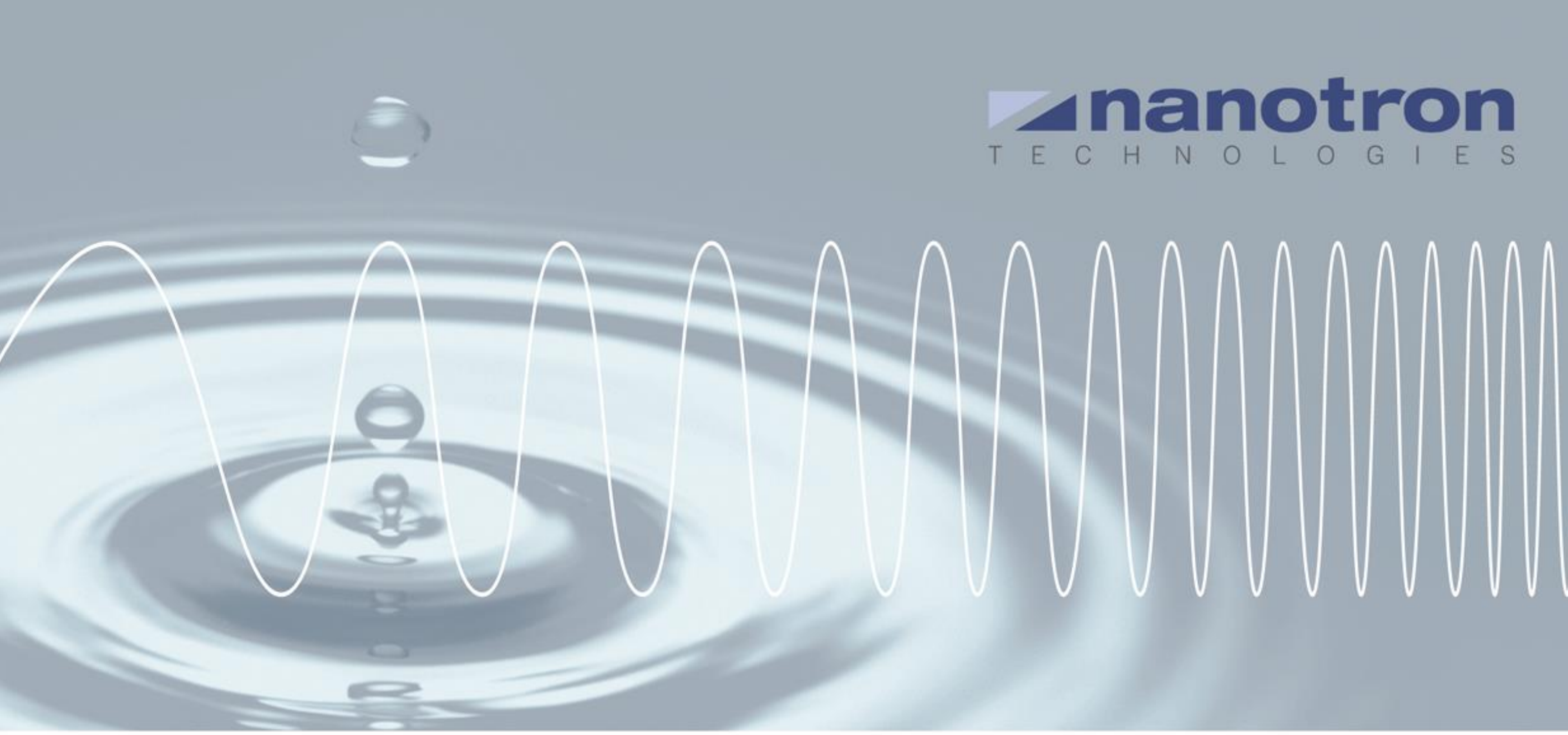

AN0513 - swarm bee LE V1 Power Modes

1.1

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Contents

1. Introduction

swarm bee should communicate with other swarm bees, navigate with them and inform about its status. In most applications, the swarm device should do all this while consuming as few energy as possible. However, there is always a tradeoff between the functionality of an electronic device and its power consumption. To give flexibility to swarm bee and optimize its consumption and functionality according to the application requirements, different power modes have been implemented. The user can select the mode that better adapts to the needs of his application even leave it up to the swarm device to dynamically change its power mode depending on its status and the environment.

All power modes described in this Application Note are implemented in swarm hardware version V1 and with firmware versions 3.0 and later.

