WillowBee LoRaWAN User Manual

for WB-L-U-2 and WB-L-W-2

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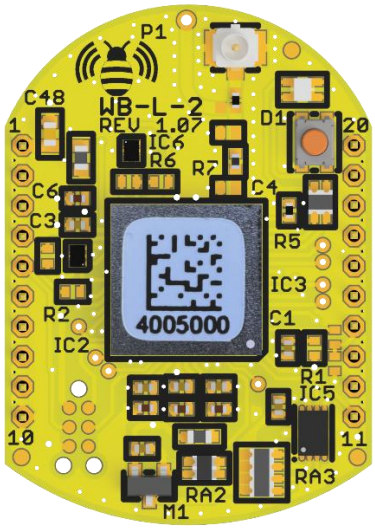

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Overview

WillowBee is an industrial wireless microcontroller module that is designed for LoRaWAN sensor end-node designs and embedded applications that need LoRaWAN communications. This device is a low-power, long-range wireless module designed for integration into IoT endpoints, capable of operating in multiple unlicensed ISM bands compliant with regional LoRaWAN frequency plans such as US915, EU868, AU915, and others. The module is built around the **STM32WL5MOCH6TR** system-on-chip from STMicroelectronics, which integrates both an STM32 Cortex M4 microcontroller and a LoRa-compatible radio transceiver.

WillowBee is pin compatible with other popular wireless devices. WillowBee is fully backed by a 3-year warranty, technical support and application assistance from BiPOM Electronics, Inc.

Microcontroller Features

- Built-in LoRaWAN 1.1.0 Stack
- Ultra Low Power
- Suitable for battery operation
- User programmable
- Configurable power output
- Maximum output power: 22 dBm
- Frequency Bands: US915/AS915/AU915/EU868/CN779/EU433/KR920/IN865/RU86 (Supported but not officially certified in all regions)
- 64 KB of RAM and 256 KB of Flash available to user applications

WillowBee Specifications

- Pin compatible with popular modules
- u.FL Antenna Connector (on WB-L-U-2)
- RF Shield
- Dual Power option: Battery or DC Power
- Temperature Range: -40°C to +85°C
- Dimensions 1.36” x 0.96” x 0.36” (34.54 mm x 24.38 mm x 9.14 mm)
- 2 LED’s and 1 Button
- 32-Mbit Serial Flash
- Configurable 15 I/O Pins
- Drivers for ADC/IO/DAC/SPI/UART/I2C interfaces
  FCC ID: **2BCAS-BIPOM-WBL**
- Part number:

WB-L-U-2	WillowBee with u.FL antenna connector
WB-L-W-2	WillowBee with built-in coil (wire) antenna

Absolute Maximum Ratings

The absolute maximum ratings are stress ratings, and functional operations under such conditions are not guaranteed. Stress beyond the limits specified in the table below may affectdevice reliability or cause permanent damage to the device.

Parameter	Min	Max	Unit
Supply Voltage	-0.3	4.0	V
IO Pin Voltage	-0.3	VCC + 0.3	V
Storage Temperature	-40	85	°C

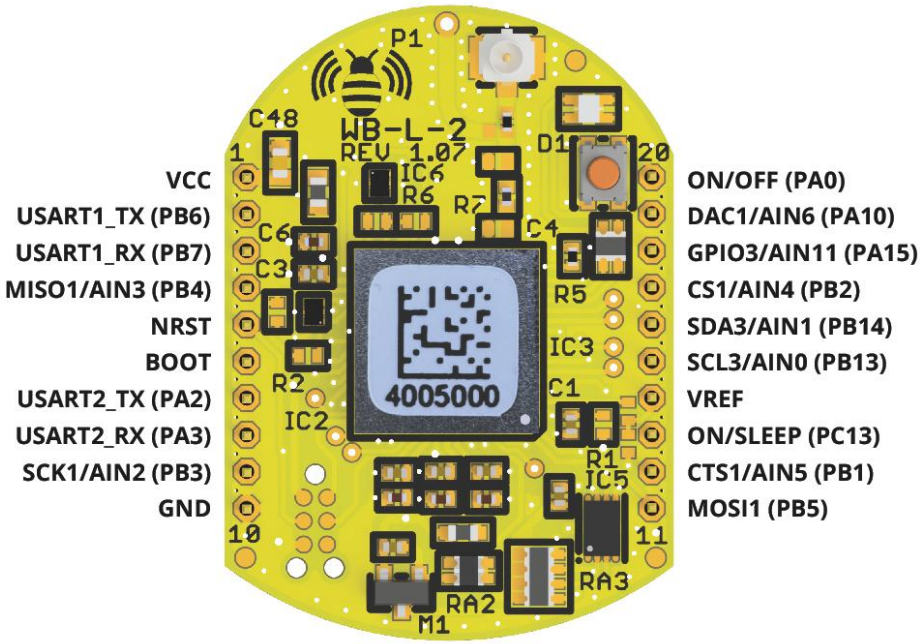
Operating beyond these ratings may cause permanent damage to the module.

Electrical Specifications

STM32WL5MOCH6TR General Operating Conditions:

Parameter	Minimum	Typical	Maximum	Unit
Operating temperature	-40	-	+85	ºC
Clock frequency (CPU)	-	-	48	MHz
VDD (core supply)	1.71	-	3.6	V
Input low voltage (V_IL)	-	-	0.3 × VDD	V
Input high voltage (V_IH)	0.7 × VDD	-	-	V
Output high voltage (V_OH)	0.8 × VDD	-	-	V
Output low voltage (V_OL)	-	-	0.4	V
Input leakage current	-	±1	±100	nA
I/O pin pull-up resistor	30	40	50	kΩ
I/O pin pull-down resistor	30	40	50	kΩ

WB-L-U-2 AND WB-L-W-2 PINOUT



Pin	Signal	I/O	Description
1	VCC	POWER	MAIN POWER SUPPLY 2.3V - 3.6V
2	USART1_TX	INPUT/OUTPUT	UART DATA
3	USART1_RX	INPUT/OUTPUT	UART DATA
4	MISO1	INPUT/OUTPUT	SPI DATA
5	NRST	INPUT	RESET
6	BOOT	INPUT	BOOT
7	USART2_TX	INPUT/OUTPUT	UART DATA
8	USART2_RX	INPUT/OUTPUT	UART DATA
9	SCK1	INPUT/OUTPUT	SPI CLOCK
10	GND	POWER	
11	MOSI1	INPUT/OUTPUT	SPI DATA
12	CTS1	INPUT/OUTPUT	FLOW CONTROL
13	ON/SLEEP	INPUT/OUTPUT	WAKEUP
14	VREF	POWER	ADC REF
15	SCL3	INPUT/OUTPUT	I2C CLOCK
16	SDA3	INPUT/OUTPUT	I2C DATA
17	CS1	INPUT/OUTPUT	SPI CS
18	GPIO3	INPUT/OUTPUT	PROGRAMMABLE GPIO
19	DAC1	INPUT/OUTPUT	DAC
20	ON/OFF	INPUT	ON/OFF

