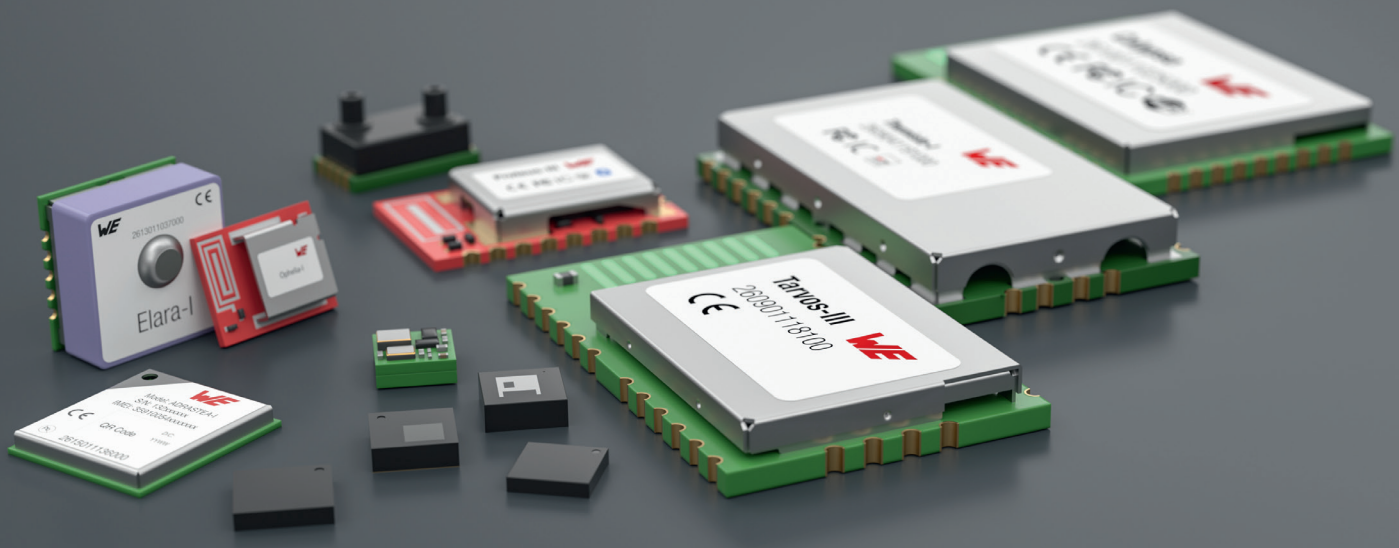

User manual

Daphnis-I

2618011181000

Version 1.0

March 27, 2024

WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

****

MUST READ

Check for firmware updates

Before using the product make sure you use the most recent firmware version, data sheet and user manual. This is especially important for Wireless Connectivity products that were not purchased directly from Würth Elektronik eiSos. A firmware update on these respective products may be required.

We strongly recommend to include in the customer system design, the possibility for a firmware update of the product.

Revision history

Manual version	Firmware version	Hardware version	Notes	Date
1.0	1.3.0	2.0	• Initial release of the manual	March 2024

Abbreviations

Abbreviation	Name
ABP	Activation By Personalization
CMOS	Complementary Metal Oxide Semiconductor
DevEUI	Device Extended Unique Identifier
EUI	Extended Unique Identifier
ESD	Electrostatic Discharge
EV	Evaluation
GND	Ground
GPS	Global Positioning System
GPIO	General Purpose Input Output
GUI	Graphical User Interface
I^2C	Inter Integrated Circuit
JTAG	Joint Test Action Group
LED	Light Emitting Diode
LNA	Low Noise Amplifier
MCU	Micro Controller Unit
OTAA	Over The Air Activation
PA	Power Amplifier
PC	Personal Computer
PCB	Printed Circuit Board
PCN	Product Change Notification
RAM	Random Access Memory
RF	Radio Frequency
RTC	Real Time Clock
SPI	Serial Peripheral Interface
SRAM	Static Random Access Memory
SWD	Serial Wire Debug
TCXO	Temperature Compensated Crystal Oscillator
TTL	Transistor Transistor Logic
TTN	The Things Network
UART	Universal Asynchronous Receiver Transmitter
UMRF	Ultra Miniature Radio Frequency
VDD	Supply voltage
WAN	Wide Area Network

Contents

1 Introduction

Daphnis-I is a low-power long-range transceiver module for Long-Range-WAN applications based on the STM32WLE5CCU6 chip. Within a Long-Range-WAN network Daphnis-I takes the role of an end node. A Long-Range-WAN gateway is required to use Daphnis-I as intended. Refer to chapter 4.2 for more information about Long-Range-WAN setup and selecting a compatible gateway.

Daphnis-I module complies with `Class A`, `Class B`, and `Class C` of Long-Range-WAN 1.0.4 specifications.

Compact 15 x 16 x 3 mm design allows the module to fit into small-size applications.The low power consumption of the Daphnis-I module makes it suitable for battery-powered applications.

The Daphnis-I module can be configured and taken into operation using AT commands via UART interface.

The Daphnis-I EV kit and "Smart Commander" tool [6] allow getting started with the module and testing its functionalities. The EV board can be connected to a USB port of a PC. The EV board also represents our reference design. For further information refer to the EV board manual [5].

The module comes with the declaration of conformity (CE) and the module is compliant to RoHS and REACH.