2. Power modes

The number of power modes that have been defined is 4: from the mode in which the swarm device is always active to the mode in which swarm bee minimizes its power consumption by working autonomously and limiting its contact with the environment to its periodic blinks.

Each swarm device sends information about its power status in the nodeID blink, so that all the neighbors can be aware of its state. This information includes: power mode in which the device operates and whether a reception window is open after that precise blink. The concept of the reception window and its frequency is explained later in this document and in [1].

2.1. Power mode 0: active

2.1.1. How to set the swarm bee in this mode

Over the UART

This is the default power mode of a swarm bee. To configure a swarm device in power mode 0, it is necessary, first, to pull down the hardware pin A_MODE (and keep it down) and then send the following API command over the UART:

```
SPSA 0
```

Over the air

It is assumed that the A_MODE pin is pulled down.

The command SPSA 0 should be sent as payload in a data packet. Booth if the current mode is 1 or 3 the data transmission should be delayed, with a maximum waiting time adjusted according to the swarm's blink rate. The complete instruction should be:

```
SDAT 1 <swarm device ID> 0A 08125554025500020400 <max waiting time>
```

2.1.2. Functionality

A swarm device in power mode 0 is always active. It can transmit a blink at any moment; this blink can be triggered by the timer and, if interrupts are enabled (API command: ICFG), by the MEMS or the GPIO pins. When a device is not transmitting it is in receive state waiting to receive messages from other devices and to start communication with them.

If the swarm device is connected to a host controller, it can send notifications over the UART any time that it receives or has new information about the network (ranging results, data or blinks from the neighbors). Additionally, it is always ready to receive commands from the host.

While in this mode, the swarm devices are always ready to react to the environment; the reaction can be triggered by a packet over the air, by the serial interface or an alert from the sensors.

2.1.3. Power consumption

In power mode 0 the swarm device is always active, and with it, all its components. As shown in Table 4-1, the radio can be either in transmit or receive mode, the sensors and GPIO pins are continuously monitored and the UART is always active. The values of the registers are, of course, always kept.

Figure 2-1 shows the current profile of a swarm bee working in power mode 0. The device is in receive mode waiting to receive any signal that triggers the transmission of a blink or initiates communication with a host controller or another swarm device. When the triggering signal is received, the device goes to transmit mode and sends the nodeID blink.

During receive mode the current consumption at 3.3 V is approx. 62 mA. At some point in time a couple of pulses are represented indicating that the device is changing to transmit mode and immediately after the transmission pulse is showed. According to the measurement settings 100 mV correspond to 10 mA.

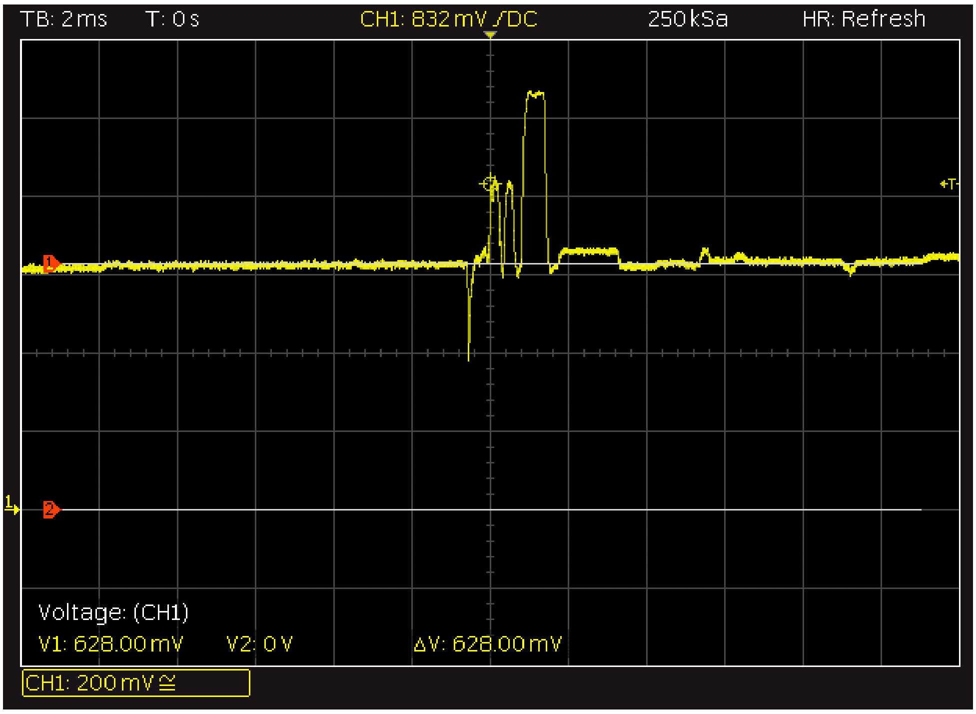

Figure 2-1 Current profile in power mode 0

2.1.4. Timing

A swarm device in power mode 0 can go to a different power mode when it receives the instruction to do so (through an API command) or when the A_MODE pin is set to high. As the device is always active, it can receive the instruction at any time and immediately change its power mode.

