelligent compute, cellular connectivity, and GPS location tracking features of the XENO+ NB-IOT ML module, customers can accelerate the development of their IoT smart metering and smart tracking products. With the freedom to focus solely on adding sensors and their unique value proposition, customers can expedite their product development while ensuring optimal security and performance.

The XENO+ NB-IOT ML module is packaged with Renesas’s RH1NB200 LTE NB-IoT modem that is designed to operate seamlessly on the networks of all major telecommunications carriers. It is an ideal solution to serve the smart metering, smart lighting and smart tracking markets. The RH1NB200 modem offers extremely low power consumption, significantly extending battery life. It also provides an integrated EAL5+ (Evaluation Assurance Level) Secure Element (SE) that provides zero compromise on security to ensure the safety of end applications, particularly smart energy and smart water metering systems.

This module is integrated with Renesas’s DA172x Multi-GNSS based GPS modem and supports GPS/QZSS L1 C/A, GLONASS L10F, BeiDouB1I, Galileo E1B/C bands. It also supports SBAS L1 C/A, WAAS, EGNOS, MSAS, and GAGAN along with A-GNSS up to 64 channels. The time to first fix is Cold Start 35s and Hot Start 1s. The Horizontal Accuracy is 2.0 m CEP.

This module has Syntiant NDP120 neural decision processor that runs multiple Audio and Sensor ML applications simultaneously with minimal power consumption. The NDP120 is designed to natively run multiple Deep Neural Networks (DNN) on a variety of architectures, such as CNNs, RNNs and fully connected networks up to 256 layers.  The NDP120’s Audio-0 (AUD0) port is interfaced with on-board stereo PDM Mics and thus helps Customers to readily run and test the Audio ML classification applications on this module. The Audio-1 (AUD1) and I2C interface pins are available in the 20x20 castellated header pins so that Customers can build carrier board to interface with external Audio Mics and I2C sensors respectively.

The module has smallest possible size with secure IoT MCU of Nuvoton ARM Cortex-M23 (M2354) Trust Zone series MCU @ 96MHz, 1MB Flash, 256KB SRAM, UART/SPI/I2C ports and GPIOs. This module has USB Type C based 5V Power input with serial debug port and Battery power input options. This module has 3 pin SWD pins for SW development and SW debug via Eclipse/KEIL IDE for Embedded SW development for the device by the users.

This module is suitable for Trusted Execution Environment (TEE) with Trusted Applications (TAs). The key security features are,

* Tamper-resistant key storage in Flash and SRAM,
* TrustZone for Armv8-M Technology,
* 8 regions MPU\_NS (for normal world) and 8 regions MPU\_S (for secure world),
* Hardware Crypto Accelerators (AES, ECC and RSA), CRC calculation unit,
* Up to 6 tamper detection pins and
* ARM Platform Security Architecture (PSA Certified Level 2 /Level 3) supported.

# Module Overview

The below table shows the brief overview of modules:

|  |  |
| --- | --- |
|  | XNO-N100N-M1 |
| Module Image |  |
| Wireless Interface | LTE Cat NB1/NB2 and  Multi GNSS |
| Antenna | External Antenna |
| Pins | 20x20 Castellated Pins |
| Size in mm | 55 x 30 mm |