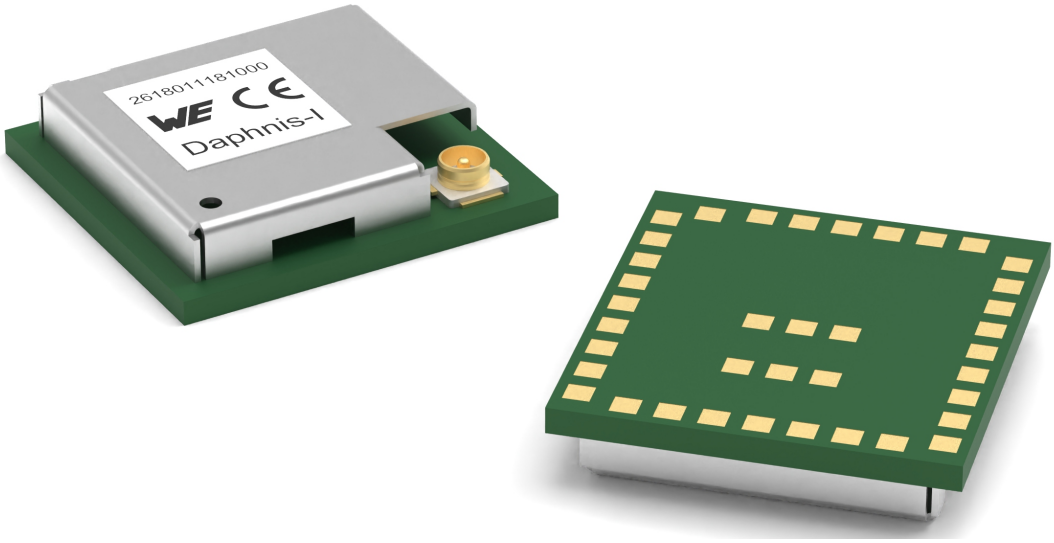

Figure 1: Daphnis-I

1.1 Block diagram

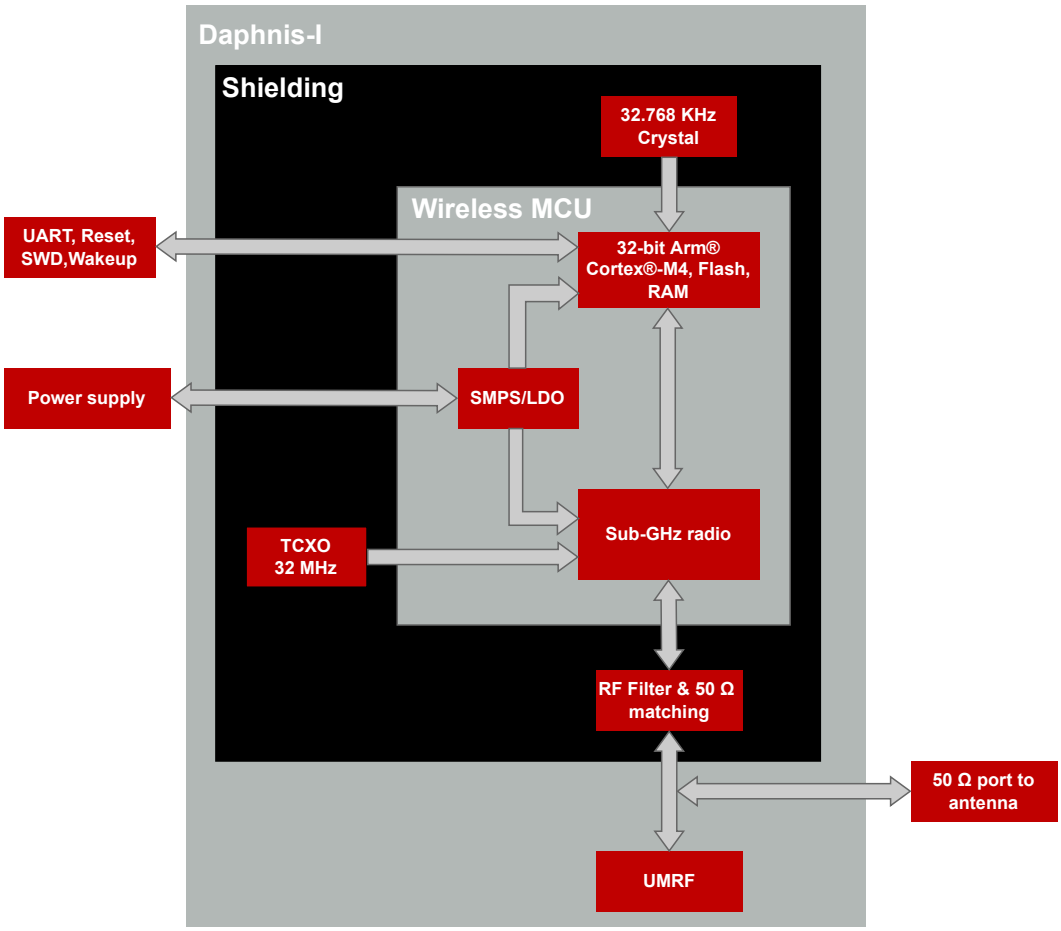

Figure 2: Block diagram

1.2 Ordering information

WE order code	Description
2618011181000	Daphnis-I Long-Range-WAN module in T&R packaging
2618019381001	Long-Range-WAN EV Kit with Daphnis-I

Table 1: Ordering information

2 Electrical and radio specifications

Unless otherwise stated, all the values given in the manual were measured on the Daphnis-I EV board with the following conditions: T = 25 °C, VDD= 3.3 V, PER 1% and internal DCDC in use.

2.1 Recommended operating conditions

Parameter	Direction	Min.	Typ.	Max.	Unit
Supply voltage (VDD)	Supply	2.0	3.3	3.6	V
Operating temperature		-40	25	85	°C

Table 2: Recommended operating conditions

An instable supply voltage may significantly decrease the radio performance and stability.

2.2 Absolute maximum ratings

Parameter	Min.	Max.	Unit
Supply voltage (VDD)	-0.3	+3.9	V
Voltage on any digital pin	-0.3	+3.9	V
Input RF level when in RX operation mode		0	dBm
Flash endurance	10 000		Write/erase cycles

Table 3: Absolute maximum ratings

2.3 Power consumption

Description	Test conditions	Typ.	Unit
TX current consumption	50 Ω load, +14dBm output power configuration	24.5	mA
RX current consumption	50 Ω load, LNA on	6.9	mA
`Idle state` current consumption	RTC enabled, full SRAM and peripheral retention	1.5	µA
`Sleep mode` current consumption	RTC disabled, backup registers retained	63.9	nA

Table 4: Current consumption

`Sleep mode` and `Idle state` currents increase significantly for temperatures above 30 °C.

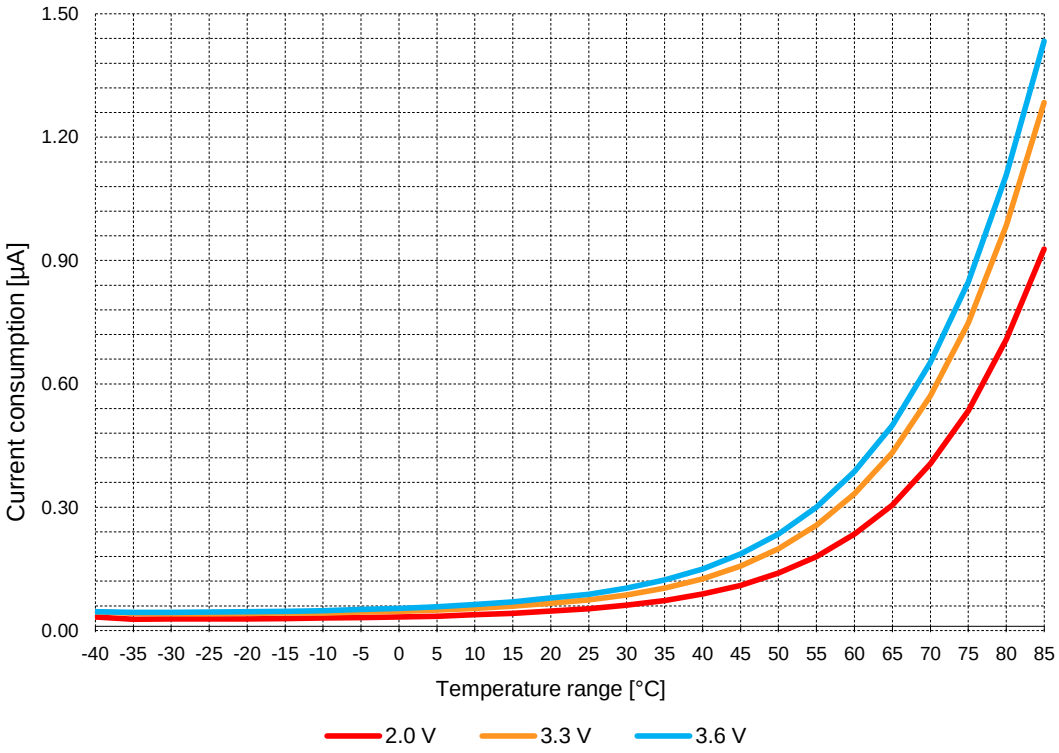

Figure 3: Current consumption during `Sleep mode`

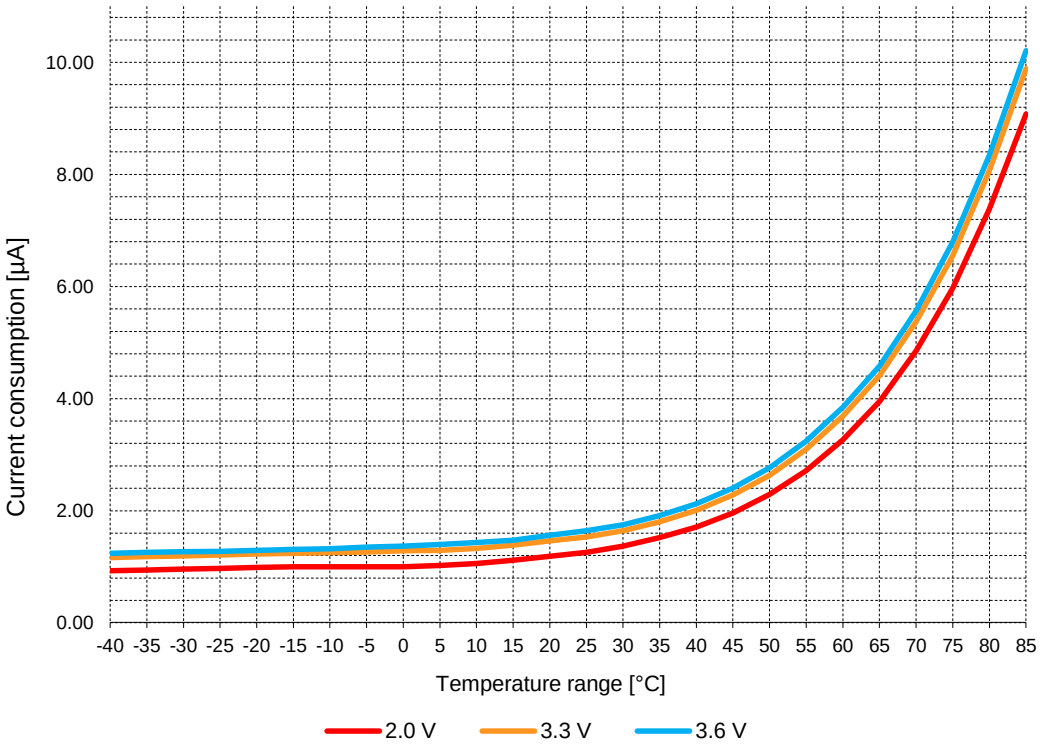

Figure 4: Current consumption during `Idle state`

2.4 Radio characteristics

Module performance is dependant on the quality of the RF link between Long-Range-WAN gateway/network and the Daphnis-I module.