2.2. Power mode 1: active and sleep

2.2.1. How to set the swarm bee in this mode

Over the UART

To set the swarm bee in power mode 1, it is necessary to keep the hardware pin A_MODE down and send the API command:

`SPSA 1`

Over the air

It is assumed that the A_MODE pin is pulled down.

The command SPSA 0 should be sent as information in a data packet. Depending on the current power mode immediate or delayed transmission can be used. In the latter case, the wait time should be adjusted to the swarm's blink rate. The complete instruction should be:

Current power mode 0 → `SDAT 0 <swarm device ID> 0A 08125554025500020401`

Current power mode 3 → `SDAT 1 <swarm device ID> 0A 08125554025500020401 <wait time>`

2.2.2. Functionality

swarm devices in power mode 1 are active or, most of the time, in sleep state. They can transmit a blink at any moment; this blink can be triggered by the timer, but also by the sensors or the GPIO pins, as long as interrupts for these components are enabled. This is due to the fact that even in sleep state the MEMS and UART are active and the GPIO pins are continuously monitored.

The radio, however, is not always active; most of the time is in sleep mode. When the sensors, GPIOs or timer generate an interrupt, the radio wakes up, transmits a blink and, by default, goes to receive mode. It stays in receive mode during a predefined time, time during which it can receive any message from the neighbors and react to it. After this time the radio goes to sleep mode until next interrupt.

The time that the swarm bee is in receive mode is called Reception Window time and it is set with the API command SRXW. The reception window may not occur after every blink; with the API command SRXO the user can decide how often the reception window is opened.

It is important to note that the swarm bee will not receive any air packet that arrives while the radio is in sleep mode. The neighbors trying to communicate with it, should be aware of the power mode in which the swarm device is and use delayed data transmissions. This delayed data transmission is applicable both for unicast and broadcast messages, and when selected, the swarm device waits until it receives a blink from the destination swarm bee. In the blink packet it will check the destination transmission mode and how many blinks it has to wait until next reception window; if this number is 0 it will send the data.

The commands are listed in Table 2-1; further explanations can be found in [1]

Table 2-1 Relevant API command for power modes 1, 2 and 3

API command	Parameter	Default value	Example
SRXW	Window length	10 ms	`SRXW 10`
SRXO	Window occurrence	1 (after every blink)	`SRXO 1`
SDAT 1	Max. waiting time		`SDAT 1 <dest> <data> 100` → wait maximum 100 ms
BDAT 1	Max. waiting time		`BDAT 1 <data> 100`

2.2.3. Power consumption

As previously said, in power mode 1, all components are always active except the radio, which can be active, either transmitting or receiving, or in sleep state. This three states can be clearly seen in Figure 2-2.