# Product Features and Specifications

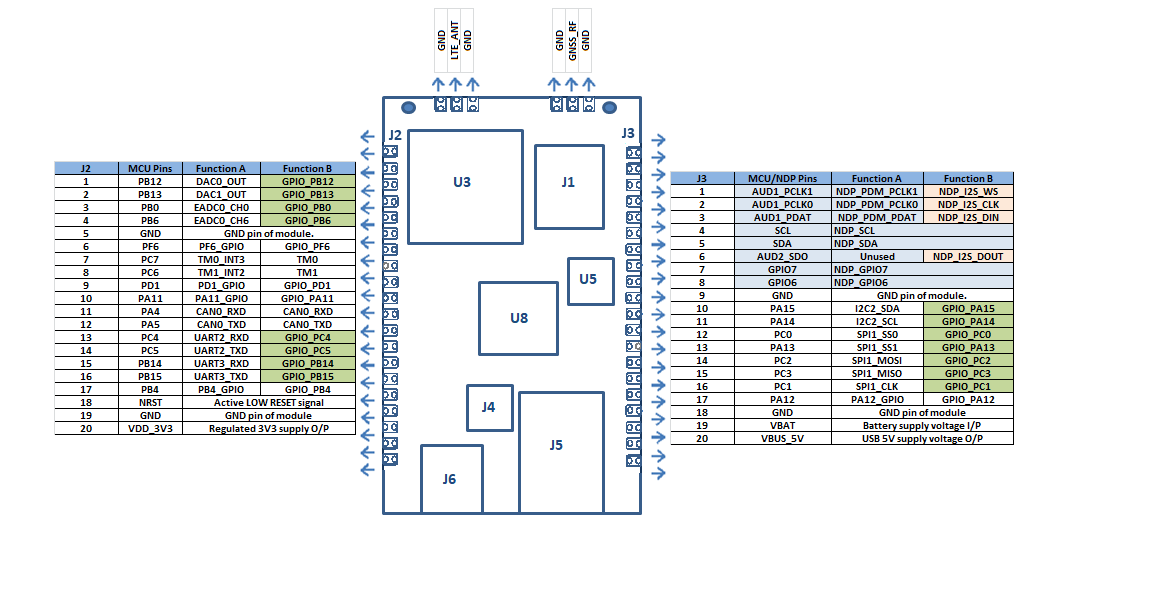
The XENO+ NB-IOT ML module product features and specifications are listed below:

**Table-1:** The Product features and specifications

|  |  |  |
| --- | --- | --- |
| **No.** | **Features** | **Specifications** |
| **Electro – Mechanical specification** | |  |
| 1 | Boards Mounting | 20x20 Castellated Pins |
| 2 | Power and Debug console | 1x USB Type C for 5V Power and Serial debug UART interface for debug messages and user inputs. |
| 3 | Antenna | Supports external antenna |
| 4 | User SW programming | 3 pin SWD pins for SW programming and debug via Eclipse/KEIL IDE. |
| 5 | Operating temperature | -40 to + 85 ℃  *Note: NDP120 is qualified for 0 to 80 ℃* |
| 6 | Operating humidity | 95% or less |
| 7 | Size | 55x30 mm |
| 8 | Weight | grams |
| **Power Specifications** | |  |
| 1 | Module input voltage | 5V from USB Type C connector  \* MOSFET based switch to auto cut-off battery power when USB 5V is present. |
| 2 | Battery input voltage | 2.5V to 5V Battery power from non-rechargeable (or) rechargeable battery. The battery options are listed below:  \* Two 1.5V AA Type Alkaline/Drycell non-rechargeable batteries connected in series for non-restricted transport.  \* 3.6V AA type (Li-SOCl2) non-rechargeable battery for Industrial applications. \* 4.2V LiFePO4 18650 rechargeable battery. The recharging circuit to be added in carrier board by customer. |
| **LTE Specifications** | |  |
| 1 | LTE | * 3GPP LTE Release 13/14 Cat NB1/NB2 compliant * LTE Cat NB1: 62.5 kbps / 27.2 kbps UL/DL throughput * LTE Cat NB2: 160 kbps / 120.7 kbps UL/DL throughput |
| 2 | SMS | SMS: Text and PDU modes |
| 3 | RF Bands | B1, B3, B5 and B8 |
| 4 | RF Sensitivity | NB-IOT Low Band: -108dB  NB-IOT High Band: -108dB |
| 5 | RF Maximum Output Power | 23dBm |
| 6 | Antenna | Supports external antenna |
| **GPS Specifications** | |  |
| 1 | GPS | * Multi GNSS: GPS/QZSS L1 C/A, GLONASS L10F, BeiDouB1I, Galileo E1B/C bands. * SBAS L1 C/A, WAAS, EGNOS, MSAS, and GAGAN * A-GNSS |
| 2 | Channels | Up to 64 channels |
| 3 | Time to First Fix | Cold Start 35s and Hot Start 1s |
| 4 | The Horizontal Accuracy | 2.0 m CEP |
| 5 | Rx Sensitivity | Tracking -160 dBm, Cold Start -145 dBm, Hot Start -160 dBm |
| **Neural Decision Processor Specifications** | |  |
| 1 | Neural Processor | Syntiant Core 2 NDP120 |
| 2 | Supported Layers | Fully connected, 2D Convolution, Deep-wise convolution, Recurrent neural network including LSTM and GRU and Average & max pooling. |
| 3 | Neural parameters | Upto 896K neural parameters in 8-bit mode, 1.6M parameters in 4-bit mode and 7M+ parameters in 1-bit mode. |
| 4 | Audio interface (onboard) | 1x on-board Stereo PDM Mics connected to AUD0 port. |
| 5 | Audio interface (external) | 1x Audio interface (AUD1 and AUD2) for external Mics.   * PDM mode: AUD1 port alone used with PDM*\_PCLK0, PDM\_PCLK1, PDM\_PDAT* signals on module header. * I2S mode (4-wire): Both AUD1 & AUD2 ports are used with *I2S\_WS, I2S\_CLK, I2S\_DIN, I2S\_DOUT* signals on module header. |
| 6 | Sensor Interface | 1x I2C Interface for connecting any I2C sensors like Accelerometer, Gyro, Pressure, Temperature,..etc sensors. |
| 7 | Other Interface | 2x GPIO signals available on module header pins. These 2 GPIOs can be alternatively configured as UART: *UART\_TX* and *UART\_RX* interface. |
| **CPU & Other Specifications** | |  |
| 1 | CPU | Nuvoton M2354 series MCU with ARM Cortex-M4 at 96MHz |
| 2 | Flash Memory | 1MB with Preassigned FOTA section |
| 3 | RAM | 256KB SRAM |
| 4 | Additional Flash | 8MB Serial Flash for NDP firmware and ML models storage |
| 5 | Sensor Interfaces | On Function-A pins:  1x SPI with two chip selects  2x UART  1x I2C  1x CAN  2x ADC  2x DAC  2x PWM  5x GPIOs |
| 6 | RTOS | FreeRTOS |