The following factors and tasks are critical for the performance of the Daphnis-I module:

- External 868 MHz antenna for signal reception and transmission,
- RF trace delivering the signal from the external antenna to the RF pad of the Daphnis-I module,
- minimization of external and environmental effects.

Unless noted otherwise, the Daphnis-I EV board is in static mode.

Description	Min	Typ.	Max	Unit
Frequency band	868.0	868.6	870.0	MHz
Radio data rate	0.25		50	kbit/s
RX sensitivity				
DR0		-138.0		
DR5		-124.6		dBm
DR6		-121.8		
DR7		-107.5		
TX power		+13.4		dBm

Table 5: Radio characteristics

2.5 Pin characteristics

Pin specifications listed in the table below. For more details refer to [3].

Parameter	Min.	Typ.	Max.	Unit
Input high-level voltage	0.7 ×VDD		VDD	V
Input low-level voltage			0.3 ×VDD	V
Output low-level voltage, 4 mA, 8 mA, 10 mA, VDD ≥2.0V			0.4	V
Output low-level voltage, 20 mA, VDD ≥2.7 V			1.3	V
Output high-level voltage, 4 mA, VDD ≥2.0 V	VDD-0.45 V			V
Output high-level voltage,CMOS port, 8 mA,VDD ≥2.7 V	VDD-0.4 V			V
Output high-level voltage,TTL port, 8 mA, VDD ≥2.7 V	2.4			V
Output high-level voltage, 20 mA, VDD ≥2.7 V	VDD-1.3 V			V
Internal pull-up resistance	25	40	55	kΩ
Internal pull-down resistance	25	40	55	kΩ

Table 6: Pin characteristics

3 Pinout

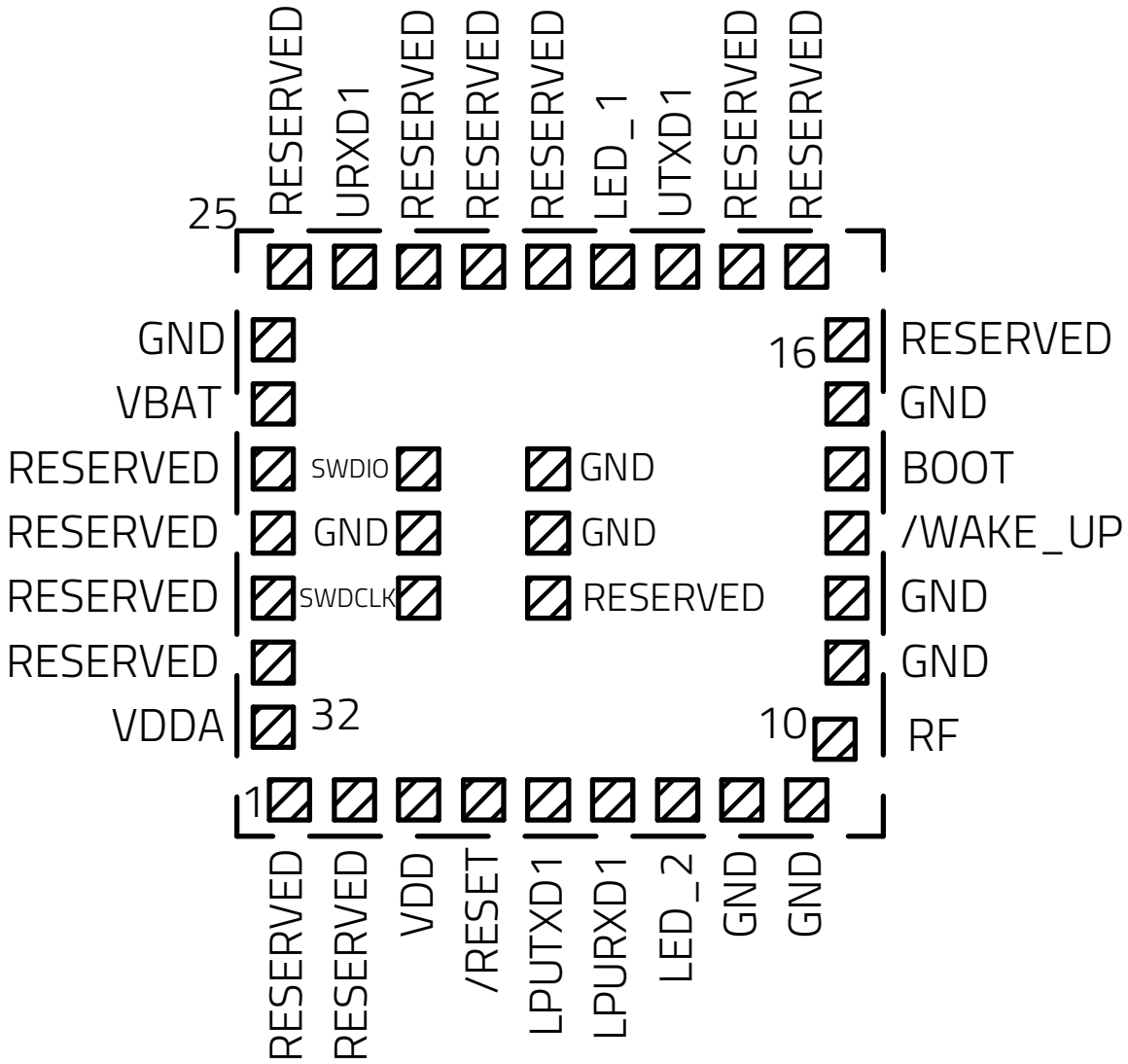

Figure 5: Pinout (top view)

Pin Number	STM32WLE5CCU6	Designation	I/O	Description
1	PB7	*RESERVED*	–	Reserved (**shall be soldered and electrically unconnected.**)
2	PB8	*RESERVED*	–	Reserved (**shall be soldered and electrically unconnected.**)
3	–	*VDD*	Supply	Power supply for module
4	–	*/RESET*	Supply	Reset
5	PA2	*LPUTXD1*	Output	Application UART transmit
6	PA3	*LPURXD1*	Input	Application UART receive, refer to chapter *LPURXD1 pin*
7	PA4	*LED_2*	Output	Refer to chapter *LED pins*
8	–	*GND*	Supply	Negative supply voltage
9	–	*GND*	Supply	Negative supply voltage
10	–	*RF*	RF	50 Ohm RF connection to transceiver
11	–	*GND*	Supply	Negative supply voltage
12	–	*GND*	Supply	Negative supply voltage
13	PA0	*/WAKE_UP*	Input	Refer to chapter */WAKE_UP pin*
14	PH3-BOOT0	*BOOT*	Input	Refer to chapter *BOOT pin*
15	–	*GND*	Supply	Negative supply voltage
16	PA5	*RESERVED*	–	Reserved (**shall be soldered and electrically unconnected.**)
17	PA6	*RESERVED*	–	Reserved (**shall be soldered and electrically unconnected.**)
18	PB2	*RESERVED*	–	Reserved (**shall be soldered and electrically unconnected.**)
19	PA9	*UTXD1*	Output	Bootloader UART transmit
20	PA7	*LED_1*	Output	Refer to chapter *LED pins*
21	PA8	*RESERVED*	–	Reserved (**shall be soldered and electrically unconnected.**)
22	PA12	*RESERVED*	–	Reserved (**shall be soldered and electrically unconnected.**)
23	PB6	*RESERVED*	–	Reserved (**shall be soldered and electrically unconnected.**)
24	PA10	*URXD1*	Input	Bootloader UART receive, Refer to chapter *URXD1 pin*
25	PA11	*RESERVED*	–	Reserved (**shall be soldered and electrically unconnected.**)

26	–	*GND*	Supply	Negative supply voltage
27	–	*VBAT*	Input	Input from backup battery
28	PA15	*RESERVED*	–	Reserved (**shall be soldered and electrically unconnected.**)
29	PB4	*RESERVED*	–	Reserved (**shall be soldered and electrically unconnected.**)
30	PB5	*RESERVED*	–	Reserved (**shall be soldered and electrically unconnected.**)
31	PB3	*RESERVED*	–	Reserved (**shall be soldered and electrically unconnected.**)
32	–	*VDDA*	Supply	Positive supply voltage analog (VDDA)
B1	PA14	*SWDCLK*	Input	Serial wire clock (SWD Interface)
B2	PA1	*RESERVED*	–	Reserved (**shall be soldered and electrically unconnected.**)
B5	PA13	*SWDIO*	I/O	Serial wire data (SWD Interface)
B3, B4, B6	–	*GND*	Supply	Negative supply voltage

Table 7: Pinout

3.1 */RESET* pin

The /RESET pin of the module is an active-low logic input. /RESET pin is internally connected to a permanent pull-up resistor. No external pull-up is needed.