Radio Technology

- **Modulation:** LoRa™ (Chirp Spread Spectrum)
- **Transmitter Output Power:** Programmable, up to **+22 dBm**
- **Frequency Range:** Configurable for various LoRaWAN frequency bands, including 902.3 MHz to 914.9 MHz (uplink), 923.3 MHz to 927.5 MHz (downlink) for North America (US915).
- **Bandwidths Supported:** LoRa: 125 kHz (standard), 500 kHz (for higher data rates)
- **Spreading Factors:** All spreading factors supported by LoRaWAN
- **Channel Plan:** Supports LoRaWAN compliant regional channel plans including US902-928 MHz and other international bands.
- **Hopping:** Frequency hopping enabled for compliance with FCC Part 15.247

Transmit Behavior

- Transmission is event-driven under LoRaWAN Class A operation.
- A typical uplink lasts **< 1 second**, followed by receive windows per LoRaWAN spec.
- **Duty cycle and dwell time** are controlled by the LoRaWAN MAC and remain within FCC limits.
- Frequency hopping is implemented as per LoRaWAN regional parameters for the US.

Power & Host Interface

- **Operating Voltage:** 2.8 V to 3.5 V DC
- **Transmit Current (22 dBm):** ~135 mA
- **Receive Current:** ~10 mA
- **Sleep Current:** < 2 µA

Typical Power Consumption of WillowBee at 3.3V power supply and 25° ambient temperature:

Mode	Current	Unit
Sleep (Stop2 mode)	2.0	µA
MCU Processing (CPU 48 MHz active)	8.0	mA
Receive (LoRa RX, SF7–SF12)	11.0	mA
Transmit @ +22 dBm (max power)	115.0	mA
Transmit @ +14 dBm (typical)	42.0	mA

Temperature Sensor

STM32WL5MOCH6 microcontroller on WillowBee has a built-in temperature sensor, integrated into the analog peripheral block and connected internally to the ADC. This temperature sensor is better for internal thermal monitoring and not suitable for high-precision ambient temperature sensing. For calibrated, application-grade temperature data, an external temperature sensor (e.g., I²C or analog) should be used.

STM32WL5MOCH6TR Internal Temperature Sensor Specifications:

Parameter	Value
Connected to	ADC input channel 17 (ADC_IN17)
Resolution	Up to 12 bits (ADC dependent)
Voltage Resolution @ 3.3V	0.805 mV/LSB
Temperature Resolution	Approximately 0.1 °C per LSB
Typical Accuracy (Calibrated)	±1 °C to ±2 °C
Uncalibrated Accuracy	Up to ±5 °C
Temperature Range	-40 °C to +125 °C
Response Time	~10 µs (depends on sampling)
Calibration Constants	TS_CAL1 @ 30 °C, TS_CAL2 @ 110 °C
Use Case	Internal die temperature monitoring (not ambient)

Analog to Digital Converter (ADC)

STM32WL5MOCH6TR microcontroller module on WillowBee has a built-in SAR (Successive Approximation Register) ADC with 16 external input channels. Not all channels are brought out to WillowBee pins.

ADC Supports:

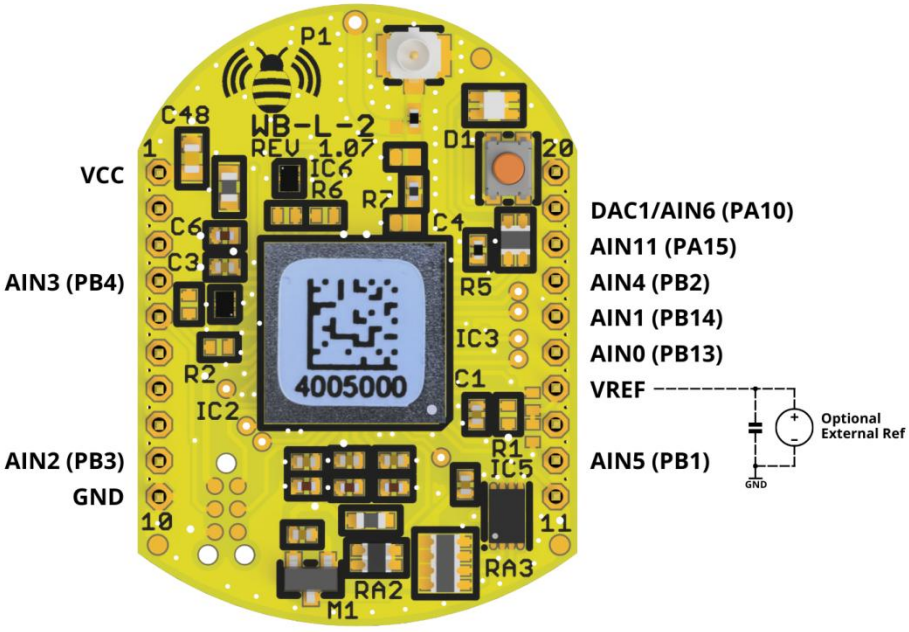
- VREFINT (internal reference 2V or 2.5V for peripherals like ADC or DAC)
- Temperature sensor
- VBAT monitoring

ADC has optional hardware oversampling for improved resolution and noise rejection. Accuracy is influenced by VREF+ stability, PCB layout, and sampling time. For better effective resolution (e.g., ~14-bit noise-free), oversampling and filtering techniques can be applied.

Feature	Value
Maximum Resolution	12 bits
Configurable Resolutions	6, 8, 10, or 12 bits via software
Input Range	0 to VREF+ (usually VDDA or external reference)
Maximum Sampling Rate	1 channel at ~2.5 million samples per second

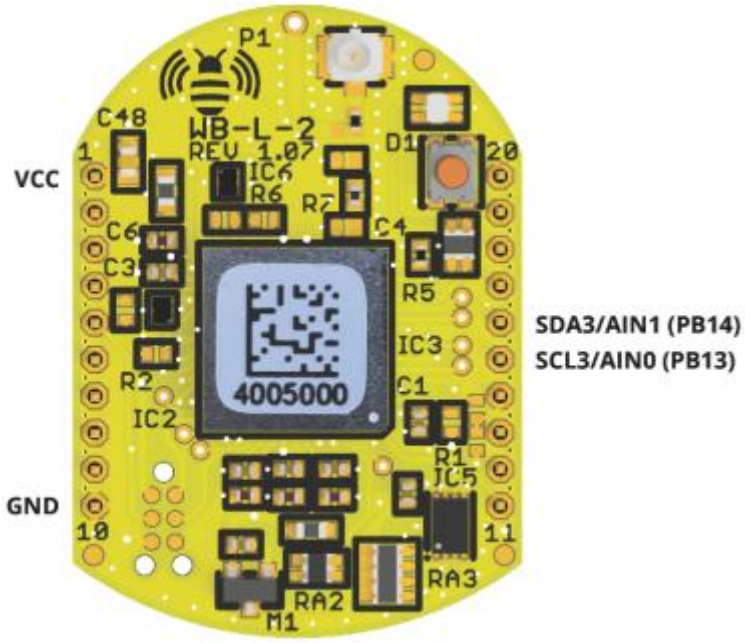
ADC/DAC: ADC inputs on pins 4, 9, 12, 15, 16, 17, 18 and 19 / DAC output on pin 19.

