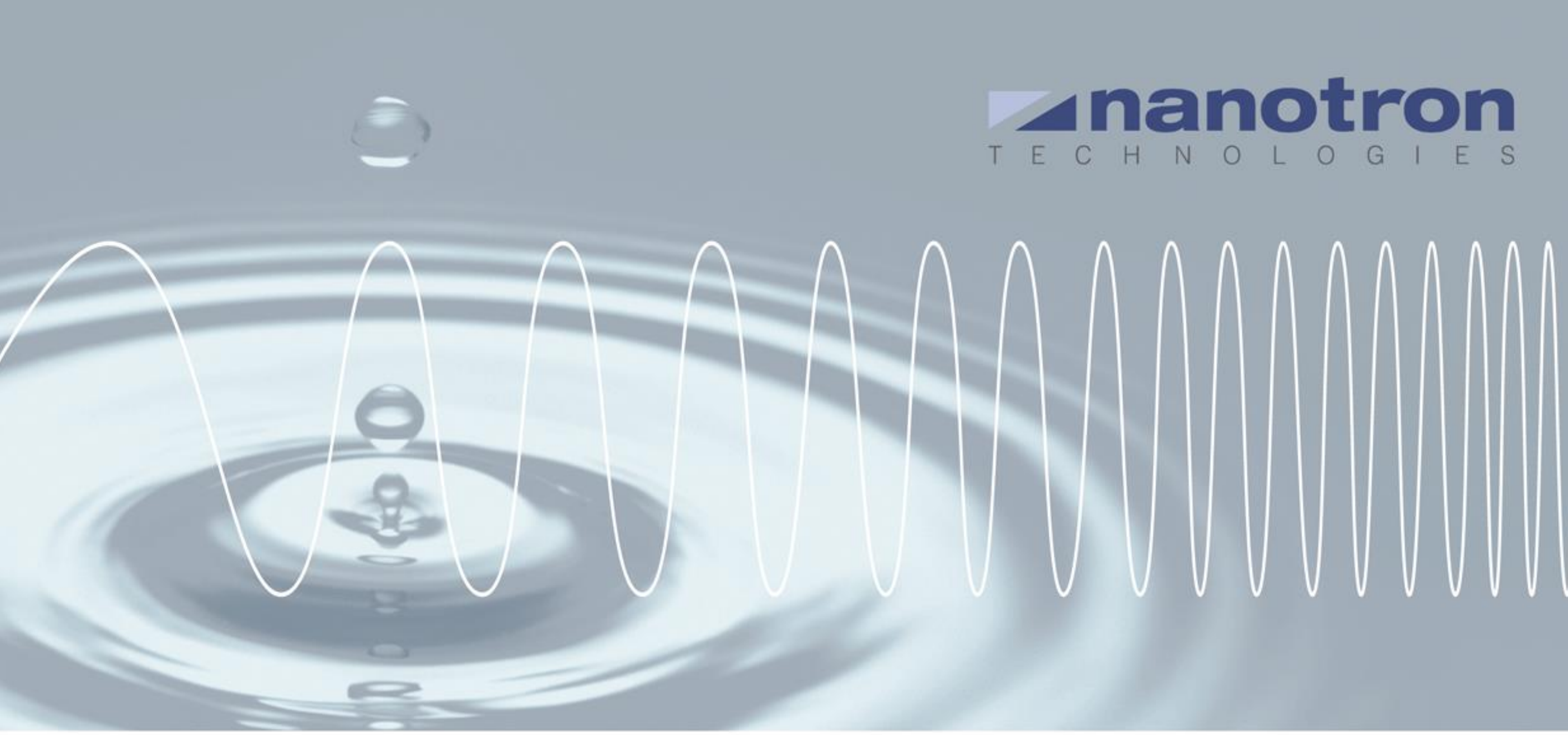

AN0504 Tag Design with *swarm* bee LE

1.4

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1. Introduction

The *swarm* bee LE CSS radio module is a fully integrated wireless node. The module works both in applications with collaborative location technology based on TOF (ranging) and fixed location technology based on TDOA (time difference of arrival) and supports concurrent communication.