- Internally pulled HIGH: Turn on module regulators and power up the module.
- Pulled LOW: Turn off module regulators and shutdown the module.

The user must ensure that the voltage level on the /RESET pin is pulled below the 0.3 x VDD level, otherwise the reset is not recognized by the module.

3.2 */WAKE_UP* pin

The host connected to this pin should always keep the state of this pin HIGH and pull it to LOW to immediately wake up the module from `Sleep mode`.

- Pulled LOW: Wake up internal MCU of module from sleep mode.
- Pulled HIGH: Allow internal MCU of module to go into sleep mode.

This pin is internally pulled-up during `Sleep mode`, otherwise it is high impedence mode.

3.3 *RF* pin

The *RF* pin provides a 50 Ω RF signal. This pin must be connected to the external antenna via 50 Ω feed line.

If the *RF* pin is used, do not connect any cable or adapter to the UMRF connector.

3.4 *BOOT* pin

The firmware update of the module over the UART interface is managed by the secure bootloader implemented as a part of the standard firmware.

The *BOOT* pin must be held HIGH during the boot-up process to activate the secure UART bootloader. Otherwise, the module starts the application firmware.

The *LED_1* will toggle to indicate that the module is in the bootloader mode and waiting for the firmware file to be sent.

Due to the internal pull-down resistor, the module by default starts in the application firmware, after a power up or reset event.

The *BOOT* pin is internally connected to a 10 kΩ pull-down resistor.

3.5 *LPURXD1* pin

This pin is internally pulled HIGH in application mode and it is in high impedence in bootloader mode.

3.6 *URXD1* pin

This pin is high impedence in application mode and it is open-drain and needs an external pull up resistor in bootloader mode.

3.7 *LED* pins

The pins *LED_1* and *LED_2* are active HIGH.

Mode	*LED_1*	*LED_2*
`Bootloader`	Blinking (Turns ON for 3000 ms, Turns OFF for 3000 ms)	OFF
`Application`	Turns ON for 500 ms and then turns OFF whenever data has been sent to or received from the network	Turns ON when the module successfully joins the network

Table 8: LED pins behavior

LED_2 is in high impedence mode in bootloader mode.These pins can source up to 8 mA, for more details refer to `Pin characteristics`.

4 Functional description

The Daphnis-I Long-Range-WAN module is intended to be used as a radio sub-system in order to provide Long-Range-WAN communication capabilities to the system.

Daphnis-I is a compact, high-performance Long-Range-WAN module with ultra-low power consumption.

The UART acts as the primary interface between the module and a host MCU. The module can be configured and operated using a set of AT commands over UART.

4.1 Module key features

Feature	Description
Physical dimensions	15 mm x 16 mm x 3 mm
Radio chipset	STM32WLE5CCU6
Supported protocol	Long-Range-WAN
Supported Long-Range-WAN specification	1.0.4 [1]
Supported regional parameters	2-1.0.1 [2]

Supported Long-Range-WAN classes	`Class A`
	`Class B`
	`Class C`

Module interfaces	UART
Supported frequency bands	EU868
Maximum power transmission	14 dBm
`Sleep mode` current consumption	63.9 nA
Operating voltage	2.0 V to 3.6 V
Operating temperature	-40 °C to 85 °C

Table 9: Module Key Features

4.2 Long-Range-WAN network setup

The Long-Range-WAN network consists of the end nodes, the gateways and the network server.

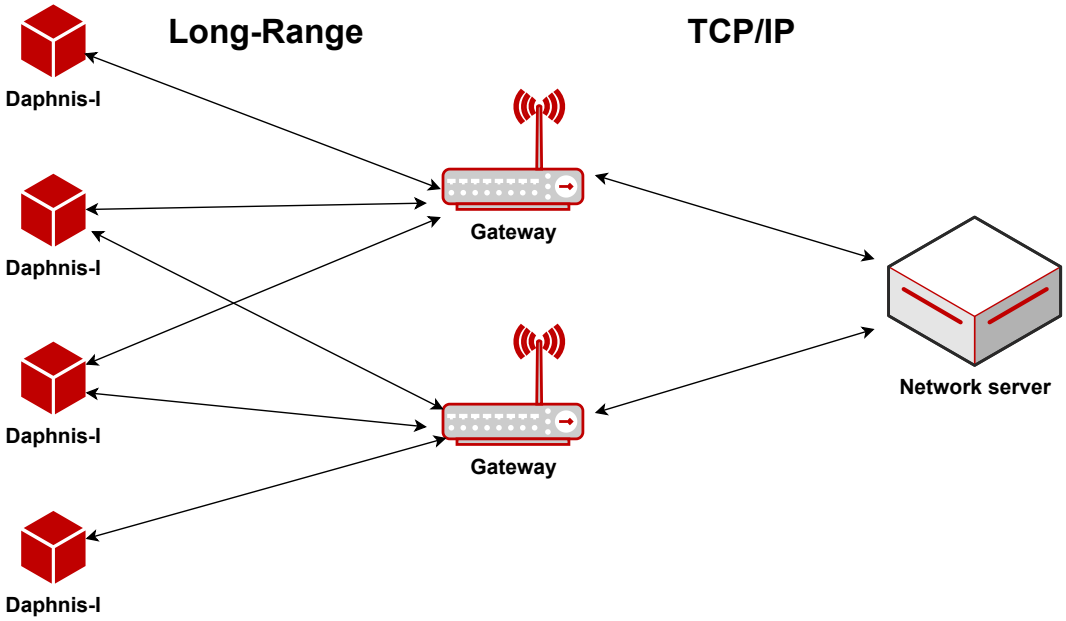

Figure 6: Long-Range-WAN network setup

The end nodes represent Daphnis-I, which usually exist in end devices. Using these end nodes, data can be sent to or received from the gateways in a Long-Range-WAN frame encapsulated in a Long-Range packet.

The Long-Range-WAN gateways act as a bridge between the end nodes and the Long-Range-WAN network server, decapsulating the Long-Range packets received within their range from the end nodes and encapsulate the resulting Long-Range-WAN frames in TCP/IP packets and send them to a Long-Range-WAN network server using TCP/IP. Additionally, the gateways decapsulate the TCP/IP packets received from the Long-Range-WAN network server and encapsulate the resulting Long-Range-WAN frames in Long-Range packets and send them to the end nodes.

In order for the gateway to be compatible with Daphnis-I, the gateway should support EU868 regional parameters version 2-1.0.1.

Some gateways have an embedded Long-Range-WAN network server. If the embedded network server is used, it should support Long-Range-WAN 1.0.4 specification.

The Long-Range-WAN network server is the core of the network as its responsible for security and data routing through the network. It also manages uplinks that have been sent to the

network server from the gateways and removes duplicates. It also schedules downlinks on the closest gateway to the end nodes. The network server is usually connected to application servers for further processing of the data.

In order for the network server to be compatible with Daphnis-I, it needs to support EU868 regional parameters version 2-1.0.1 and Long-Range-WAN 1.0.4 specification.