VREF: A very precise buffered reference voltage on pin 14.



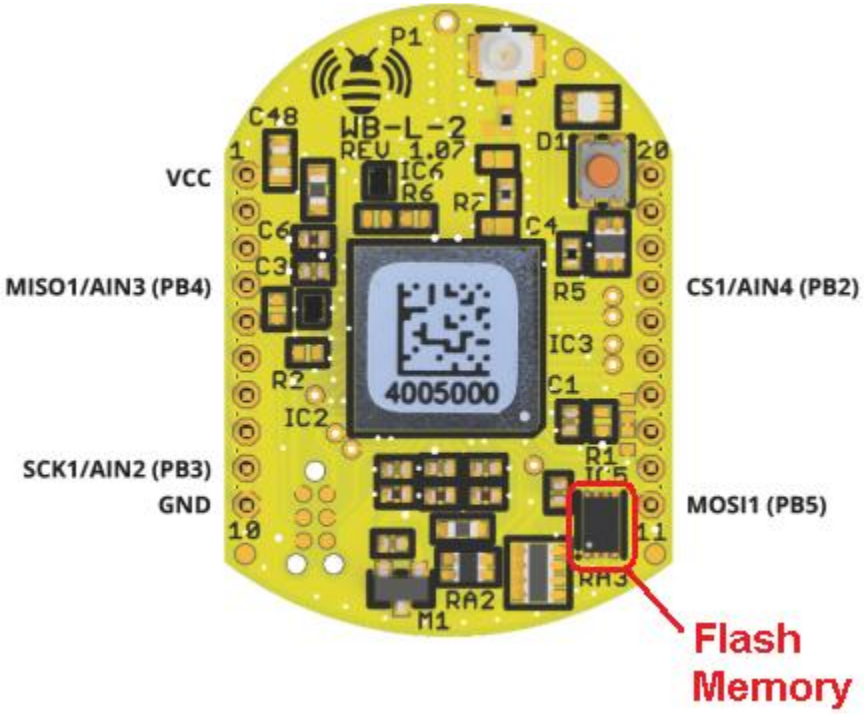
Serial Interfaces

I2C: Hardware I2C on pins 15 and 16 (mapped to microcontroller's I2C interface 3)

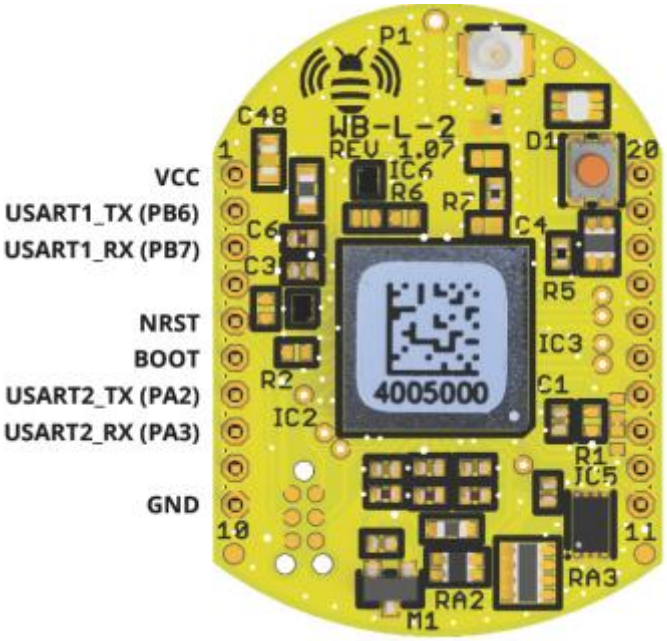


SPI: Hardware SPI on pin 4,9,11,17 for external devices using SPI1

Hardware SPI2 connected to on-board Flash Memory

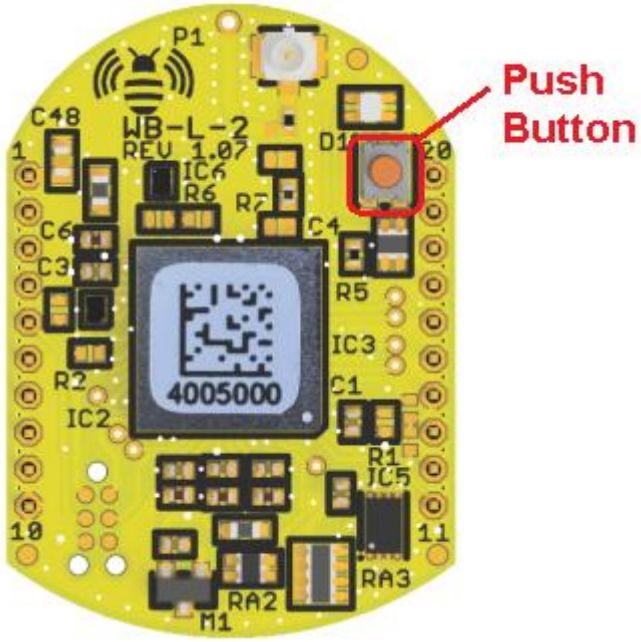


UART: Dual hardware UART's. UART1 on pins 2 and 3. UART2 on pins 7 and 8. Combined with BOOT (pin 6) and NRST (pin 5), UART2 allows firmware download to WillowBee over UART2.