This application note describes the necessary steps to create tag designs utilizing the *swarm* bee LE module. It explains how to utilize nanotron's new *swarm* bee LE radio module to build smart tags with host controller and basic tags without host controller. Circuit diagrams for both architectures are shown and could easily be replicated by the user for rapid prototyping and quick time to market.

Design recommendations are provided with regards to antenna design, power management and mechanical design. Calculation examples help to estimate battery life depending on application specific parameters like the location blink rate.

2. Tag Building Blocks

A *swarm* bee tag, as shown in Figure 2-1, mainly comprises the following blocks: antenna, transceiver, optional host, power supply and housing.

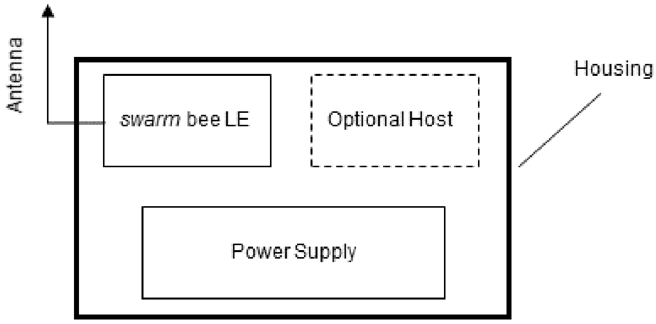

Figure 2-1 General building blocks of a *swarm* bee tag

2.1. Antenna

The *swarm* bee RF interface is a standard 50 Ohm RF-port which requires a 50 Ohm load for optimal RF performance. It is possible to connect antennas via RF connectors like U.FL as well as printed PCB antennas or chip antennas. The RF port is DC-decoupled.

Note: There are specialized companies who can help with specific antenna designs. In case you need to optimize your antenna solution while meeting certain mechanical constraints you may want to consult with them.

2.1.1. Chip Antenna

There are a lot of manufacturers who provide 2.4 GHz chip antenna, for example Antenova, Murata, Taiyo Yuden, TDK, Yageo, Johanson, etc. Figure 2-2 shows a chip antenna from Johanson, type 2450AT43A100.

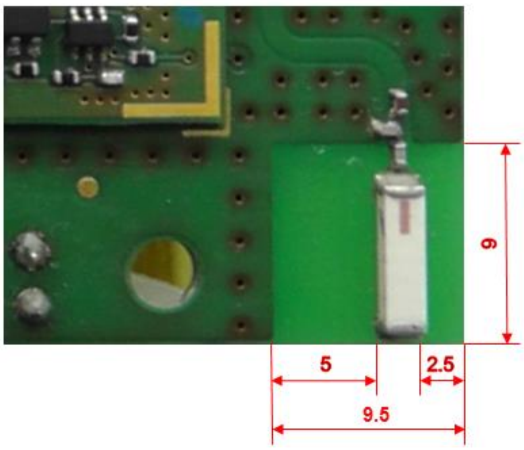

Figure 2-2 Chip antenna on a two-layer PCB

A chip antenna needs to create a 50 Ohm load impedance. The matching networks can be usually found in the data sheet of the chip antenna.

A “T” matching network is widely used to meet most application requirements, see Figure 2-3. Please pay attention to the following during design of antenna matching circuit:

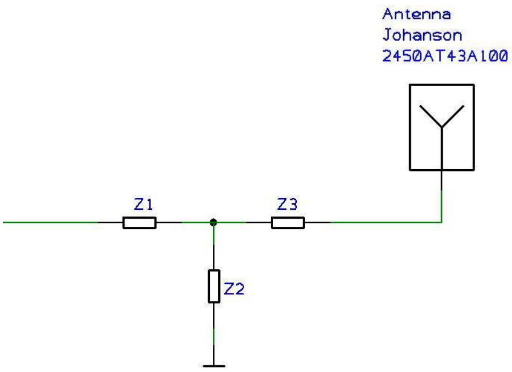

Figure 2-3 Sample matching network of chip antenna

- It is recommended to choose "low-pass", i.e. Z1 and Z3 as inductor and Z2 as capacitor.
- The typical range of inductor is 1 nH … 8.2 nH, and as for capacitor 0.2 pF … 2.7 pF.
- If serial matching components Z1 and Z3 are not needed, they can be replaced by 0 R resistors.
- If Z2 is not needed, it must be left open.
- The leading line to the antenna must have a 50 Ohm impedance.
- It is recommended to use special RF components with SMD type, the size of which should not be larger than 0402 (metric code).
- The PCB material and layout must be taken into consideration.
- It is recommended to measure the related parameters in an RF-Lab to get an optimized design.
- Certain area surrounding the antenna must be free of circuitry. Generally, the minimum is 3 mm, see Figure 2-2 for example (The dimensions are in mm.).