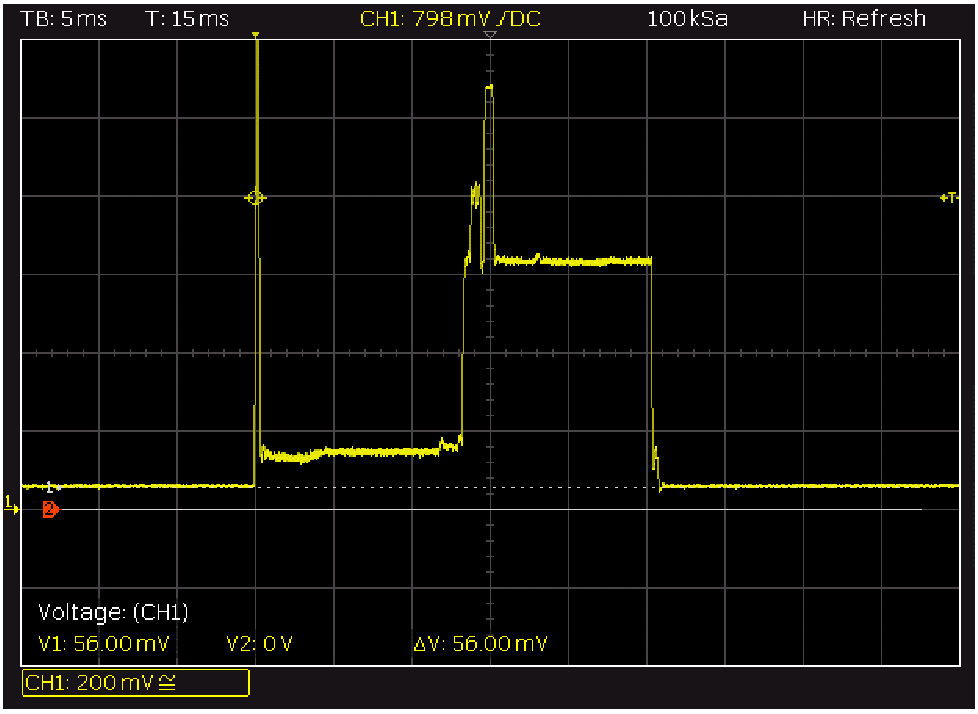

Figure 2-2 Current profile of power mode 1. 100mV correspond to 10 mA

The figure shows the current profile of a swarm device working in power mode 1. Initially the swarm device is in sleep mode consuming approx. 5.6 mA @ 3.3 V. Then, a high and narrow pulse indicates that the device has been triggered to wake up the radio. This pulse is followed by period with a bit higher power consumption, this is the initialization, and when needed also calibration, time. After a short while the radio is ready and goes to active mode. In this case it goes first to receive mode, does a very short listen before talk and then it goes to transmit mode. Once the blink has been transmitted the swarm device opens the reception window, in this case during 10 ms, and finally goes to sleep again. The power consumption during transmission and reception is similar to power mode 0; while in sleep mode the current consumption is reduced by one order of magnitude.

2.2.4. Timing

A swarm device in power mode 1 can go to a different power mode when it receives the instruction to do so (through an API command) or when the A_MODE pin is set to high. As the UART is continuously active this can happen at any moment, if however, the instruction is sent over the air, it will only happen during a reception window. In any case, the time in between the swarm device receives the order and it actually changes its power mode is minimal.

2.3. Power mode 2: active and snooze

2.3.1. How to set the swarm bee in this mode

Power mode 2 can only be set by hardware; the pin A_MODE needs to be set high. Once the swarm bee is set in power mode 2, it can only be changed to a different mode by pulling the A_MODE pin low.

It is not possible to set this power mode over the UART or over the air.

2.3.2. Functionality

A swarm bee working in power mode 2 is only active for a short time. Most of the time, it is in snooze state.

During snooze state the radio and the UART are disabled, the sensors are not monitored, the GPIO pins are not controlled and the register values are not kept. The only component that can cause an interrupt is the timer that periodically triggers the nodeID blinks. When the timer interrupt happens, the swarm device wakes up, restores the registers' values, starts to control the GPIO pins according to their configuration, enables the UART and checks the value of the sensors. After all this, the radio goes to transmit state and sends a nodeID blink. Then, by default, it goes to receive mode for a predefined period of time and finally goes back to snooze state. That time during which the swarm bee is in receive mode is called Reception Window and it is set with the API command SRXW. The reception window may not occur after every blink; the API command SRXO sets how often the reception window is opened.

Similar to the power mode 1, it is important that neighbor devices trying to communicate with the swarm bee in power mode 2 are aware of its power mode. The swarm bee cannot receive any air packet while in snooze state; thus neighbors trying to communicate with it, should be aware and use delayed data transmissions. This delayed data transmission is applicable both for unicast and broadcast messages, and when selected, the transmitting swarm device waits until it receives a blink from the destination swarm device. Then, the transmitting swarm bee checks the power mode of the destination and the field indicating the number of blinks until next reception window; if this number is 0 it sends the data, if not, it keeps waiting.

Note that the UART is only active and allows communication with the host while the radio is active. Thus, if after one blink the reception window is not open and the radio goes immediately to snooze state, the UART also. In case the swarm device is active for a while after the blink, the UART notifies any reception to its host (if notifications are enabled).

A host controller can use the active time of the swarm bee to send commands either over the air or via the UART. It is important to take into account that, when swarm bee goes to snooze state, it loses all the settings that were not saved in the EEPROM. To avoid losing the settings, any new settings should also be saved using the API command SSET (save settings).