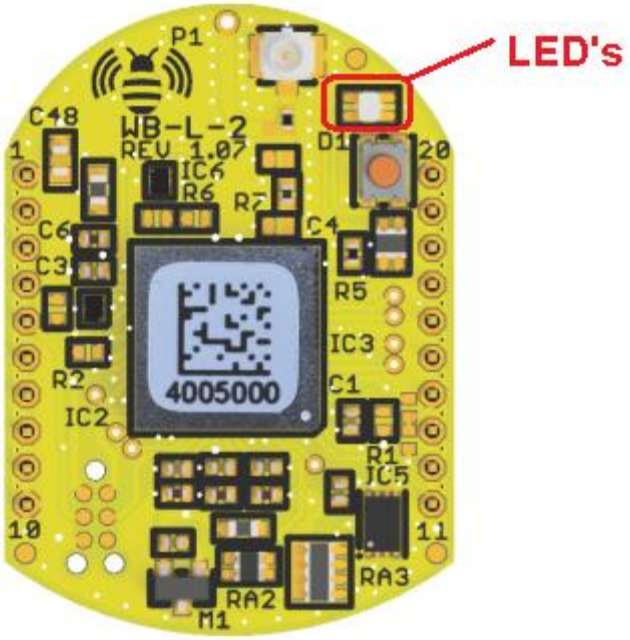
Serial Wire Debug (SWD) port: This interface is available on X5 Tag-Connect pads and allows debug devices such as ST Micro's ST Link to be used for high-speed firmware download and debug. Contact BiPOM Electronics for a special cable for this interface.

Push Button: Push button is connected to port PA0 of the microcontroller which also acts as ON/OFF pin to wake up the microcontroller. One of the alternate functions of PA0 pin is wakeup function (WKUP1).



LED's: WillowBee has an on-board dual-color LED. The LED is mapped to microcontroller pins as follows:

LED	Port	Function
Green	PA5	High to turn on Low to turn off
Red	PA6	High to turn on Low to turn off



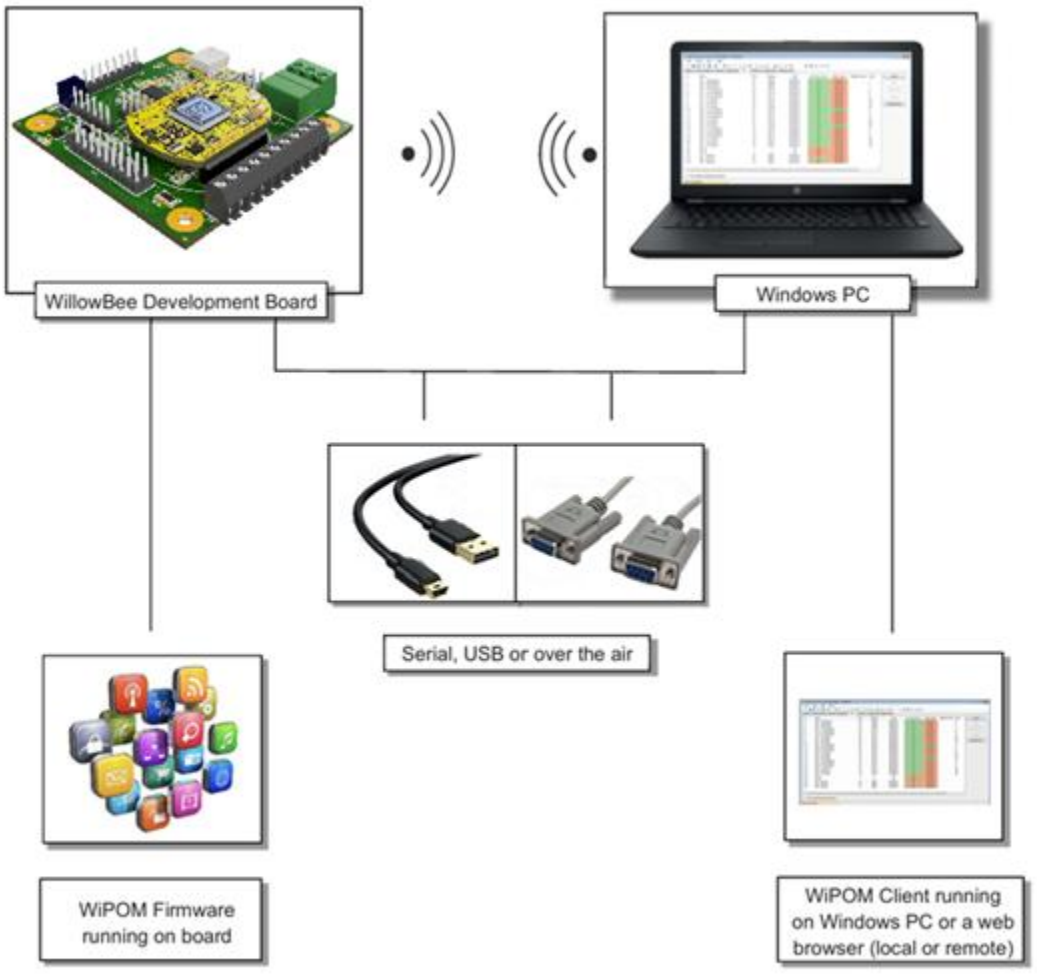
Intended Applications

This module is designed to be embedded in a wide range of IoT devices, including:

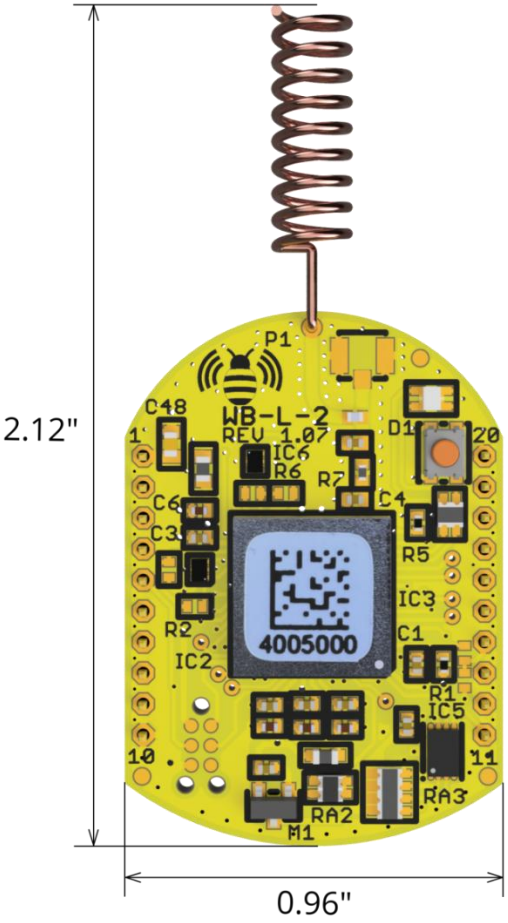
- Smart meters
- Wireless sensors
- Industrial monitoring equipment
- Asset tracking solutions