2.1.2. U.FL Standard Connector

Alternatively, an external antenna can be chosen for the *swarm* bee tag. It can bee connected to *swarm* bee LE module through a 2.4 GHz RF-connector on the carrier board of the module. A widely used connector of this kind is a U.FL-R-SMT connector, see Figure 2-4. A proper RF-cable must be chosen to connect an antenna via U.FL connector.

Pay attention to the following when using U.FL connectors:

- The leading line from *swarm* bee LE module to U.FL connector must be as short as possible, see Figure 2-4;
- The leading line must have a 50 Ohm impedance;
- The leading line must be embedded in GROUND;
- No signal lines shall run in the PCB layer directly under the connector;
- Adjacent ground planes in different PCB layers must be connected with as many vias as possible;
- The ground frames surrounding the U.FL connector must be at least 5 mm away from the via lines. The area of the layer directly under the U.FL connector must be designed as GROUND.

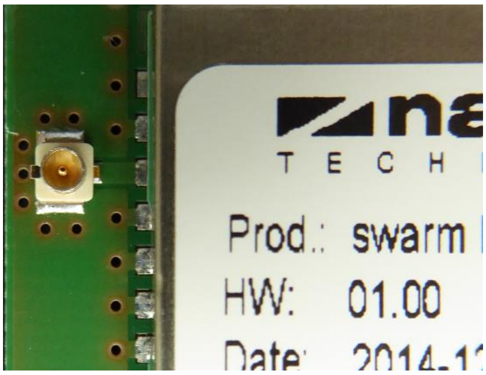

Figure 2-4 U.FL connector on a PCB

2.2. Transceiver

In each *swarm* bee LE module, the key block of a *swarm* bee tag, there is a nanoLOC TRX transceiver chip based on nanotron's CSS (Chirp Spread Spectrum) technology. The nanoLOC integrated circuit operates in the free accessible 2.4 GHz ISM band.

Please refer to [1] for more information about the nanoLOC transceiver.

2.3. Optional Host

The *swarm* bee LE module supports a number of basic tag functionalities like periodical transmission of Node ID broadcast. To utilize the basic tag functionality the module can be operated in stand-alone mode, as shown in Figure 3-1. If extended tag functionality is required, *swarm* bee LE should be used in conjunction with a host microcontroller. Using a microcontroller also provides more flexibilty to configure the tag for different modes of operation. In most cases, the performance of a small low-power 8-bit controller is sufficient. The configuration as a tag with or without controller is done by pulling pin 4 A_MODE of *swarm* bee LE to ground or leaving it open (set A_MODE to HIGH)) respectively, see Figure 3-2.

Note: With the latest *swarm* firmware (from V2.1 onwards) it is still possible to use UART when A_MODE is set to HIGH. In this case, UART wakes up periodically together with the device.

2.3.1. Basic Tag Functionality

Tags based on a stand-alone *swarm* bee LE module are suitable for collaborative and fixed location applications. They are able to transmit location broadcasts and respond to ranging requests. Most recent readings from the on-board MEMS and temperature sensor are transmitted in each of the location broadcasts as payload. Please refer to [3] for a complete list of pre-set parameters. The tag can be powered down periodically by pulling MOD_EN low (Figure 3-1).

2.3.2. Extended Tag Functionality with a Host Microcontroller

Together with a host microcontroller the *swarm* bee LE module offers several location, communication and configuration options beyond the basic tag functionality. In this configuration a tag user interface – for instance a buzzer and/or push buttons – can be implemented.

2.4. Power Supply

swarm bee LE supports the supply voltage range between 3.0 V and 5.5 V. Direct supply from primary or rechargeable batteries is possible as well as external supply via USB.