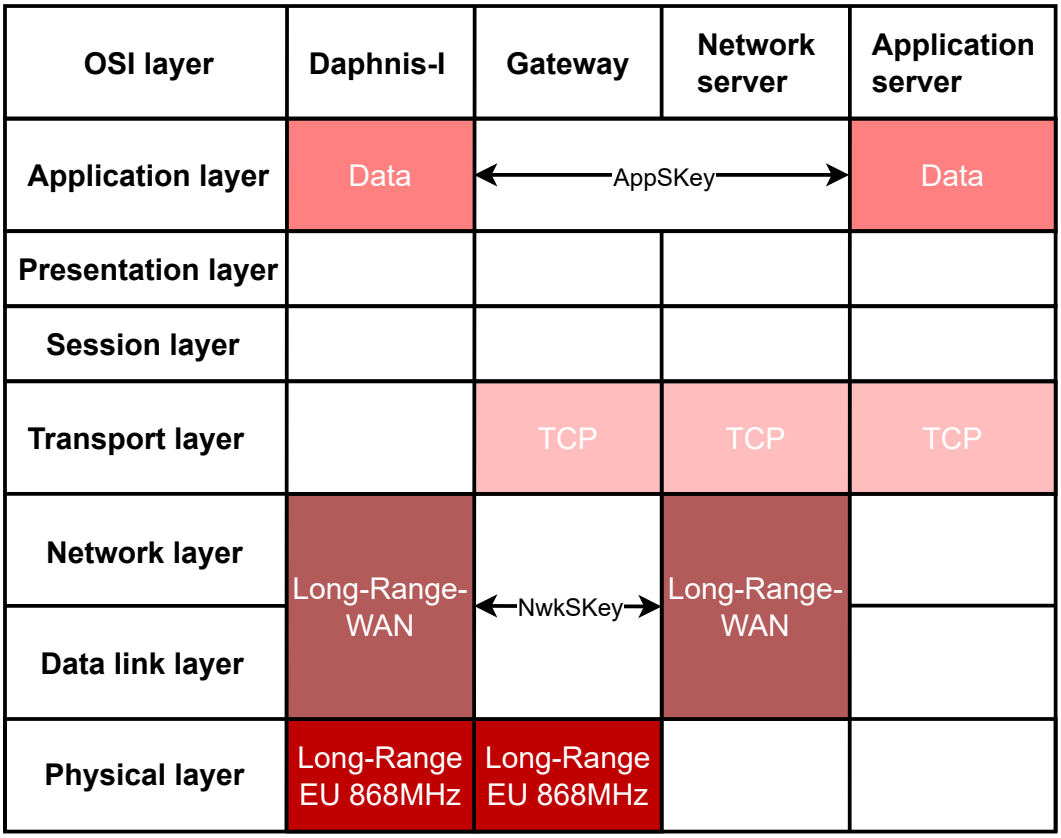

Figure 7: Long-Range-WAN stack in the OSI model

4.3 Long-Range-WAN classes

The Long-Range-WAN specification defines three device types: Class A, Class B, and Class C. Daphnis-I supports all three (Class A, Class B and Class C) Long-Range-WAN classes.

Class B and C are an extension to Class A.

4.3.1 Class A

In Class A communication is always initiated by the module, which can send an uplink message at any time. When the uplink transmission is completed, the module opens two short receiving windows (RX1 and RX2 respectively). There is a delay between the end of the uplink transmission and the start of the receive windows. If the network server does not respond during these two receive windows (RX1 and RX2), the next downlink will be available after the next uplink transmission.

The module opens the RX2 window only, when it does not receive data in RX1 (network server missed downlink tranmission in RX1).

The module in this class is in `Idle state`. It is awaken by the application UART via AT commands, then it goes back to `Idle state` again. When `AT+SEND` command is triggered, the module moves into `Active state` during the transmission window and the two RX windows. When these windows are closed, the module goes back to `Idle state`.

Between the uplink transmission and the two short receiving windows, the module remains in `Idle state`.

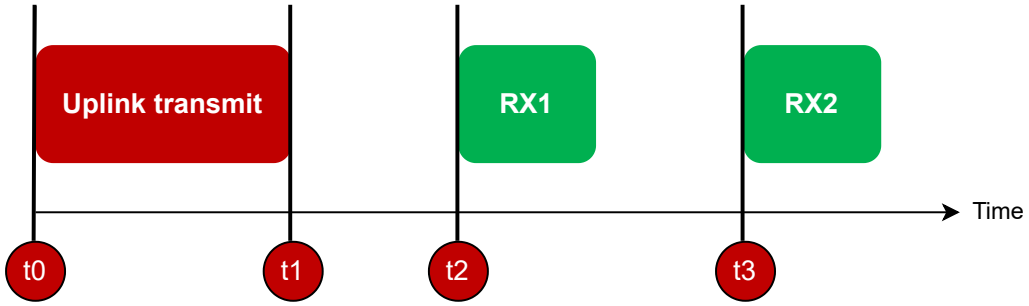

Figure 8: Class A

Time	Description
t1-t0	Transmit time on air
t2-t1	Receive (RX1) delay
t3-t1	Receive (RX2) delay

Table 10: Class A windows description

4.3.2 Class B

This class is an extension to `Class A`. In addition to `Class A`, the module opens periodic receive windows which are called ping slots.

The network server sends beacons through the gateway, so that the module can align its clock with the network server's clock. The module opens a receive window (ping slots) after it receives a time-synchronized beacon from the gateway.

Any of these ping slots may be used by the network server to initiate a downlink communication.

The module in this class keeps switching between `Idle state` and `Active state` during ping slots.

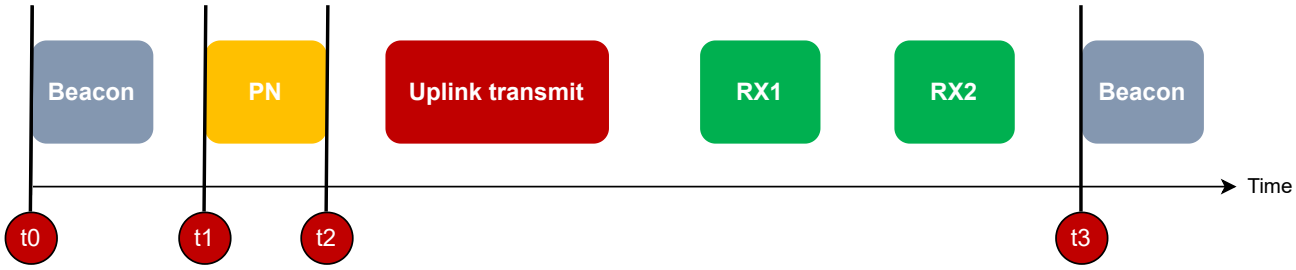

Figure 9: Class B

Time	Description
t3-t0	Beacon period
t2-t1	Ping slot

Table 11: Class B windows description

4.3.3 Class C

The module in this class has receive windows (RXC, RX1, RX2) which are almost always open. These receive windows close only when the module is transmitting.

This means in `Class C` module uses more power to operate than `Class A` or `Class B`, but `Class C` offers the lowest latency for communication from the server to the module.

The module in this class is always in `Active state` since there is a continuous receive window open.

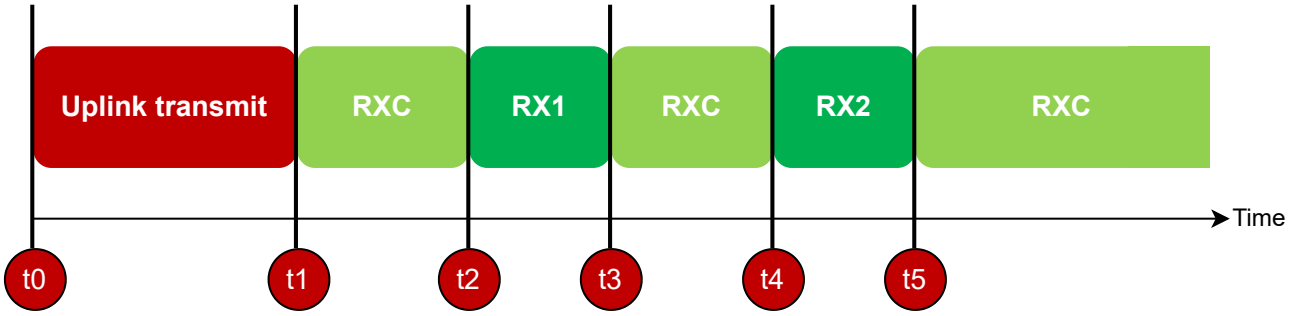

Figure 10: Class C

Time	Description
Any time except for t1-t0 or t3-t2 or t5-t4	RXC open

Table 12: Class C windows description

The default class for the Daphnis-I is Long-Range-WAN Class A. It can be changed to Class B or Class C. To change the Long-Range-WAN Class Refer `Switch the Long-Range-WAN class.`