# Module Pinouts:

This module has 20x20 Castellated pins. The Left side 20 pins mapping and Right side 20 pins mapping are listed below. The MCU port pins can be assigned with 2 predefined module functions: Function-A and Function-B. The users can also map custom functions as per MCU native GPIO functions on these pins.



## Left side 20 pins connector signals

|  |  |  |  |
| --- | --- | --- | --- |
| SNO | MCU Pins | Function A | Function B |
| 1 | PB12 | DAC0\_OUT | GPIO\_PB12 |
| 2 | PB13 | DAC1\_OUT | GPIO\_PB13 |
| 3 | PB0 | EADC0\_CH0 | GPIO\_PB0 |
| 4 | PB6 | EADC0\_CH6 | GPIO\_PB6 |
| 5 | GND | GND pin of module. | |
| 6 | PF6 | PF6\_GPIO | GPIO\_PF6 |
| 7 | PC7 | TM0\_INT3 | TM0 |
| 8 | PC6 | TM1\_INT2 | TM1 |
| 9 | PD1 | PD1\_GPIO | GPIO\_PD1 |
| 10 | PA11 | PA11\_GPIO | GPIO\_PA11 |
| 11 | PA4 | CAN0\_RXD | CAN0\_RXD |
| 12 | PA5 | CAN0\_TXD | CAN0\_TXD |
| 13 | PC4 | UART2\_RXD | GPIO\_PC4 |
| 14 | PC5 | UART2\_TXD | GPIO\_PC5 |
| 15 | PB14 | UART3\_RXD | GPIO\_PB14 |
| 16 | PB15 | UART3\_TXD | GPIO\_PB15 |
| 17 | PB4 | PB4\_GPIO | GPIO\_PB4 |
| 18 | NRST | Active LOW RESET signal to MCU. The Push button also asserts RESET signal to LOW. | |
| 19 | GND | GND pin of module. | |
| 20 | VDD\_3V3 | Regulated 3V3 supply output from module to other circuits of carrier board. | |