2.4.1. Logic Levels

Regardless of the power supply voltages of *swarm* bee LE and host, the digital signal levels from host and module are subject to the following restrictions (relative to the *swarm* bee LE module):

- VIL (input voltage low): max. 0.7 V
- VIH (input voltage high): max. 2.8 V
- VOL (output voltage low): max. 0.45 V
- VOH (output voltage high): min. 2.15 V
- FT Input (five-volt tolerant input): max. 5.5 V

For pin configuration and supply voltage range of *swarm* bee LE please refer to [2]. If host and module work from different supplies level shifters might be necessary.

2.5. Housing

The *swarm* bee LE module together with an optional host is usually mounted onto a carrier board, which (including or excluding power supply) is then put into a housing to build a tag. Operating conditions such as temperature, humidity etc. must be taken into consideration to choose the right material of the housing.

3. Utilizing *swarm* bee as a Tag

According to application requirements, a *swarm* bee tag can be designed as a tag without host controller or as a smart tag with an external host controller.

3.1. Tag without Host Controller

Figure 3-1 shows a possible configuration of *swarm* bee tag for stand-alone operation with a (chip) antenna. When an external host is connected, i.e. for debugging purpose, the same signal level restrictions are valid as for tag configuration with internal host.

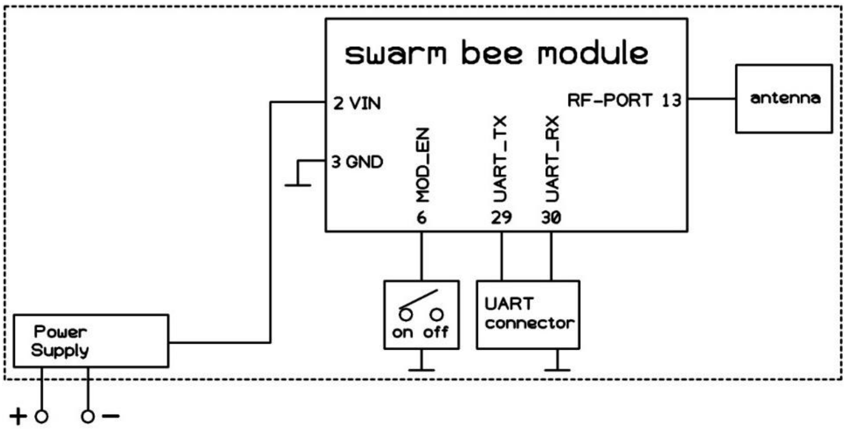

Figure 3-1 Autonomous tag without host controller

Note: For a full list of pin description (MOD_EN, UART_TX etc.), please refer to [3].

3.2. Tag with Host Controller

Figure 3-2 shows a possible configuration of *swarm* bee as a tag with host. The power supply voltage range for *swarm* bee must be within 3 V … 5.5 V. The host may have the same or a different power supply voltage. Important are the correct levels of digital signals between *swarm* bee and the host.

By pulling pin 6 (MOD_EN) to logical LOW, the *swarm* bee LE module can be completely disabled. In this case, the module draws a current of less than 1uA. The *swarm* bee LE module can be enabled by setting pin 6 to HIGH with a level from 1.5 V to VDD of *swarm* bee.

Note: Pin 6 MOD_EN must never be left open. A pull-down resistor should be connected to it. The value of this resistor should not be higher than 10% of the internal pull-up resistor connected to pin 6.

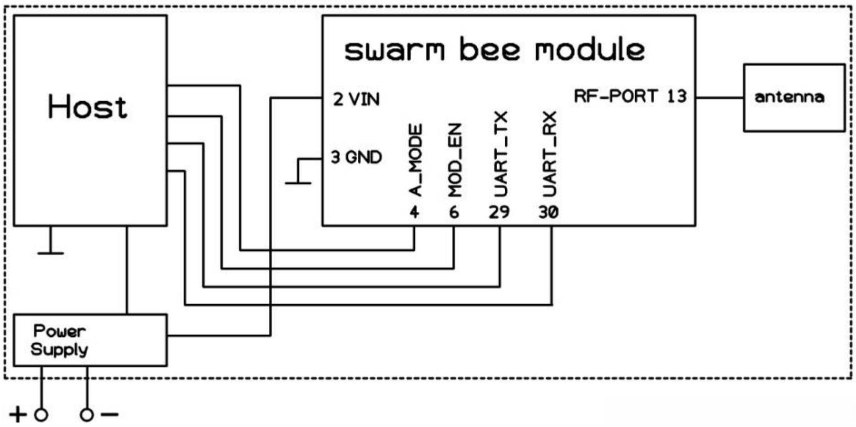

Figure 3-2 Tag with host controller

4. Power Management

The *swarm* bee LE module can go to sleep and only wake up periodically for a short time in order to save battery power. The underlying power management concept enables cooperation between the radios of a larger *swarm* even if they sleep most of the time.