4.4 Daphnis-I power modes

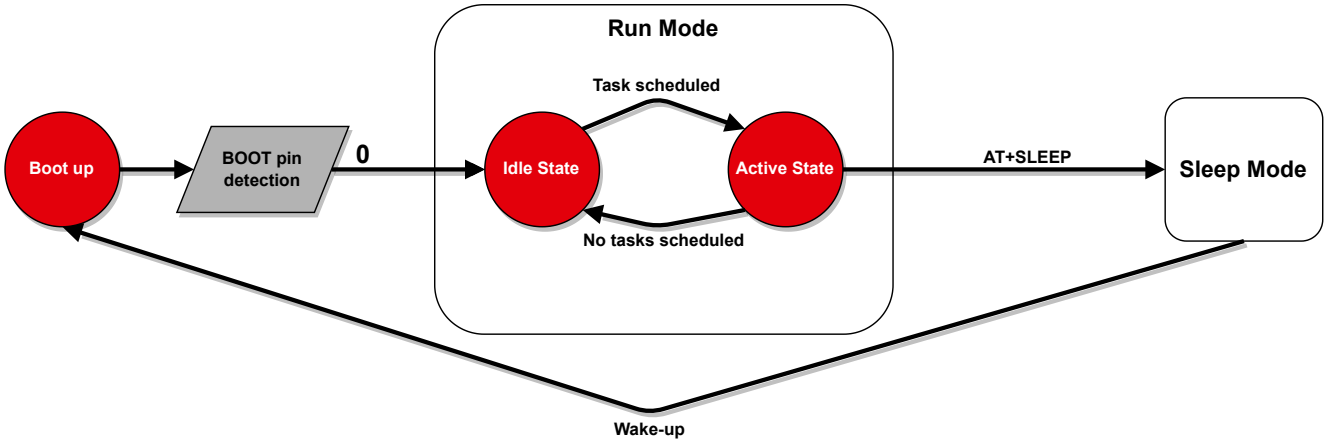

Figure 11: Power modes

4.4.1 Run mode

In this mode the module is either in `Active state` or in `Idle state`. The switching between the two states is managed automatically by the module.

4.4.1.1 Active state

The active state is when the module is parsing the received AT commands via the application UART, transmitting or receiving packets.

4.4.1.2 Idle state

The idle state is when the module is currently not performing any task.

4.4.2 Sleep mode

The module enters this mode using the `AT+SLEEP` command and exits this mode by pulling low the */WAKE_UP* pin.

5 Host connection

The Daphnis-I is intended to be used as a radio module in a system, interfaced with a host MCU. The use of an industry standard UART as the primary interface ensures a very minimal requirement set on the host MCU. As a result of this, the module can be designed in with most host controllers from an 8051 to the more advanced ARM core architecture.

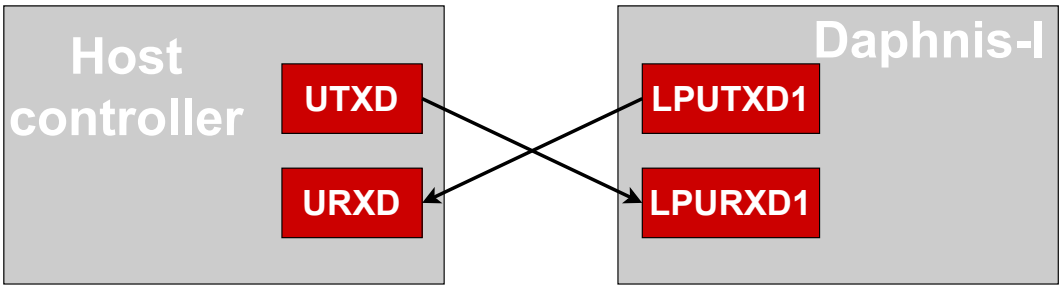

Figure 12: Host interface

5.1 UART interfaces parameters

The Daphnis-I implements two UART interfaces, one for the application and one for the bootloader with the following parameters.

5.1.1 Application UART

Parameter	Range	Standard
Baud	9600, 57600, 115200	9600
Data bits	8	8
Stop bits	1	1
Parity	none	none
Flow control	none	none

Table 13: Application UART parameters

The configuration of the application UART in factory state is 9600 baud with data format of 8 data bits, no parity and 1 stop bit ("8n1"). The baud rate of the application UART can be configured using `AT+UARTBAUDRATE`. All other parameters are fixed as shown in `Application UART parameters`. This results in a user data ratio of 10 UART symbols per 8 bit.

5.1.2 Bootloader UART

Parameter	Range
Baud	115200
Data bits	8
Stop bits	1
Parity	none
Flow control	none

Table 14: Bootloader UART parameters

The configuration of the bootloader UART in factory state is 115200 baud with data format of 8 data bits, no parity and 1 stop bit ("8n1"). All parameters are fixed as shown in `Bootloader UART parameters`. This results in a user data ratio of 10 UART symbols per 8 bit.

The firmware update process requires access of the bootloader UART.

6 Quick start

6.1 Minimal pin connections

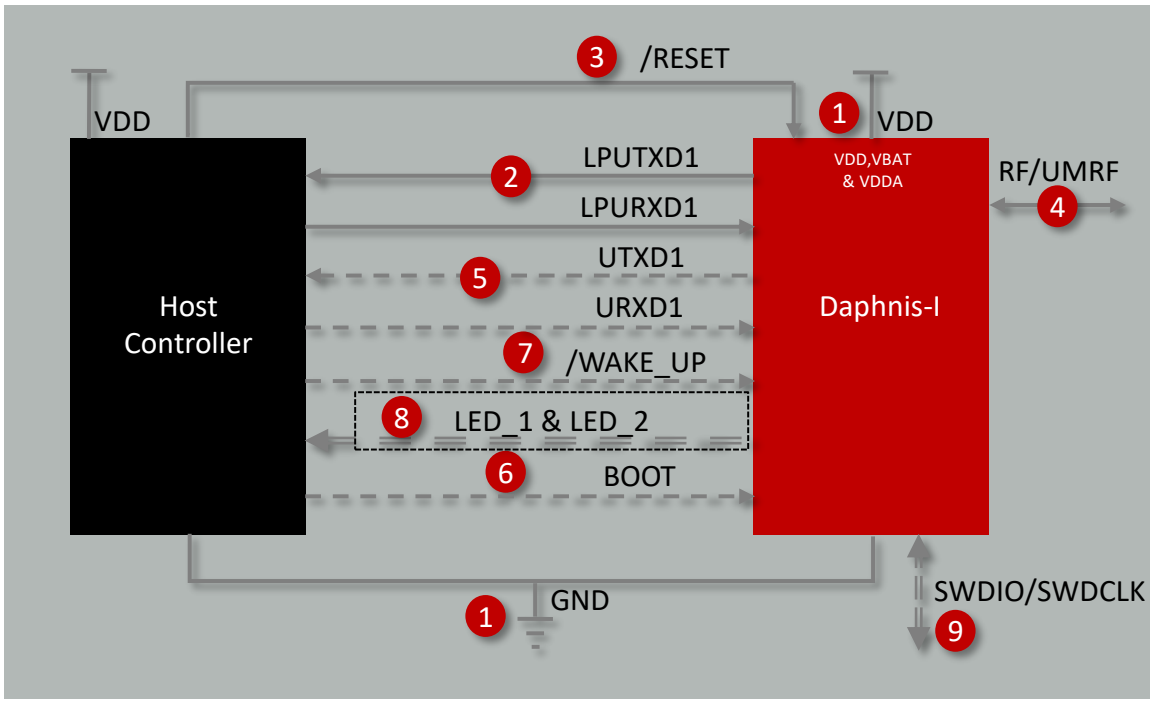

Figure 13: Minimal pin connections

The above image shows the steps to be performed to integrate the Daphnis-I into a custom end device.

1. Supply voltage and ground
   Connect pins *VDD*, *VBAT*, *VDDA* and *GND* to supply the radio module with power.

2. Application UART serial interface
   Connect the UART pins *LPUTXD1* and *LPURXD1* to the host to control the module via host. No flow control needed.