## Right side 20 pins connector signals

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SL.NO | MCU/NDP120 Pins | Function A | Function B | |
| 1 | AUD1\_PCLK1 | NDP\_PDM\_PCLK1 | NDP\_I2S\_WS | |
| 2 | AUD1\_PCLK0 | NDP\_PDM\_PCLK0 | NDP\_I2S\_CLK | |
| 3 | AUD1\_PDAT | NDP\_PDM\_PDAT | NDP\_I2S\_DIN | |
| 4 | SCL | NDP\_SCL | | |
| 5 | SDA | NDP\_SDA | | |
| 6 | AUD2\_SD0 | Unused | | NDP\_I2S\_DOUT |
| 7 | GPIO7 | NDP\_GPIO7 | | |
| 8 | GPIO6 | NDP\_GPIO6 | | |
| 9 | GND | GND pin of module. | | |
| 10 | PA15 | I2C2\_SDA | GPIO\_PA15 | |
| 11 | PA14 | I2C2\_SCL | GPIO\_PA14 | |
| 12 | PC0 | SPI1\_SS0 | GPIO\_PC0 | |
| 13 | PA13 | SPI1\_SS1 | GPIO\_PA13 | |
| 14 | PC2 | SPI1\_MOSI | GPIO\_PC2 | |
| 15 | PC3 | SPI1\_MISO | GPIO\_PC3 | |
| 16 | PC1 | SPI1\_CLK | GPIO\_PC1 | |
| 17 | PA12 | PA12\_GPIO | GPIO\_PA12 | |
| 18 | GND | GND pin of module | | |
| 19 | VBAT | Battery supply voltage input to module with 2.5V to 5V range. If Battery is connected, the module works with this battery supply. | | |
| 20 | VBUS\_5V | USB 5V supply voltage output from module to other circuits of carrier board. This is USB 5V supply. When USB cable is removed, the module will switch to Battery supply on-the-fly, if battery is connected. | | |

## NDP120 Control and Data signals

The NDP120 Neural Decision Processor is interfaced with host MCU with SPI Bus and Interrupt signals. The host MCU downloads the compiled binary of NDP120 bin packages via this SPI bus. The NDP120 uses the same SPI bus to notify the host MCU with the classified outcomes.

Also, there is external Serial Flash memory of 8MB is also interfaced in the same SPI bus. This Serial Flash is used for storing the NDP120 bin packages.

The host MCU’s Bootloader can download the new NDP120 bin packages from the FOTA server (or) from USB serial port from user’s PC/Laptop and flashes the same into this Serial Flash memory so that Customers Host application can readily use the updated Serial Flash NDP120 bin packages and download the same into NDP120.

The host MCU’s Bootloader can be used by the Customer to download the NDP120 bin packages. The Customer uses a Python utility to download the NDP120 bin packages via debug USB Serial port via USB cable from PC. The PC need to run the Python utility to download the user generated NDP120 bin packages via USB Serial port chunk by chunk. The Bootloader receives each chunk and flash the same into this Serial flash memory.

The Bootloader also helps in remote management of the NDP120 bin package image versions and auto updates the bin packages with latest version Over-The-Air (OTA).

1. The Bootloader offers OTA (Over-The-Air) download capability of NDP120 bin packages for the field deployed IOT devices.
2. The Bootloader uses TCP/IP protocol over WiFi via Socket commands for communicating with FOTA Server (Called as TUNE APP Server). The connection management (connect, dis-connect and re-connect) is handled by the Bootloader.

|  |  |  |  |
| --- | --- | --- | --- |
| SNO | MCU Pin | Pin name | Description |
| 1 | PB9 | NDP\_RST | GPIO output pin. Used as RESET signal of NDP120. Need to keep LOW for 2500ms to reset. Acts as a RESET signal to NDP120. |
| 2 | PA6 | NDP\_INT | External Interrupt capture pin. NDP120 interrupts the MCU host via this signal. |
| 3 | PA10 | NDP\_SPI\_SCK | SPI2\_SCK of MCU host. |
| 4 | PA8 | NDP\_SPI\_MOSI | SPI2\_MOSI of MCU host. |
| 5 | PA9 | NDP\_SPI\_MISO | SPI2\_MISO of MCU host. |
| 6 | PB2 | NDP\_SPI\_CS | GPIO output and used as SPI chip select-0 signal to select NDP120. |
| 7 | PB3 | FLASH\_CS | GPIO output and used as SPI chip select-1 signal to select Serial Flash memory connected with MCU host. |
| 8 | PB5 | GNSS\_CS | GPIO output and used as SPI chip select-2 signal to select GPS modem firmware download memory section with MCU host. |