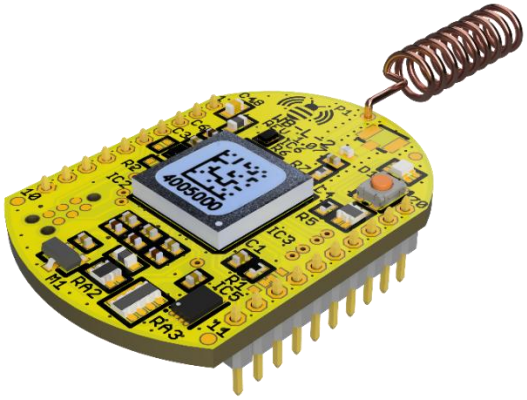
WiPOM Wireless Point of Monitoring

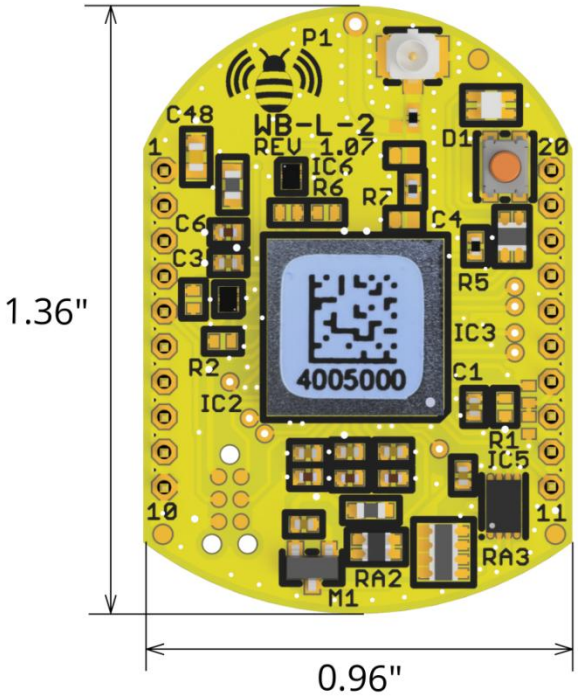
WiPOM is a software application package that adds sophisticated data logging, remote terminal, and PLC like capabilities to the WillowBee sensor board. WiPOM can run on STM32WL family of processors, WiPOM handles all aspects of Industrial IoT applications development, including I/O management, tags, alarms, events, SMS/email handling, MODBUS master and slave capability, modem detection, and management and Cloud portal support. WiPOM runs directly on WillowBee sensor board. Coupled with the WiPOM Client running on a Windows PC or on a web server, programming the WillowBee sensor board is reduced to a series of configuration selections to build a complete IoT system. WiPOM takes software out of the equation for faster time to market. Creating remote monitoring and control systems and sensors has not been easier.