3. Reset
   Connect the */RESET* pin to the host to allow a hard reset of the module.

4. Antenna connection
   The antenna connection must be performed either via *RF* pin or via UMRF connector.

5. (Optional) Bootloader UART serial interface
   Connect the UART pins *UTXD1* and *URXD1* to the host or to testpads to perform firmware updates. No flow control pins are needed.

6. (Optional) Boot
   Connect the *Boot* pin to the host to set the module into bootloader mode to perform firmware updates.

7. (Optional) Wake up
   Connect the */WAKE_UP* pin to the host to wake up the module when it is in `Sleep mode`.

8. (Optional) Status indication
   Connect the *LED_1* and *LED_2* pin to the host controller to allow easy indication of the status of the module.

9. (Optional) Flash and debug interface
   In case of custom firmware development, it is recommended to additionally have the pins *SWDIO* and *SWDCLK* accessible in order to support a fail-safe update of firmware. A standard socket on the customer's PCB for connecting a flash adapter can be useful for debugging purposes (e.g. a JTAG 2*10 pin header with 2.54 mm pin-to-pin distance).

6.2 Antenna connection

Daphnis-I's external antenna connection allows the user to choose between *RF* pin or UMRF connector.

6.2.1 *RF* pin

The *RF* pin provides a 50 Ω RF signal. This pin must be connected to the external antenna via 50 Ω feed line.

If the *RF* pin is used, do not connect any cable or adapter to the UMRF connector.

6.2.2 UMRF connector

The ultraminiature RF connector placed on the top of the module can be used to connect an external antenna via a 50 Ω *UMRF*[1] *cable*.

If the connector is used, neither the RF pin shall be electrically connected, nor the pad shall be connected to an open trace. For mechanical stability it shall be connected to a solder pad.

[1] The UMRF connector is equivalent to MHF 1 and U.FL.

6.3 Power up

After powering the module, the */RESET* pin shall be held low for another Δt_1 of 1 ms after the *VDD* is stable to ensure a safe start-up. The module will send a `+SYSNOTF` event (+SYSNOTF:READY) to indicate "ready for operation" after Δt_2 of about 1125 ms from releasing the */RESET* pin.

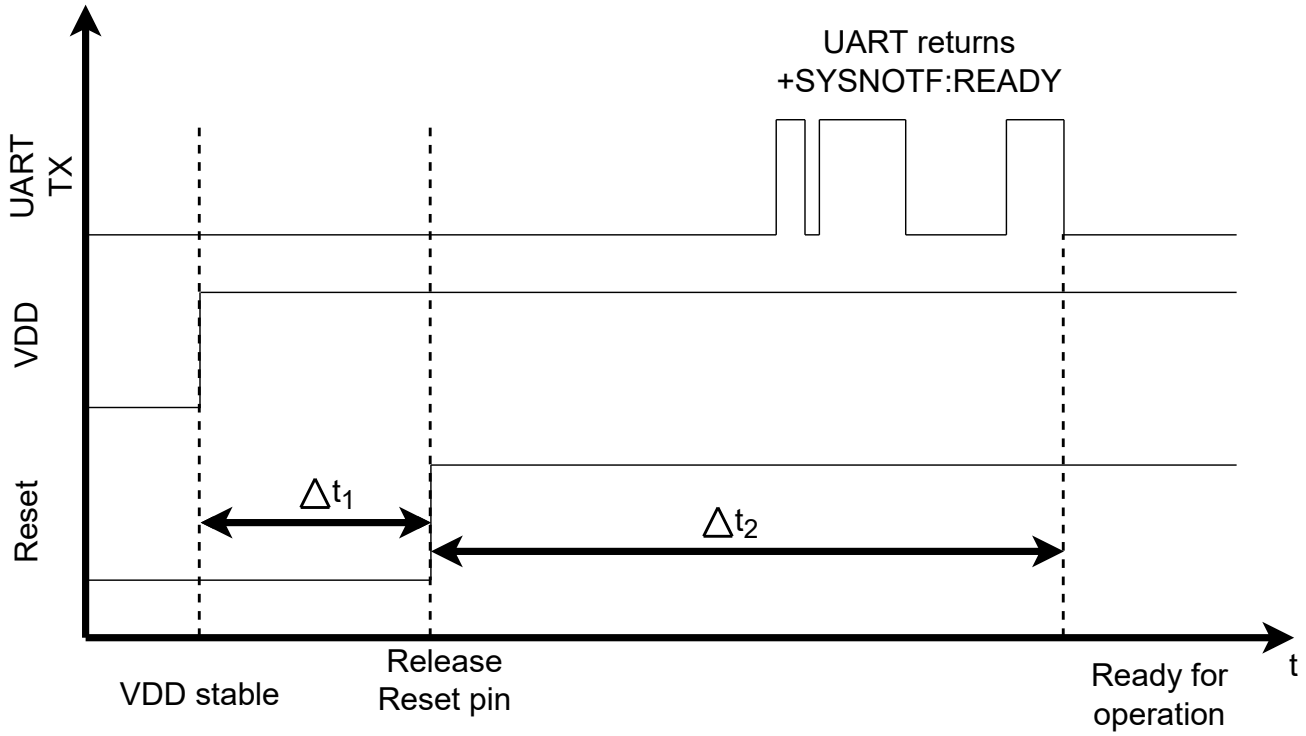

Figure 14: Power up

6.4 Quick start example

In this example, it is demonstrated how the Daphnis-I joins a Long-Range-WAN network and exchanges data with it. For this purpose a public network server provided by *TTN* is used.

TTN is a free public network server, where all members agree that everyone can use their gateways to communicate with their applications. This means that when you connect your gateway to TTN the usage of the gateway is not limited to your end nodes but to all nodes that are using TTN within the range of the gateway.

Note that depending on the Long-Range-WAN network server of your choice, the steps to set it up may differ. Nevertheless, after the network is set up, the commands that the MCU has to send to the Daphnis-I to join the network and to exchange data with it, will be the same.

It is recommended to use the Daphnis-I EV kit and Smart Commander [6] PC tool to take the module into operation.

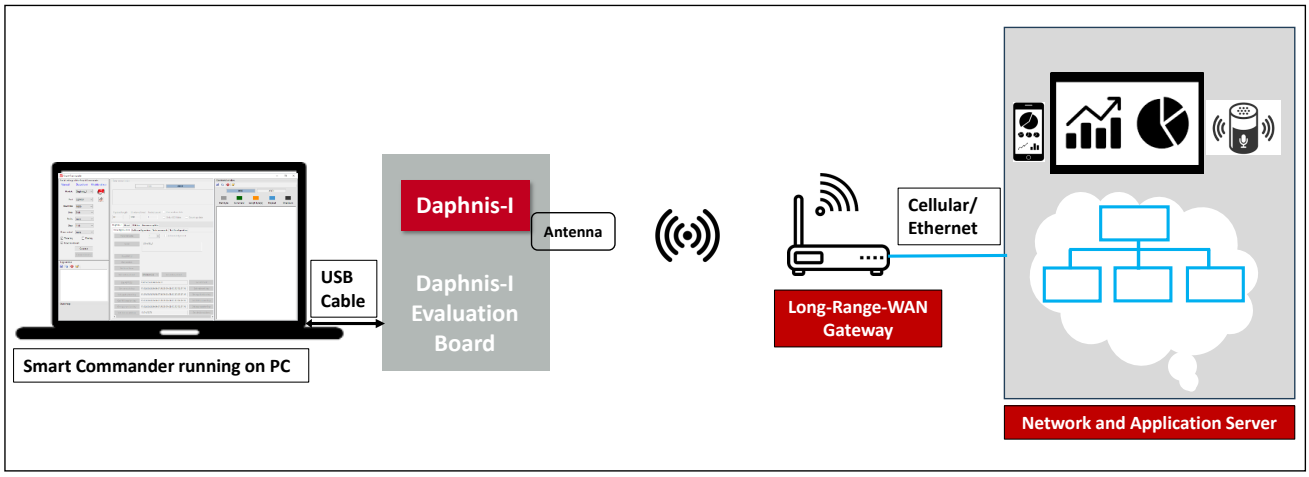

Figure 15: Daphnis-I quick start setup

Before starting setting up the module, consider the following prerequisites:

1. Daphnis-I EV Kit.
2. Computer with a serial terminal emulator. The use of Würth Elektronik eiSos's Smart Commander [6] PC tool is recommended.
3. A public or private Long-Range-WAN gateway with connection to the network server.