When changing the configuration over the air the user needs to wait first until the remote device is active. Once communication is possible, it can utilize some specific API commands to keep the device active until the re-setting has been finalized. In this way, the device is prevented from going to snooze state before the process is finished. [2] gives a detailed explanation on how to configure the devices over the air.

2.3.3. Power consumption

In power mode 2, the swarm bee can be in active or snooze state. During snooze state, register settings are lost, the UART is disabled, GPIOs not controlled and the MEMS not active. This allows to reduce the power consumption down to approx. 4.5 µA.

Figure 2-3 shows the current profile of the device in this mode. As in the previous mode the swarm device is initially in low power mode, in this case snooze mode. While in this mode all components are disabled thus the current consumption is reduced down to approx 4.5 µA @ 3.3 V. At some point in time the timer triggers the swarm device that starts to switch on its components. Once everything is ready, the device proceeds like in power mode 1. The radio goes to receive state, performs a very short listen-before-talk, then it transmits the blink and immediately after opens the reception window during 10 ms. Once the reception window is over, the device goes again to snooze mode.

It can be appreciated that now the wake-up time is longer than in power mode 1. This happens because while in other power modes the swarm device only calibrates every 5 seconds, in power mode 2 the device calibrates before every blink.

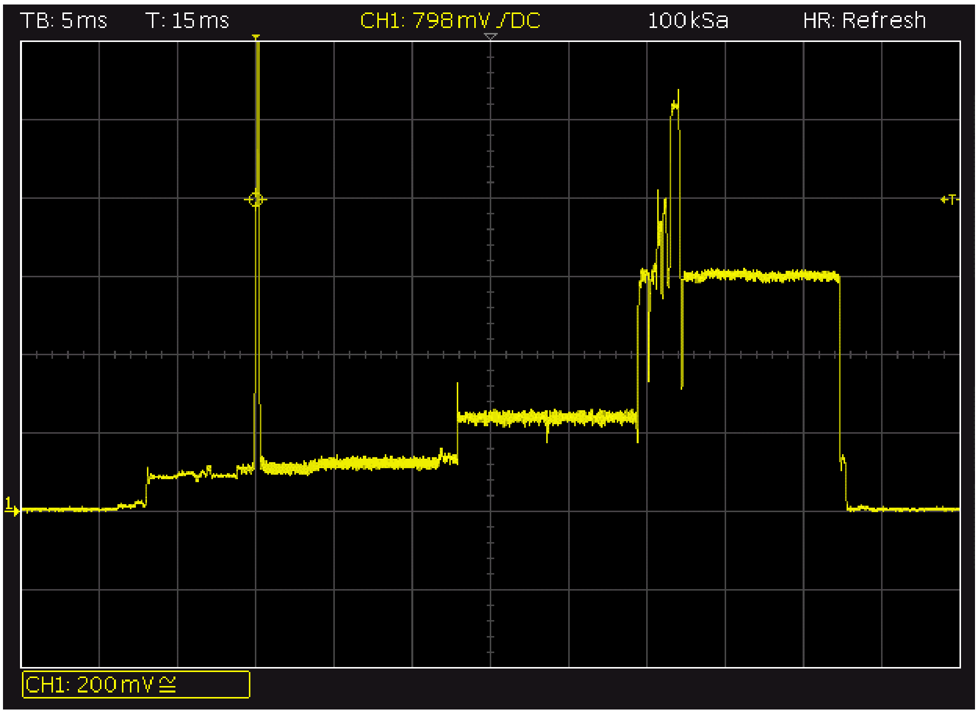

Figure 2-3 Current profile in power mode 2. 100mV correspond to 10 mA

2.3.4. Timing

Going from any power mode to mode 2 is immediate; as soon as the A_MODE pin is set to high, the devices goes to power mode 2. Doing the inverse, however, is not equally fast. When the device in power mode 2 and the A_MODE pin is set to low, the change does not apply until the next blink. Only when the swarm device goes active (to transmit the blink in this case), and with it its microcontroller, can the swarm bee detect the change of the pin status.

2.4. Power mode 3: active and nap

2.4.1. How to set the swarm bee in this mode

The basic advantage of power mode 3 is that it sets the swarm device to the lowest possible power mode at the same time that allows the user select the wake-up sources. Therefore, the user needs to first decide by what means the device should wake up in addition to the RTC. The wake-up can be triggered by the MEMS or any of the GPIOs independently, however we recommend to always use at least one of the GPIOs as wake-up source, as using only the MEMS for this purpose could be problematic when communication with the swarm device is needed.