## NB-IOT Modem and GPS Modem Control and Data signals

**Modem control pins:**

|  |  |  |  |
| --- | --- | --- | --- |
| SNO | MCU Pin | Pin name | Description |
| 1 | PB7 | MOD\_PWREN | GPIO Output pin. Used to enable the power for both NB-IOT and GPS modems. By default, both NB-IOT and GPS modems are powered down during the power-on time of module. The MCU SW need to power-up these modems by making it LOW.  0 – ENABLE Power to both NB-IOT and GPS modems.  1 – SHUTDOWN Power to both NB-IOT and GPS modems. |
| 2 | PB8 | MOD\_RESET | GPIO Output pin. Used to Reset the LTE Module. Need to keep LOW for at least 500ms to reset both NB-IOT and GPS modems. |
| 3 | PA7 | MOD\_RING | GPIO Input pin. Default state is HIGH. Pulled to LOW for a specific duration to indicate SMS, URC or Phone call ring status to MCU.  SMS - LOW for 120ms  URC - LOW for 60ms  Phone call - LOW until host accepts the call or caller stops calling |
| 4 | PB1 | MOD\_PS\_STATUS | GPIO Input pin. Indicates LTE module On/Off status.  1 - Module is ON  0 - Module is OFF |

**NB-IOT Modem UART pins:**

|  |  |  |  |
| --- | --- | --- | --- |
| SNO | MCU Pin | Pin name | Description |
| 1 | PA2 | MOD\_RX | UART1 RX of MCU |
| 2 | PA3 | MOD\_TX | UART1 TX of MCU |
| 3 | PA1 | MOD\_CTS | UART1 CTS of MCU. The CTS is driven by modem to MCU to indicate whether modem can accept UART data.  0 – Modem is ready and can accept data  1 – Modem is not ready and can’t accept data |
| 4 | PA0 | MOD\_RTS | UART1 RTS of MCU. The RTS is driven by MCU to modem to indicate whether MCU can accept UART data.  0 – MCU is ready and can accept data  1 – MCU is not ready and can’t accept data |

**GPS Modem UART pins:**

|  |  |  |  |
| --- | --- | --- | --- |
| SNO | MCU Pin | Pin name | Description |
| 1 | PB10 | GNSS\_RXD | UART4 RX of MCU |
| 2 | PB11 | GNSS\_TXD | UART4 TX of MCU |

**NB-IOT Modem Firmware Upgrade pins:**

|  |  |  |
| --- | --- | --- |
| SNO | Pin name | Description |
| 1 | TP1 | NB-IOT modem NBIOT\_UART1\_TX |
| 2 | TP2 | NB-IOT modem NBIOT\_UART1\_RX |
| 3 | TP3 | NB-IOT modem NBIOT\_UART2\_TX |
| 4 | TP4 | NB-IOT modem NBIOT\_UART2\_RX |

The user can upgrade the NB-IOT modem firmware through these test point pins.

# SW Functional Specifications

## Bootloader Application Functional Specifications

This module comes with Bootloader as a standalone Boot time application which is executed by default at the boot time. This Bootloader has capability to download following firmware from XENO Flashing PC utility tool via debug UART console as well as from Cloud FOTA server via LTE NB-IOT network:

* 1. Host MCU firmware
  2. NDP120 bin packages
  3. GNSS firmware

The Bootloader helps in management of the devices above 3 firmware image versions and auto updates this device firmware with latest version Over-The-Air (OTA).

1. The Bootloader helps the customers to flash the above firmware/binaries from XENO flashing PC utility tool.
2. The Bootloader offers OTA (Over-The-Air) firmware download capability for the deployed IOT devices to download the above firmware/binaries from Cloud FOTA server.
3. The Bootloader uses TCP protocol over LTE NB-IOT network for communicating with Cloud FOTA Server (Called as TUNEAPP Server). The connection management (connect, dis-connect and re-connect) is handled by the Bootloader.
4. The TUNEAPP server allows embedded firmware updates for all deployed IOT devices in the field via LTE NB-IOT network. The TUNEAPP server will be uploaded with new firmware files so that all deployed IOT devices firmware update is taken care. This TUNEAPP server validates the devices credentials and informs device Bootloader to initiate the Over-The-Air download of new device firmware.

During the initial 3 to 5 seconds of power-on boot time, the Bootloader code checks with the Cloud FOTA server for any new updated version firmware available in the server. If it is available, it downloads the firmware and updates the same.