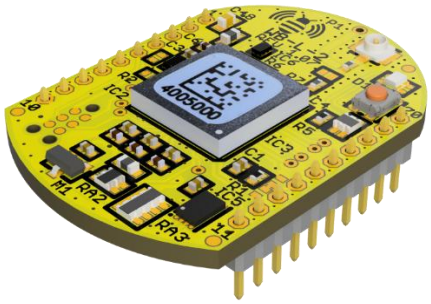


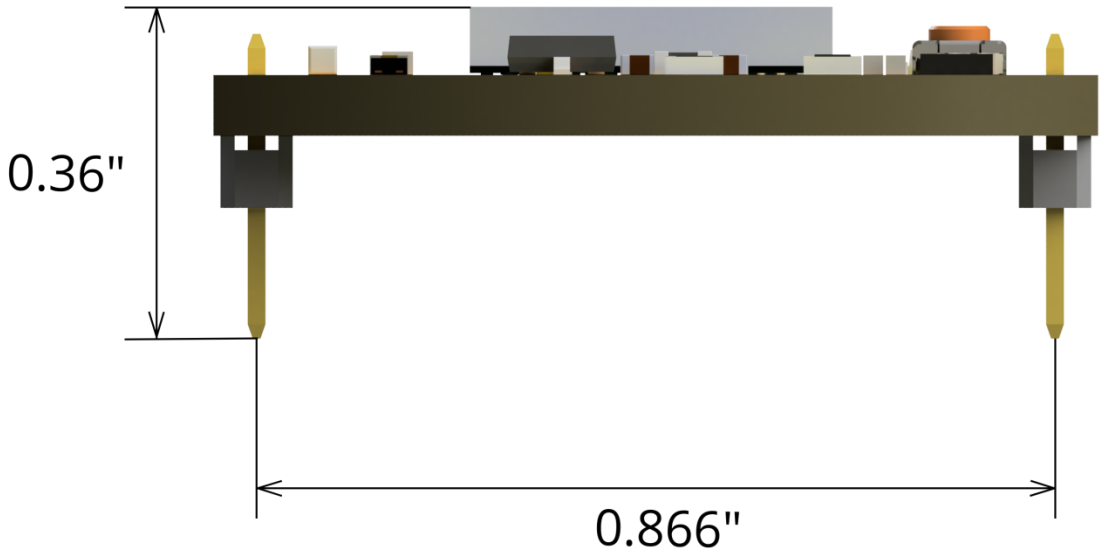
Dimensions



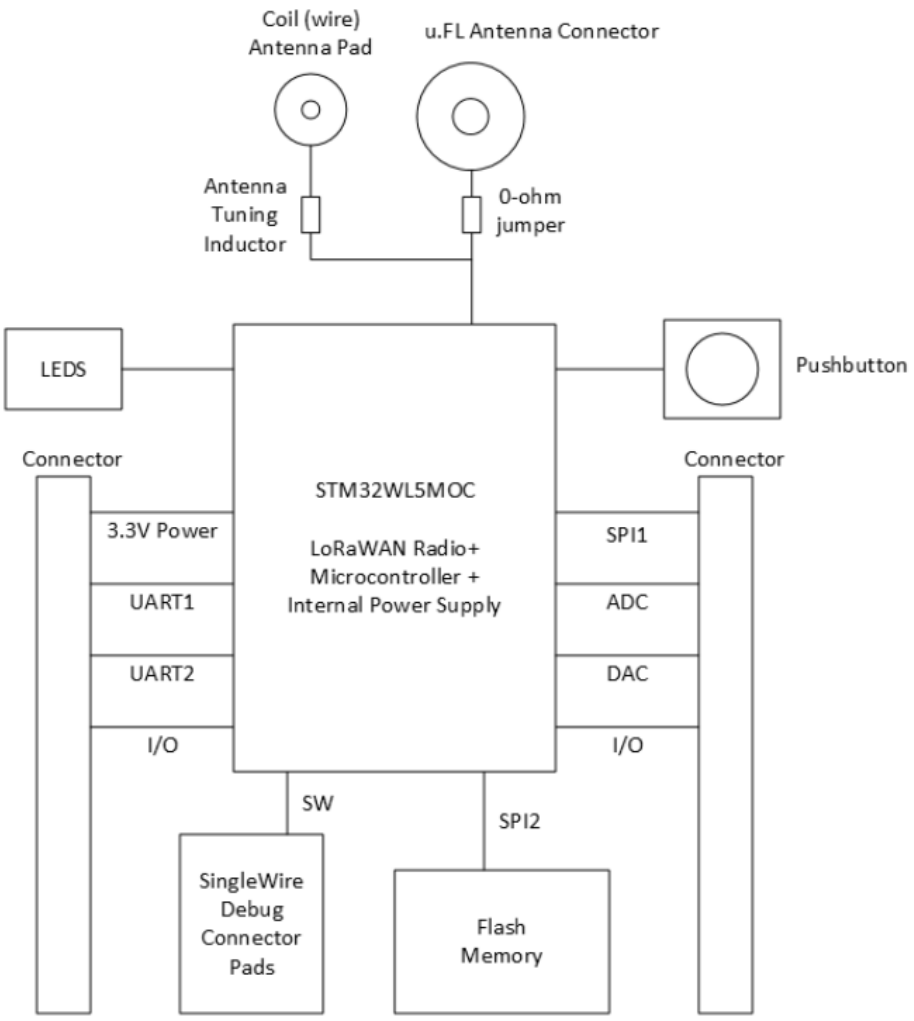



1.36"
0.96"
P1
WB-L-2
REV 1.07
C48
D1
IC6
R6
R7
C6
C4
C3
R5
IC3
4005000
R2
C1
IC2
R1
IC5
RA3
RA2
M1
1
20
10
11




0.36"
0.866"

WillowBee WB-L Block Diagram

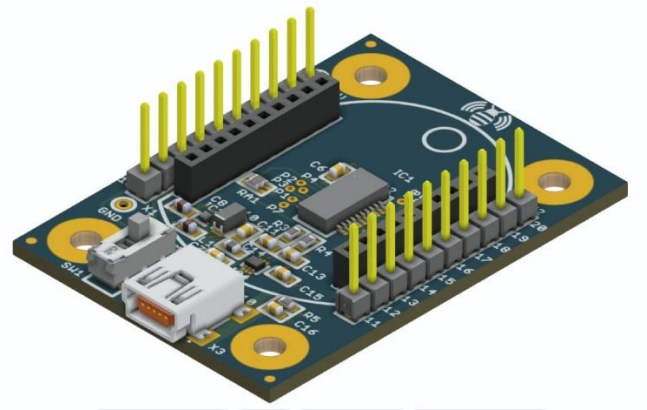


Development Boards

BRD-WB-L-USB

BRD-WB-L-USB is a versatile carrier board that can be used for evaluation, demonstration and deployment of WillowBee LoRaWAN product.

BRD-WB-L-USB is fully backed by a 3-year warranty, technical support and application assistance from BiPOM Electronics, Inc.



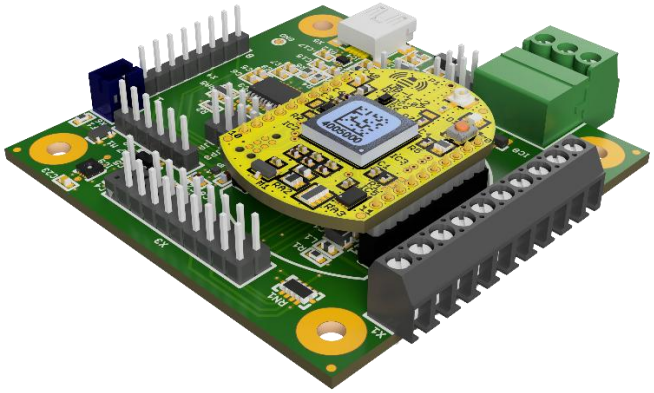
Features

- Pin headers for easy access to WillowBee pins
- Communication Method: USB
- Type B Mini high-retention USB connector
- USB connector approved for industrial environments
- FTDI chip to convert USB to serial port
- Powers WillowBee from 5 Volts on USB
- 3.3V Regulator for WillowBee
- 4 mounting holes
- Switch to select program mode
- Temperature range: -40°C to +85°C
- Dimensions : 1.95" x 1.40" x 0.64" (inches); 49.5mm X 35.6mm X 16.2mm (metric)
- Supported by popular development packages
- Micro-IDE integrates GCC Compiler and Downloader for WillowBee
- Keil uVision and ST Micro Cube support
- Command line downloader for any 3rd party development tool
- Examples for all major build environments
- Various LoRa sensor projects
- Libraries and drivers for a variety of sensor components and IC's.
- Generic UART, I2C, SPI, 1-wire, analog and digital I/O drivers
- Open source examples
- Warranty Period: 3 years

MINI-MAX/WB-1

MINI-MAX/WB-1 is a compatible development and deployment board for WillowBee. With powerful capabilities and seamless integration, the MINI-MAX/WB-1 is the perfect choice for developers looking to create cutting-edge IoT applications. MINI-MAX/WB-1 enables rapid sensor development.

MINI-MAX/WB-1 is fully backed by a 3-year warranty, technical support and application assistance from BiPOM Electronics, Inc.

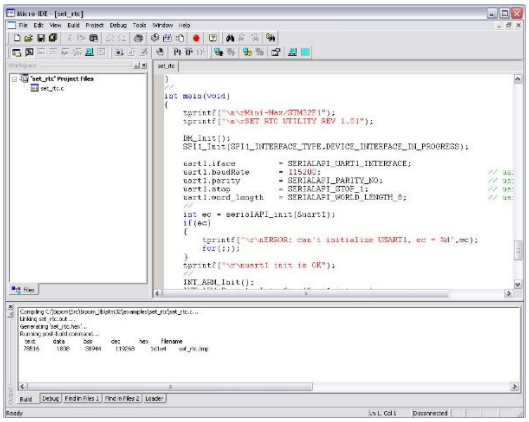


Features

- Compatible with both LoRaWAN and LTE-M1/NB-IoT WillowBee's
- Expansion connector for easy access to WillowBee
- Communication Method: USB and RS485
- Type B Mini high-retention USB connector
- USB approved for industrial environments
- FTDI chip to convert USB to serial port
- External power or 5 Volts on USB
- 3.3V Regulator for WillowBee
- Connector for optional 3.6V battery
- 4x Analog inputs, 12-bit resolution, screw terminal
- 1x Digital output, open drain
- 1x Digital input, dry contact
- Expansion bus interface to low-cost peripheral boards
- 4 mounting holes
- Temperature range: -40°C to +85°C
- Dimensions: 2.35" (59.7mm) x 2.40" (61mm)
- Supported by popular development packages
- Micro-IDE integrates GCC Compiler and Downloader for WillowBee
- Keil uVision and ST Micro Cube support
- Command line downloader for any 3rd party development tool
- Examples for all major build environments
- Various LoRa sensor projects
- Libraries and drivers for a variety of sensor components and IC’s.
- Generic UART, I2C, SPI, 1-wire, analog and digital I/O drivers
- Open source examples
- Warranty Period: 3 years

WillowBee Development System

Free C/C++ development system for WillowBee modules.