Over the UART

When the power mode 3 is set, the swarm device goes to nap mode immediately. As usual, at this moment it loses all the settings that were not saved in EEPROM thus after next blink it will go back to its previous power mode. For this reason the following steps are recommended:

1. Select the desired wake-up sources (i.e. GPIO 0 and MEMS) and assert them. This is, in case of a GPIO set it to high level.
2. Send the commands:

   GPIO 0 2

   ICFG 103 (corresponding mask for GPIO 0 and MEMS)
3. Set the pin GPIO high and send the commands:

   SPSA 3

   SSET
4. Pin GPIO 2 can be set back to low.

Once the device is in power mode 3, it is still possible to modify the wake-up sources, either over-the-air or thought the serial interface. Of course, in both cases the swarm device needs to be active.

Over the air

It is assumed that the A_MODE pin is pulled down.

Similar to over the UART setting, the corresponding GPIO pin should be set as wake-up pin and the swarm device needs to be active until the new power mode is saved. In this case, however, it is not possible to manually control the status of the wake-up pin. Thus, the swarm bee should be kept active by using the streaming mode (SSTART).

The command SSTART is detailed in [1]. It is normally used when many commands needs to be sent to a device in low power mode. Upon reception of SSTART the device will stay active for the indicated time.

The steps to follow are:

1. Start the streaming mode: The SSTART command should be sent over the air using the SDAT command. Depending on the current power mode of the swarm device immediate or delayed transmission can be used.

   Current power mode 0

   SDAT 0 <swarm device ID> 0B 081255540255000323fDE8 (SSTART 65000)

   Current power mode 1

   SDAT 1 <swarm device ID> 0B 081255540255000323fDE8 <max wait time>
2. The commands: GPIO 2 2, ICFG 130, SPSA 3 and SAVE should be sent immediately after over the air.

   SDAT 0 <swarm device ID> 0B 08125554025500035A0002 (GPIO 0 2)

   SDAT 0 <swarm device ID> 0B 08125554025500035C0103 (ICFG 103)

   SDAT 0 <swarm device ID> 0A 08125554025500020403 (SPSA 3)

   SDAT 0 <swarm device ID> 09 081255540255000101 (SSET)
3. Once all the messages have been acknowledged, the streaming can be stopped (otherwise it will automatically stop after 65000 ms)

   SDAT 0 <swarm device ID> 09 081255540255000125 (SSTOP)

More information on how to build the over the air commands can be found in [3].

2.4.2. Functionality

When the swarm bee works in power mode 3, it is most of the time in nap mode. By default, the radio is disabled, the sensors are not monitored, only the GPIOs in wake-up mode are monitored and the UART is disabled.
At some point in time an interrupt will be generated. The cause could be either the timer or, when enabled, a GPIO or the MEMS. At that moment the UART will be enabled, the radio will be activated and, if not done

yet, the MEMS will be monitored and the GPIOs controlled. The swarm device will first send a nodeID blink; after the blink the behavior will depend on what was the cause of the interrupt:

- Interrupt caused by the timer. After transmitting the nodeID blink the radio goes to receive mode during the predefined time for its reception window. After the reception window the swarm device will go to nap mode until next interrupt.
- Interrupt generated by a GPIO. After the nodeID blink the radio will go to receive mode, the UART will remain active and the MEMS monitored. All the components will stay active as long as the GPIO that generated the interrupt is in high level. When the timer indicates it, the device will send its periodic blink.
- Interrupt generated by the MEMS. In this case the behavior will be similar to the case when the timer generates the interrupt. After the blink there will be a reception window or not, depending on the parameter SRXO and after the device will go to nap mode.

As in the previous modes, it is important that the swarm devices trying to communicate with a swarm bee in power mode 3 are aware of it. The swarm bee cannot receive any air packet that arrives while the radio is in nap mode. The neighbors trying to communicate with it, should be aware of the power mode in which the swarm device is and use delayed data transmissions. This delayed data transmission is applicable both for unicast and broadcast messages, and when selected, the swarm bee will wait until it receives a blink from the data destination. In the blink packet it will check the destination transmission mode and how many blinks it has to wait until next reception window; if this number is 0 it will send the data.

2.4.3. Power consumption

The current profile of a swarm bee in power mode 3, showed in Figure 2-4, has the same shape as when it is in power mode 1 but the current level while in nap mode is much lower than in sleep mode.