The module comes with device authentication mechanism part of Bootloader using PKCE (Proof Key for Code Exchange) based Device authentication. The PKCE is used to provide one more security layer to the authorization code flow of OAuth. The Bootloader initiates the Device Authorization Flow by requesting a set of verification codes from the authorization server by issuing an TCP/IP socket requests to the authorization server. The server can approve or deny the requests to authorise the device. After successful authentication of device, the server issues valid access token to the device. The access-token has a limited lifetime mentioned in minutes. When it expires the Bootloader can fetch a new refresh-token. This access-token can be read by user’s main embedded application.

At the end of Bootloader execution, the Bootloader launches the user’s main embedded application.

**AT Commands supported during Bootloader time**

The user inputs for device configuration are done via AT Commands through debug console. The user can press escape character during the boot time to initiate AT commands from debug console. The format of AT command is “AT%<cmd>=<args>” where <cmd> is the command name and <args> is the list of arguments. There are four types of AT Commands.

|  |  |  |
| --- | --- | --- |
| SNO | Types | Description |
| 1 | Read command AT%<cmd>? | This command returns currently set value of the parameters. |
| 2 | Write command AT%<cmd>=<arg1,arg2,..> | This command sets user defined parameter values. |
| 3 | Test command AT%<cmd>=? | This command returns list of supported parameters and its possible values as help info to users. |
| 4 | Execution command AT%<cmd> | This command is non-argument command and reads value of parameters. |

### SW Version Command

|  |  |
| --- | --- |
| SW Version command | |
| AT%SWVER  Execution command | Response:  **%SWVER-FIRMNAME: <Device-SW>**  **%SWVER-NUM: <V10>**  **%SWVER-DATE: <dd-mon-yyyy>**  **OK** |

### Setting FOTA Server Configuration

|  |  |
| --- | --- |
| Setting FOTA Server Configuration | |
| AT%FOTASERCFG=<Server URL>,<Port>  Write command | Response:  **OK** |
| AT%FOTASERCFG?  Read command | Response:  **%FOTASERCFG-URL: <FOTA server URL>**  **%FOTASERCFG-PORT: <Port number>**  **OK** |

### Setting PKCE Configuration

|  |  |
| --- | --- |
| Setting PKCE Configuration | |
| AT%PKCE=<PKCE Secret>  Write command | Response:  **OK** |
| AT%PKCE?  Read command | Response:  **%PKCE-SECRET: <PKCE Secret>**  **OK** |

### Device Info Command

|  |  |
| --- | --- |
| Device Info command | |
| AT%DEVINFO  Execution command | Response:  **%DEVINFO-DEVNAME: <Device name>**  **%DEVINFO-IPADDR: <IP Address>**  **%DEVINFO-MACID: <WIFI MAC ID>**  **OK** |

## User Application Functional Specifications

At the end of Bootloader execution, the Bootloader launches the user’s main embedded application. This user application runs as main application as per their IoT device requirements to manage the sensors, interfaces, memory, and transfer the data via LTE NB-IOT network. The LTE network configuration, sensor configuration, sensor data transfer via TCP Sockets/HTTP/MQTT APIs are maintained by the user embedded application as per their application requirements.

The embedded device’s memory map is defined as per below table so that memory map has 2 sections: 1) Bootloader section, 2) Main user application firmware.

|  |  |
| --- | --- |
| **Features** | **Description** |
| Memory map of program flash of embedded device | 1. **BOOTLOADER\_MEMORY**   Contains Bootloader FIRMWARE.   1. **MAIN\_FIRMWARE\_MEMORY**   Contains ISR\_VECTOR and Main running app’s MAIN\_FIRMWARE, MAIN\_FIRMWARE\_SWVER info memory segments. |

The main application firmware name, version number and release date in MAIN\_FIRMWARE\_SWVER info memory segment so that the Bootloader can use this information. The Bootloader uses PKCE based authentication with FOTA server and after successful authentication, the server issues valid access token to the device so that the Bootloader can use this access token to interact with FOTA server for Over-The-Air firmware download to upgrade to latest main application firmware version.

|  |  |
| --- | --- |
| **Features** | **Description** |
| MAIN\_FIRMWARE\_SWVER memory segment: Main Firmware Info memory section (User application firmware info) | {  FIRM\_NAME: <Device-SW>  SWVER: <V10>  DATE: <dd-mm-yyyy>  } |

# Module Layout and Dimensions

This module layout and dimensions are shown below.

Module Dimensions (in mm)