4.1. Power Modes

With regards to its power consumption a *swarm* bee LE module can be used either *managed* or *unmanaged*. There are three different low power modes (*managed*) which are controlled by *swarm* API, see Table 4-1.

Table 4-1 Power Modes of *swarm* bee LE

Power mode	A_MODE pin	Power management	Meaning	Power-Down Mode	Consumption
0	Low	Disabled	Un-managed	None	Always active
1	Low	Enabled	Managed	Sleep	Reduced
2	High	-	Managed	Snooze	Lowest
3	Low	Enabled	Managed	Nap	Lowest

For a detailed description of the power modes, please refer to [3].

4.2. Calculating Power Consumption

Power consumption depends on the tag design, the use of power modes, the location update rate and the location method adopted. Power consumption varies for different application scenarios.

4.3. Battery Lifetime

The battery lifetime of a stand-alone tag can be calculated when power consumption is known and the battery capacity is given. In the following a sample calculation is shown for typical location sequences.

4.3.1. Collaborative Location (Ranging)

swarm bee tags can be used for collaborative location (as shown in Figure 4-1) where one moving tag ranges with one or more other moving or fixed tags in its neighbourhood. Local anchors which have received ranging results forward them to the location server which calculates the accurate location of the tag.

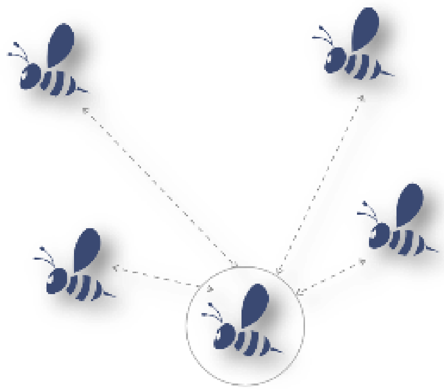

Figure 4-1 Collaborative location of *swarm* bee tags

When a *swarm* bee tag only ranges to one tag, the energy consumption for a ranging cycle is about 1200 µAs, when the tags work in 80MHz. If the ranging interval is 10 s, the battery capacity 1200 mAh and the battery efficiency 90%, the approximate battery lifetime T_1 can be calculated as follows:

$$T_1 = \frac{1200\ mAh * 90\ \%}{1200\ \mu As\ /10\ s} = 9000\ \text{h}$$

When a *swarm* bee tag ranges to more than one tags, the energy consumption for a ranging cycle would be increased by about 300 µAs per tag. If the other paramters are not changed, the approximate battery lifetime T_2 for ranging to two tags can be calculated as follows:

$$T_2 = \frac{1200\ mAh * 90\ \%}{(1200+300)\ \mu As\ /10\ s} = 7200\ \text{h}$$

Similarly, the approximate battery lifetime T_3 for ranging to three tags can be calculated as follows:

$$T_3 = \frac{1200\ mAh * 90\ \%}{(1200+300*2)\ \mu As\ /10\ s} = 6000\ \text{h}$$

Ranging with just one tag provides proximity information only, ranging values from two tags can be used to determine lateral location information and ranging with three reference tags allows to calculate a 2D location value.

Note: To simplify the approximate calculation, the power down consumption has been neglected. For an accurate calculation of the battery lifetime, this parameter must be considered. Specifically for long ranging intervals this component might even dominate.

4.3.2. Fixed Location (TDOA)

swarm bee tags can be used for fixed location as well, see Figure 4-2. During fixed location, a moving tag sends out its node ID blink regularly. Anchors on fixed points receive the blinks and forward them to the location server which calculates the location of the tag based on TDOA (time difference of arrival).