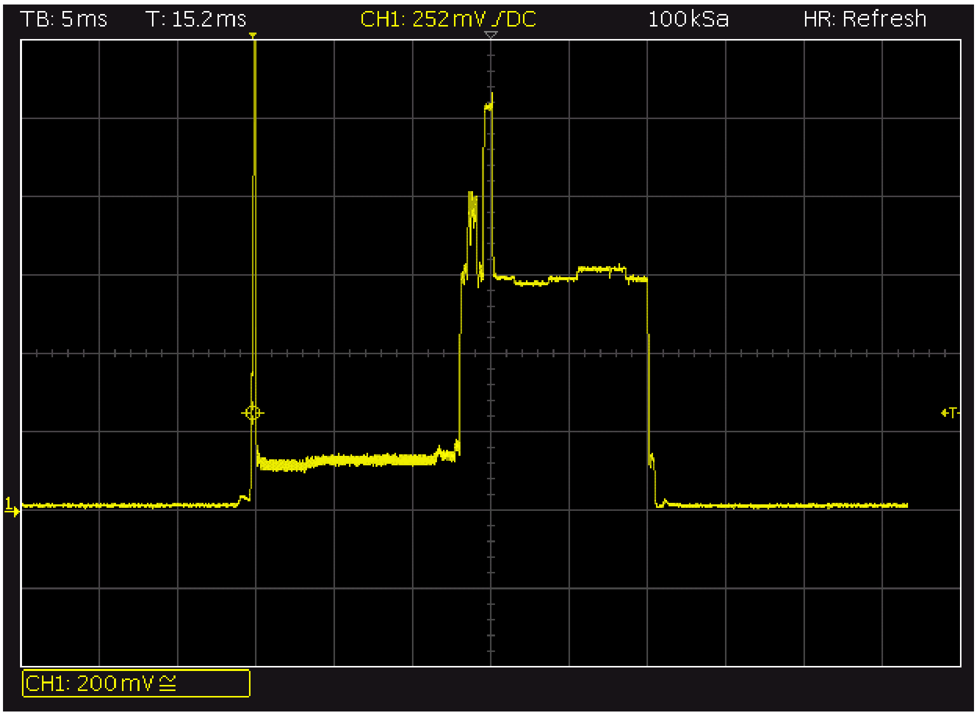

Figure 2-4 Current profile in power mode 3. 100mV correspond to 10 mA

The power consumption while a swarm device is in power mode 3 depends on which components are allowed to generate interrupts. The lowest consumption is achieved when only GPIO 0 is enabled as wake-up pin.

Table 2-2 Power consumption in power mode 3 for different settings

GPIOs in mode 3	Enabled interrupts	Current level approx. during nap mode @ 3.3 V	Settings
Only GPIO 0	Only GPIO 0	4.5 µA	GPIO 0 2 ICFG 001
Only GPIO 0	All GPIOS	450 µA	GPIO 0 2 ICFG 0FF
Only GPIO 0	GPIO 0 and MEMS	600 µA	GPIO 0 2 ICFG 100
Only GPIO 0	All GPIOs and MEMS	600 µA	GPIO 0 2 ICFG 1FF
Any GPIO	Only GPIO 0	4.5 µA	GPIO x 2 → x:1..3 ICFG 001
Any GPIO	All GPIOS	200 µA	GPIO x 2 → x:1..3 ICFG 0FF
Any GPIO	GPIO 0 and MEMS	400 µA	GPIO x 2 → x:1..3 ICFG 100
Any GPIO	All GPIOs and MEMS	600 µA	GPIO x 2 → x:1..3 ICFG 1FF