Features

- Micro-IDE: A Windows-based Integrated Development Environment, Serial Loaders, Terminal
- Complete online documentation, Project Examples. Support for ARM GCC Compiler
- Download Link: www.bipom.com/wb_down.php

Host Device Integration

This section provides integration instructions for BiPOM's WillowBee WB-L-U-2 and WB-L-W-2 LoRaWAN modules into host devices, intended to support FCC and ISED (Canada) modular certifications. It describes required design considerations for antenna integration, PCB layout, power supply, RF exposure, and compliance labeling.

ESD Protection:

Store WillowBee modules in **ESD-safe packaging** (shielding bags, conductive trays)

Ensure **ESD wrist straps**, **antistatic mats**, and **ionizing blowers** are used during:

- Assembly
- Testing
- Manual handling

Mark host device PCB with **ESD caution symbols** if exposed during field servicing.

Antenna Connector:

u.FL coaxial connector is provided on WB-L-U-2 for antenna connection.
No external antenna connector on WB-L-W-2 (internal antenna).

Labeling:

The host device must display:
“Contains FCC ID: 2BCAS-BIPOM-WBL” “Contains IC: 33805-BIPOMWBL”

If the label is not visible after integration, the information must also be included in the user manual.

All integration and end-user documentation will include the required statements in accordance with 47 CFR §§ 15.19, 15.21, and 15.105.

Certified Antennas for BiPOM WillowBee:

WB-L-U-2: External antenna connection via u.FL connector
WB-L-W-2: Integrated coil (wire) antenna

The module supports **external antennas**, with verified operation and FCC/ISED testing conducted using the following 3 antenna types:

Model	Manufacturer	Type	Frequency MHz	Ground Plane	Peak Gain (dBi)
2JW1115-C943B	2J	Dipole	863-870, 902-928	Not needed	2.3 @868 MHz 3.3 @915 MHz
2JF0415P-010MC137	2J	Flex PCB	863-870, 902-928	Not needed	2.7 @868 MHz 3.6 @915 MHz
SI328100009	2J	Coil (wire)	863-870, 902-928	Needed	-0.3

All three antennas have **50-ohm** nominal impedance. Only antennas of the same type (Dipole or Flex PCB type for WB-L-U-2) and **equal or lesser gain** will be marketed with the module.

RF Exposure:

The module is intended for use in devices that maintain a **minimum separation distance of 20 cm** from the human body. Final host devices will include proper labeling and user instructions to ensure compliance with FCC and ISED RF exposure guidelines.

FCC RF Exposure Statement:
"This equipment complies with FCC radiation exposure limits set forth for an uncontrolled environment. This transmitter must not be co-located or operated in conjunction with any other antenna or transmitter."

ISED RF Exposure Statement:
"This equipment complies with RSS-102 radiation exposure limits set forth for an uncontrolled environment. This transmitter must not be co-located or operated in conjunction with any other antenna or transmitter."

Separation Distance:

A minimum separation distance of 20 cm between the antenna and any person must be maintained to comply with FCC and ISED RF exposure requirements.

Compliance Statement

The module will be labeled with a valid FCC ID **2BCAS-BIPOM-WBL**, and all integration and end-user documentation will include the required statements in accordance with 47 CFR §§ 15.19, 15.21, and 15.105 as shown below:

FCC §15.19(a)(3) – Compliance Statement

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.

FCC §15.21 – Unauthorized Changes Warning

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC §15.105(b) – Class B Digital Device Interference Notice

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 interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and 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.

FCC Modular Integration Instructions (per KDB 996369 D03 2.2–2.12)

2.2 Host Labeling Requirements

Q: What labeling must the host product include?
A: The host must be labeled with the following:

"Contains FCC ID: 2BCAS-BIPOM-WBL"
"Contains IC: 33805-BIPOMWBL"

If the module label is not visible after installation, this labeling must appear on the exterior of the host device.

2.3 Antennas

Q: What antennas can be used with the module?
A: Only the antennas listed in the FCC/ISED filing (monopole, dipole, chip, etc.) may be used. Any antenna substitution requires a Class II permissive change.

2.4 RF Exposure

Q: What RF exposure considerations must the host design address?
A: The module is approved for use in systems where the antenna is ≥20 cm from the user. Host products must include RF exposure labeling and guidance per FCC/OET guidelines.

2.5 Antenna Connection

Q: Is the antenna permanently attached, or does it use a unique connector?
A: The module uses [e.g., a u.FL connector / solder pad] and complies with the FCC requirement for unique/non-user-accessible connections.

2.6 Co-location

Q: Can the module be co-located with other transmitters?
A: Co-location is not permitted unless additional testing is performed and approved under a new filing.

2.7 OEM Installation Guidance

Q: What guidance is required for installation into host systems?
A: The module must be installed according to the mechanical and electrical guidelines in the integration guide, including layout, ground, shielding, and clearance requirements.

2.8 Data / Control Interfaces

Q: Does the module include any data/control interfaces?
A: Yes, it uses UART and/or SPI interfaces for host communication. These interfaces do not bypass RF shielding or violate certification limits.

2.9 Module Shielding

Q: Does the module have shielding?
A: Yes. The STM32WL5MOCH6TR module is a shielded device. The metal can covers all RF components and is tied to ground in the PCB design.

2.10 Test Modes

Q: How is the module placed into test mode?
A: Test mode is activated via serial commands or firmware control. Instructions are available upon request for FCC testing purposes.

2.11 Grantee Contact Info

Q: Who is responsible for compliance and support?
A:
BiPOM Electronics, Inc.
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2.12 Miscellaneous

Q: Any other requirements?
A: Host products must not alter RF paths, antenna configurations, or power settings unless re-certified. Compliance with Part 15 limits must be confirmed in the host configuration.

PCB Layout Considerations:

Use of a multi-layer PCB is recommended as the host circuit PCB. Multiple layers allow for a large, continuous ground plane under and around WillowBee.

A 4-layer or 6-layer PCB is recommended with ground planes. For cost critical applications, a 2-layer PCB can also be used. If using a multi-layer PCB, it is advisable to bury noisy signal or power traces on internallayers of the PCB and sandwich them between solid GND planes to provide shielding.

The ground pin of WillowBee should be connected directly to the ground reference plane with the ground vias placed as close to the WillowBee pads as practical.

Power supplied to WillowBee should be clean and isolated from potential noisesources originating from the application circuitry. This can be achieved using filters or linear regulation in the power feed to WillowBee.

The power source supplying WillowBee must have sufficient current sourcing capability to satisfy WillowBee's maximum specified current draw, plus some additional margin for good design practice.

On the same layer that WillowBee is mounted, do not place any copper (i.e. traces, vias, pours) in the Copper Keepout Region. It is however recommended to place an RF ground reference plane underneath WillowBee on the next adjacent layerof the PCB.