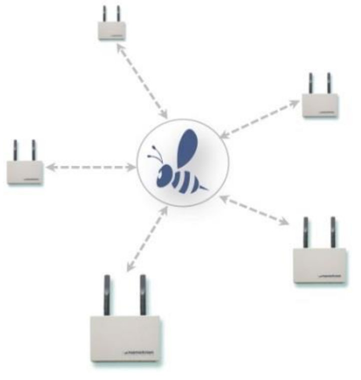

Figure 4-2 Fixed location of a *swarm* bee tag

For this application the power consumption of a tag mostly depends on the blink interval and it is much lower than in collaborative location. The measured value for each blink is about 900 µAs. If the blink interval is 1 s, the battery capacity 1200 mAh and the battery efficiency 90%, the approximate battery lifetime T_4 can be calculated as follows:

$$T_4 = \frac{1200\ mAh * 90\ \%}{900\ \mu As\ /1\ s} = 1200\ \text{h}$$

Note: To simplify the approximate calculation, the power down consumption has been neglected. For an accurate calculation of the battery lifetime, this parameter must be considered. It dominates for long phases of sleep between blinks.

4.3.3. Combined Location Modes

Depending on requirements of an application, *swarm* bee tags may be used for combined location modes, i.e. in areas where relative location information is needed between radio nodes, a tag must range with other tags in order to avoid collisions or dangers. In other areas, a tag may just need to send its own node ID blink so that the server can detect the position of this tag. In this case, the battery lifetime of a tag can be calculated combining parameters for both collaborative and fixed location.

4.4. Battery Monitoring

In order to monitor the battery voltage level, the voltage can be read out through a voltage divider which is connected to Pin 24 of the module, as shown in Figure 4-3. Two resistors of 2.2 MΩ and 2.7 MΩ are required for the circuit. 2.7 MΩ must be connected to VIN (battery voltage, 3 ~ 5.5 V) and 2.2 MΩ to GND.

Depending on battery voltage, there is a permanent power consumption over the voltage divider with a little less than 1µA. *To avoid wrong results of battery value, this voltage divider with the two resistors mentioned above must be used.*

If it is not necessary for the user to get the voltage value, the voltage divider may be spared. In this case, the *Pin 24 must be connected to GND permanently*. If Pin 24 is left open, any values can be read out as battery voltage values, which are wrong values.

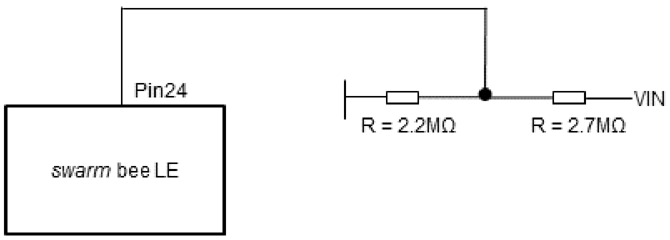

Figure 4-3 Connection of a voltage divider to *swarm* bee LE

Note: For a full list of pin description (e.g. GPIO pins), please refer to [3].