2.4.4. Timing

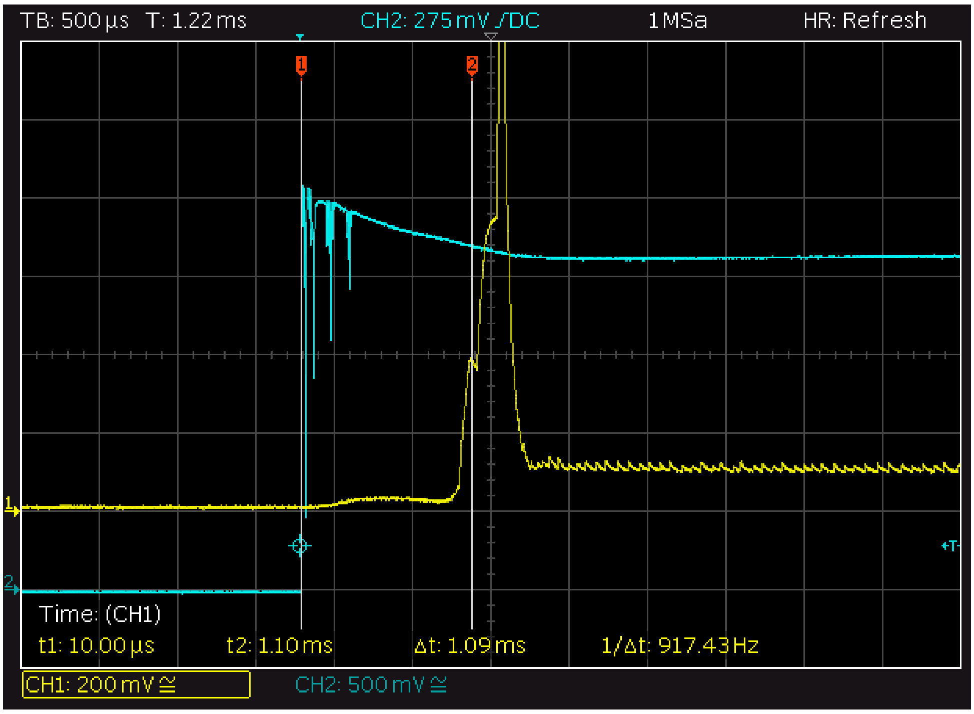

Figure 2-5 Wake-up time in power mode 3

The transition time from nap mode to active mode depends on the device configuration. If interrupts for the wake-up GPIO have been enabled the transition to active mode will be done as soon as said pin is set to high level. This is shown in Figure 2-5; the state of the wake up pin is depicted in blue, and the power profile in yellow. The time in between the wake-up pin goes to high level and the wake-up process start is only 1 ms. If, on the contrary, interrupts are disabled, the device will not go to active state until next time the timer triggers a blink.
Changing to a different power mode is also immediate, once the device receives the instruction to do so. For this, the device needs, of course, to be in active mode.

3. Fast wake-up from any power mode

In order to temporarily wake up the module regardless of the power mode in which it is set, a new feature has been added in the swarm bee firmware.

3.1. How to set up the GPIO pins as wake-up pins

This mode corresponds to the mode 2 of the GPIO command in the API. Thus to set one of the GPIO pins in this mode the command sent to the swarm bee is:

`GPIO x 2` , where x: 0, 1, 2, 3 indicates the selected pin.

It is not necessary that only one pin is configured as wake-up pin, multiple functions can do this function simultaneously.

3.2. Functionality

Any GPIO pin can be set as wake-up source. When the selected pin is set to low, the swarm device acts according to the power mode in which it is configured. As soon as the said pin goes to high level swarm bee will wake up and go to active mode, either transmit or receive; it will behave similar to power mode 0. This means that the swarm bee radio and the UART will be active and all interrupts set by the ICFG command (MEMs and/or GPIOs) will trigger the transmission of a blinkID. The swarm device will stay in this mode as long as the pin remains in high level, and will go to its configured power mode when the pin is again set to low level.

4. Summary

Table 4-1 summarizes the power consumption of the swarm bee LE in the different power modes.

Table 4-1 Summary - Power status

swarm bee State	Components state		Approx. power consumption
	Component	State	
Power mode 0: Active	Radio	Transmit/Receive	Receive 62 mA @ 3.3 V Transmit xx mA @ 3.3 V
	UART	Active	
	GPIOs	Monitored	
	Sensors	Monitored	
	Registers' values	Kept	
Power mode 1: Sleep	Radio	Disabled	5.6 mA @ 3.3 V
	UART	Active	
	GPIOs	Monitored	
	Sensors	Monitored	
	Registers' values	Kept	
Power node 2: Snooze	Radio	Disabled	4.5 µA @ 3.3 V
	UART	Disabled	
	GPIOs	Not controlled/monitored	
	Sensors	Not monitored	
	Registers' values	Lost	
Power mode 3: Nap	Radio	Disabled	from 4.5 µA to 500 µA @ 3.3 V (*see Table 2-1)
	UART	Disabled	
	GPIOs	Monitored*	
	Sensors	Monitored*	
	Registers' values	Lost	

5. References

[1] swarm API V3.0, nanotron Technologies, 2016
[2] AN0510 Unlocking parameters for over-the-air configuration, nanotron Technologies, 2015
[3] AN0602 RTLS tag back channel v 1.1, nanotron Technologies, 2016

Document History

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3/2/2016	MLA	1.0	Initial version
30/11/2016	MLA	1.1	Over the air configuration added

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