Make sure that the selected antenna is nominally matched to 50-ohms at the frequency band that WillowBee is operating. If not sure, contact BiPOM Electronics for design help. A good antenna match is critical to the performance of WillowBee’s transceiver and should not be overlooked.

If the final host product contains multiple transceivers or receivers that could potentially be active at the same time, make sure to space their antennas as far apart as is practical to minimize coupling between antenna elements. To further mitigate interference between these radio devices, RF filtering and shielding should be considered to reduce unwanted signals in the frequency bands of interest.

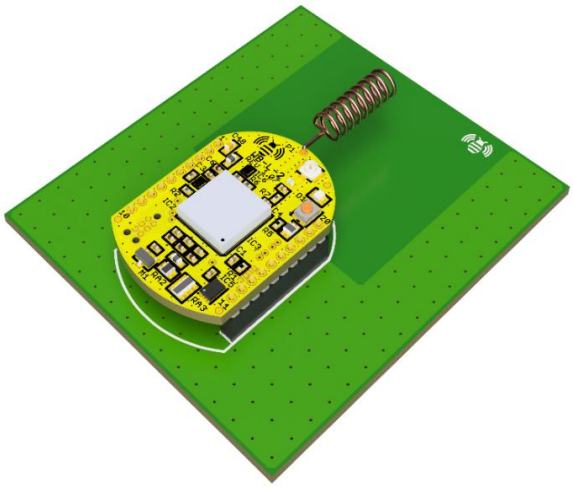
Controlled Impedance Line:

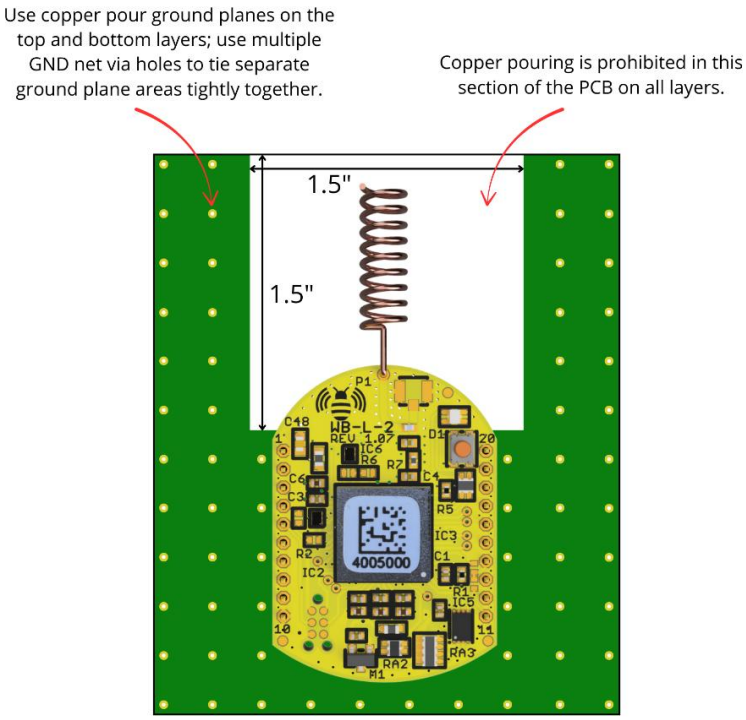
The PCB trace between the RF output pad and the antenna connector must be a 50-ohm controlled impedance microstrip or coplanar waveguide. Keep the RF trace as short and direct as possible.

Grounding:

A continuous RF ground plane should be located directly under the module. Stitching vias should surround the ground pads.

Copper Keepout:





Sockets can be used on the host circuit board for ease of removing and replacing WillowBee. Alternatively, WillowBee can be soldered directly to the host circuit board.

If using dual 2-millimeter pitch 10-pin female sockets, the preferred socket part number is NPPN101BFCN-RC by Sullins. Similar sockets can also be used. No traces or copper pours under the RF line or antenna area.

Noise Isolation:

Place antenna away from noisy components (DC-DC converters, switching regulators, and high-speed digital traces). Maintain at least 5mm clearance from any high-speed or high-current circuits.

Mechanical Placement:

Ensure the module is installed with correct orientation.
Do not place the module inside metal enclosures without RF windowing.

Prototyping Recommendation:

A PCB prototype, not a breadboard, is preferred for RF designs.

Power Supply Requirements:

- Operating voltage: 2.8V to 3.5V DC
- Peak TX Current (22 dBm): ~135 mA.
- RX Current: ~10 mA.
- Sleep Current: <2 µA.
- Preferably, use a low-noise, linear regulator. Place both a 1uF and a 100nF ceramic capacitor close to VCC pin. Ideally, the regulator should be close to WillowBee for point of load regulation.
- At lower supply voltages (such as 2.8V), the maximum achievable RF output power may be reduced slightly compared to operation at 3.3V.
- Ensure the power source can handle peak transmit current without droop.

Co-Location:

WillowBee LoRaWAN module's antenna can be co-located with other antennas, but strict RF coexistence guidelines must be followed to ensure:

1. Regulatory compliance (FCC, ISED, CE)
2. Minimal interference
3. Stable wireless performance

Key Co-location Guidelines:

Item	Recommendation
Antenna Separation Distance	• For most FCC modular approvals, if multiple antennas transmit simultaneously, at least 20 cm separation is typically required between antennas unless documented and tested together. • If antennas do not transmit at the same time, they can be mounted closer, but care must still be taken to avoid coupling.
Frequency Band Overlap	If co-located antennas operate in similar or harmonically related bands (e.g., 900 MHz LoRa + 2.4 GHz Wi-Fi), consider: • Proper filtering and shielding • Avoiding cross-coupling through nearby ground planes • Managing intermodulation products
Cross-Platform Interference	Keep LoRa antenna away from: • Cellular antennas (LTE, 5G) may overwhelm the LoRa front-end • GNSS antennas: LoRa spurs may affect L1 band (~1575 MHz) • BLE / Wi-Fi antennas: Separate by orientation or shielding
Antenna Orientation and Ground Plane	For PCB or chip antennas: • Avoid overlapping keepout zones or placing them back-to-back • Preserve minimum spacing and ground cutouts recommended by antenna vendors • Match antenna polarization to avoid pattern nulls
WillowBee Certification Context	WillowBee is FCC and ISED certified with specific antennas. If you co-locate with another RF device and modify the RF environment, you may need: • FCC Class II Permissive Change • New testing (co-location assessment)

Final Host Compliance:

The integrator is responsible for ensuring that the host device complies with FCC Part 15B (unintentional radiator) and Canadian ICES-003 (unintentional radiator) regulations.

Unauthorized changes to the module or final product may void FCC/ISED modular certification.

Additional testing may be required if the final configuration deviates from the tested setup.