5. Module Dimension & Soldering Information

5.1. Module Dimension

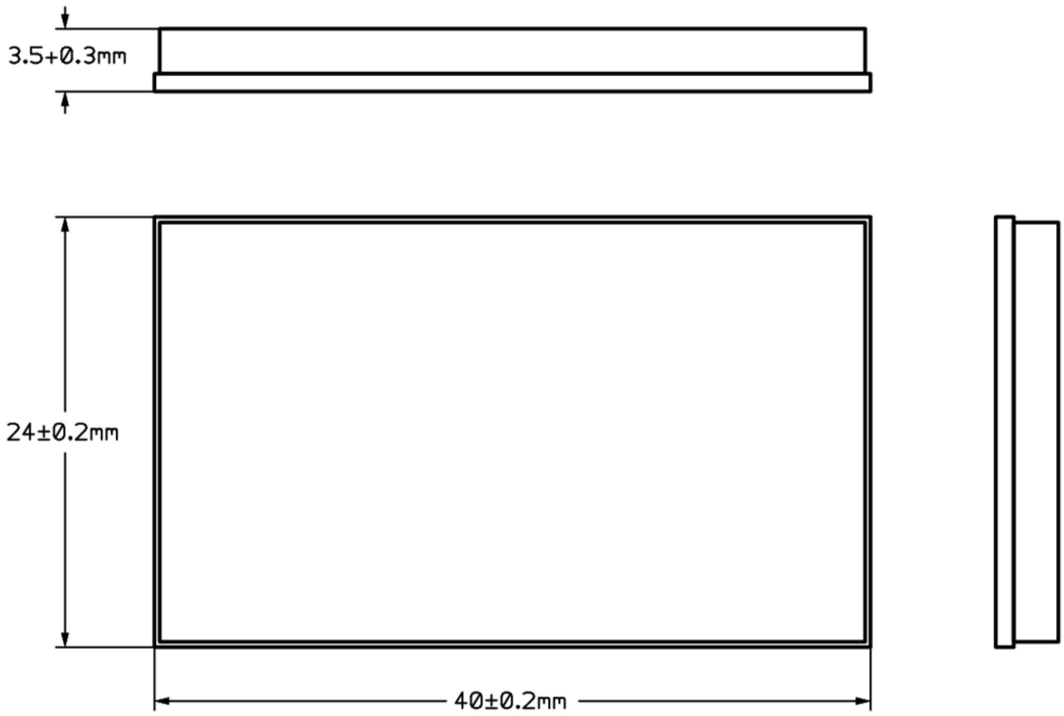

Figure 5-1 *swarm* bee LE module, dimensions

5.2. Footprint

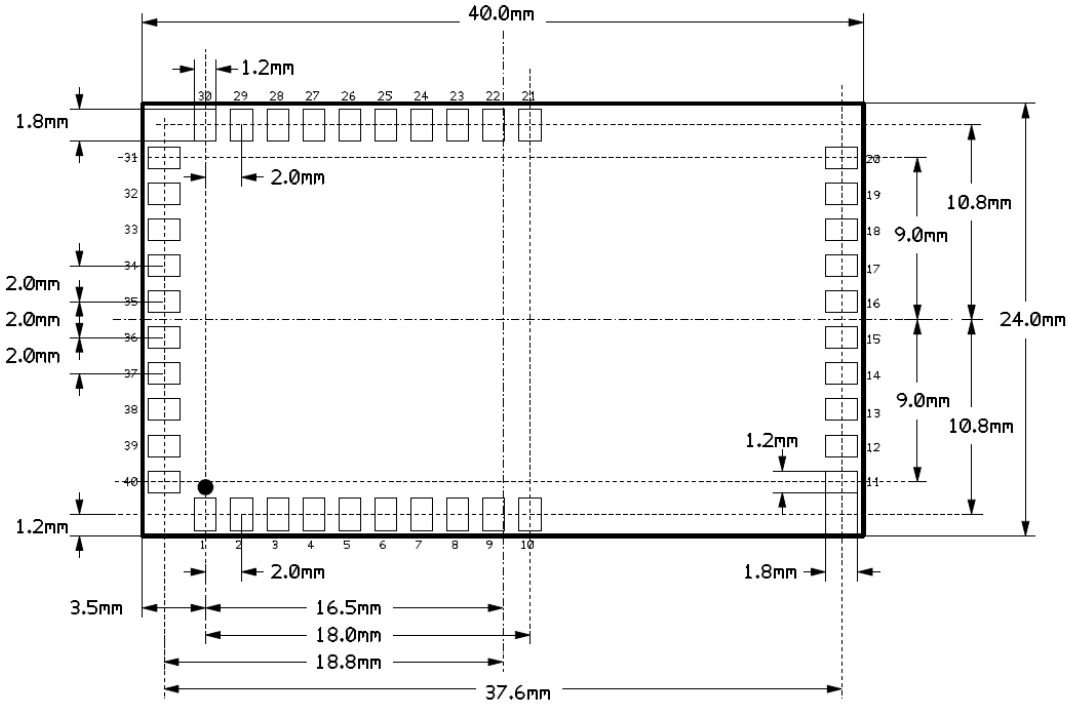

Figure 5-2 *swarm* bee LE module, footprint

5.3. Recommended Landing Pattern

The same dimensions for the solder paste screen are recommended, depending on the solder screen thickness.

The shaded area in Figure 5-3 must be kept copper-free.

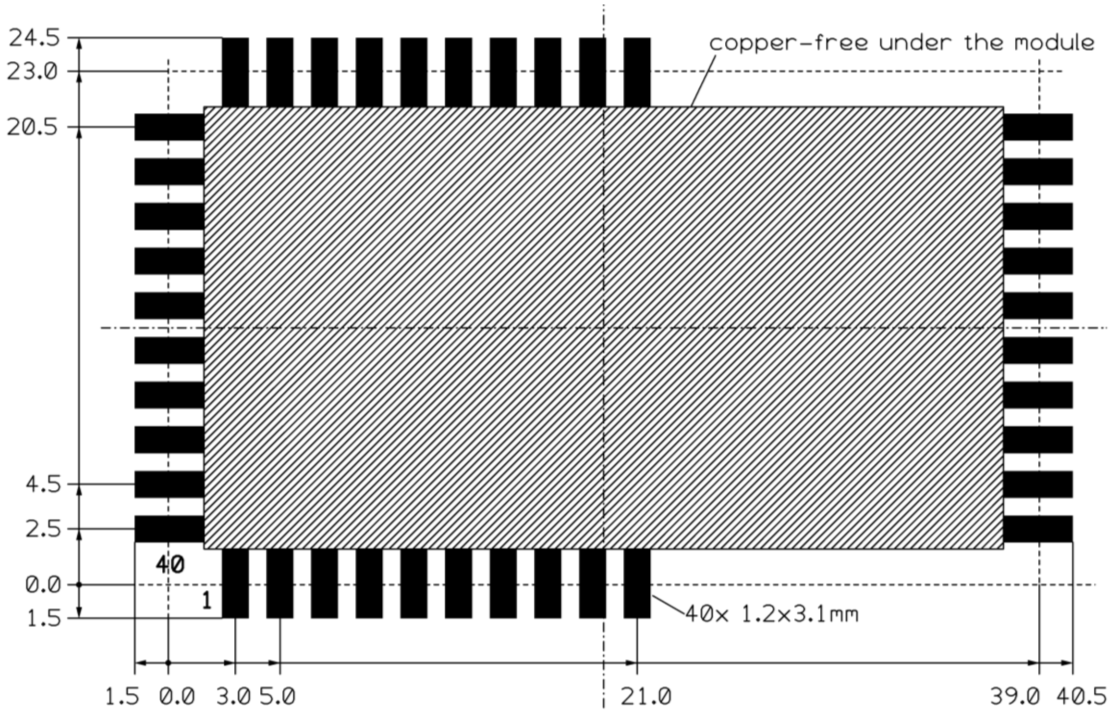

Figure 5-3 *swarm* bee LE module – footprint and landing pattern (top view)

5.4. Soldering Information

For lead-free reflow soldering, the following conditions are recommended:

- max. Solder Peak Temperature: 200°C
- Solder Paste: for example ALPHA® CVP-52

Note: Refer to [2] for more information about reflow soldering.

6. Firmware Update

The *swarm* bee LE module is always delivered with the latest firmware. In case that a new firmware version is available after the delivery, users can update the firmware using the firmware update tool. Please refer to [4] for more information about how the firmware is updated through the host interface.

7. References

[1] nanoLOC Data Sheet V2.01, Apr. 2008, Doc ID: NA-06-0230-0388-2.01
[2] *swarm* bee LE Data Sheet V1.3, May 2016 , Doc ID: NA-14-0267-0002-1.3
[3] *swarm* API V3.0, Apr. 2016, Doc ID: NA-13-0267-0003-3.0
[4] AN0507-*swarm* bee LE Firmware Update V1.0, Oct. 2014, Doc ID: NA-14-0267-0017-1.0

Document History

Date	Author	Version	Description
2014.09.30	JDI	1.0	Initial version.
2015.04.10	JDI	1.1	Battery monitoring added; power saving mode updated.
2015.11.02	JDI	1.2	Design hints for chip antenna (chapter 2.1.1) added. Power modes added. Typos corrected.
2016.04.04	JDI	1.3	Update of Table 4-1 according to API 3.0.
2016.05.31	JDI	1.4	Figure 2-4 and Figure 5-3 replaced.

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Today nanotron's *embedded location platform* delivers location-awareness for safety and productivity solutions across industrial and consumer markets. The platform consists of chips, modules and software that enable precise real-time positioning and concurrent wireless communication. The ubiquitous proliferation of interoperable location platforms is creating the location-aware Internet of Things.

Further Information

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