4. An account on TTN.
5. An application on a TTN public server.

6.4.1 Setting up the module

1. Connect the external antenna provided with the EV kit.
2. Connect the EV board to the PC using a USB cable. One COM port should be detected. Check the device manager to acquire the COM port names of the EV board. A typical name is "COMxy" in windows systems or /dev/ttyUSB0 in linux systems.

To interact with the module, it is advised to use the Smart commander tool. Otherwise, a terminal program (like "PuTTY", "HTerm" or "Tera Term" for windows) has to be run and the corresponding COM port has to be opened using the default settings of the mounted Daphnis-I module.

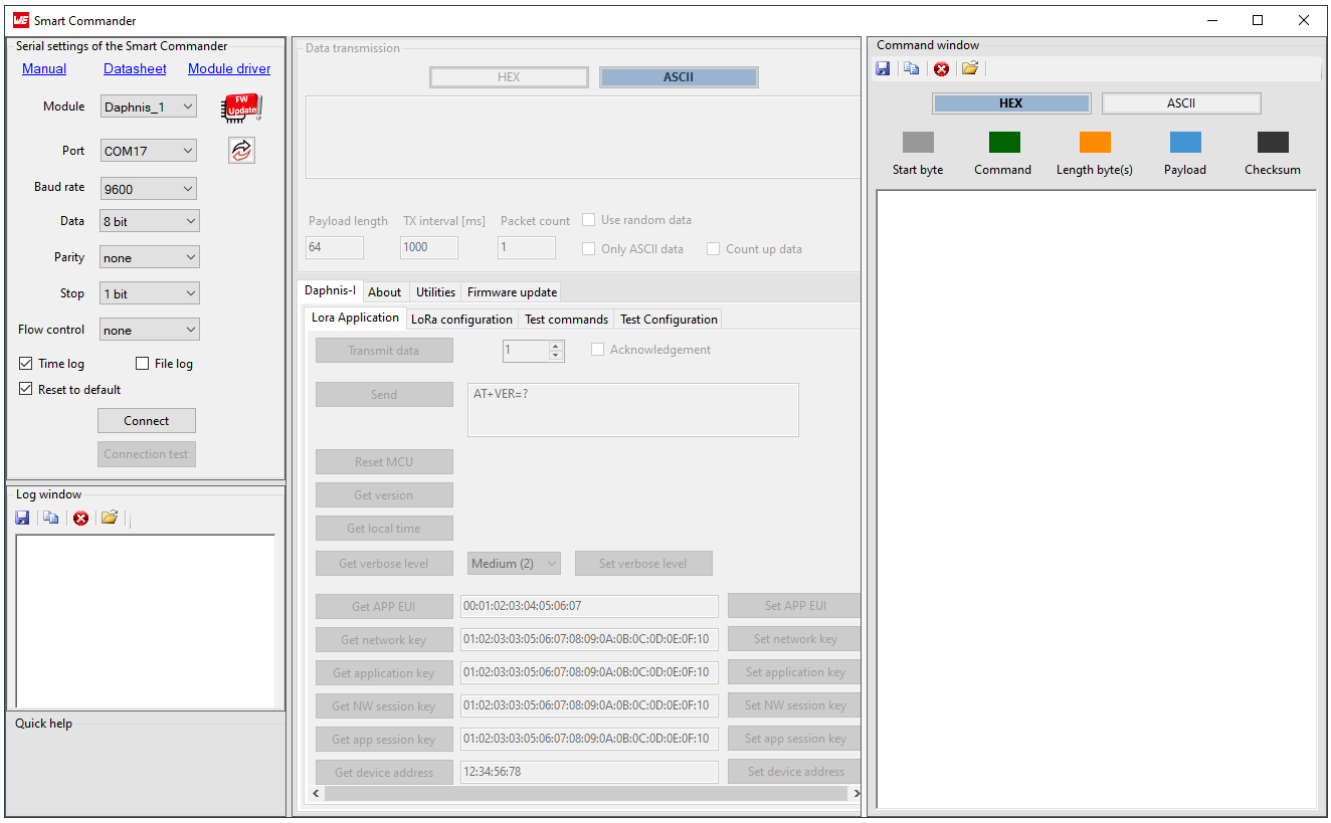

Figure 16: Smart Commander

3. Press the reset button on the EV board to ensure a clean start-up of the module. When the Daphnis-I is ready, the output console should display the following:

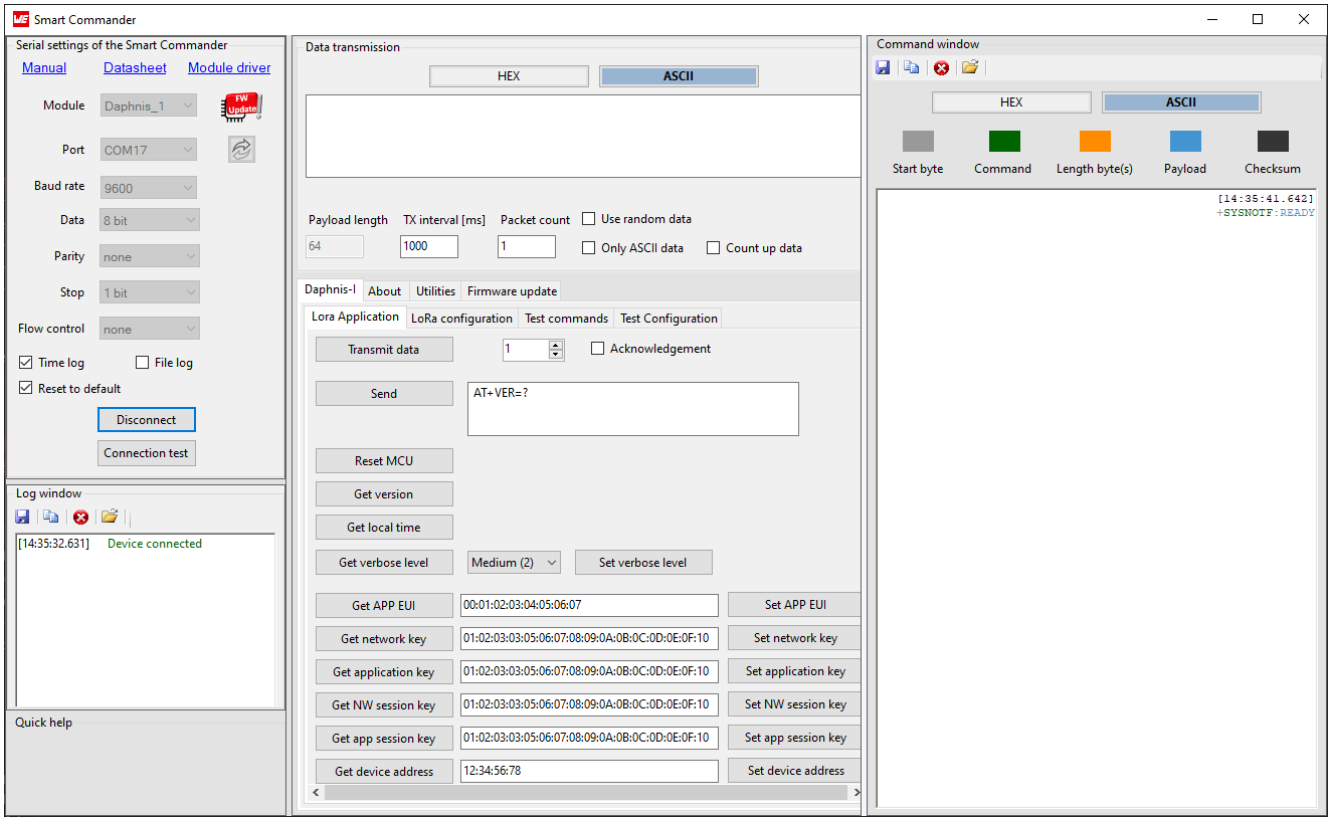

Figure 17: Smart Commander `+SYSNOTF` event

4. As preparation for the module registration process, described in the following chapter, it may be good to know the DevEUI. Thus request the default value of the module's DevEUI:

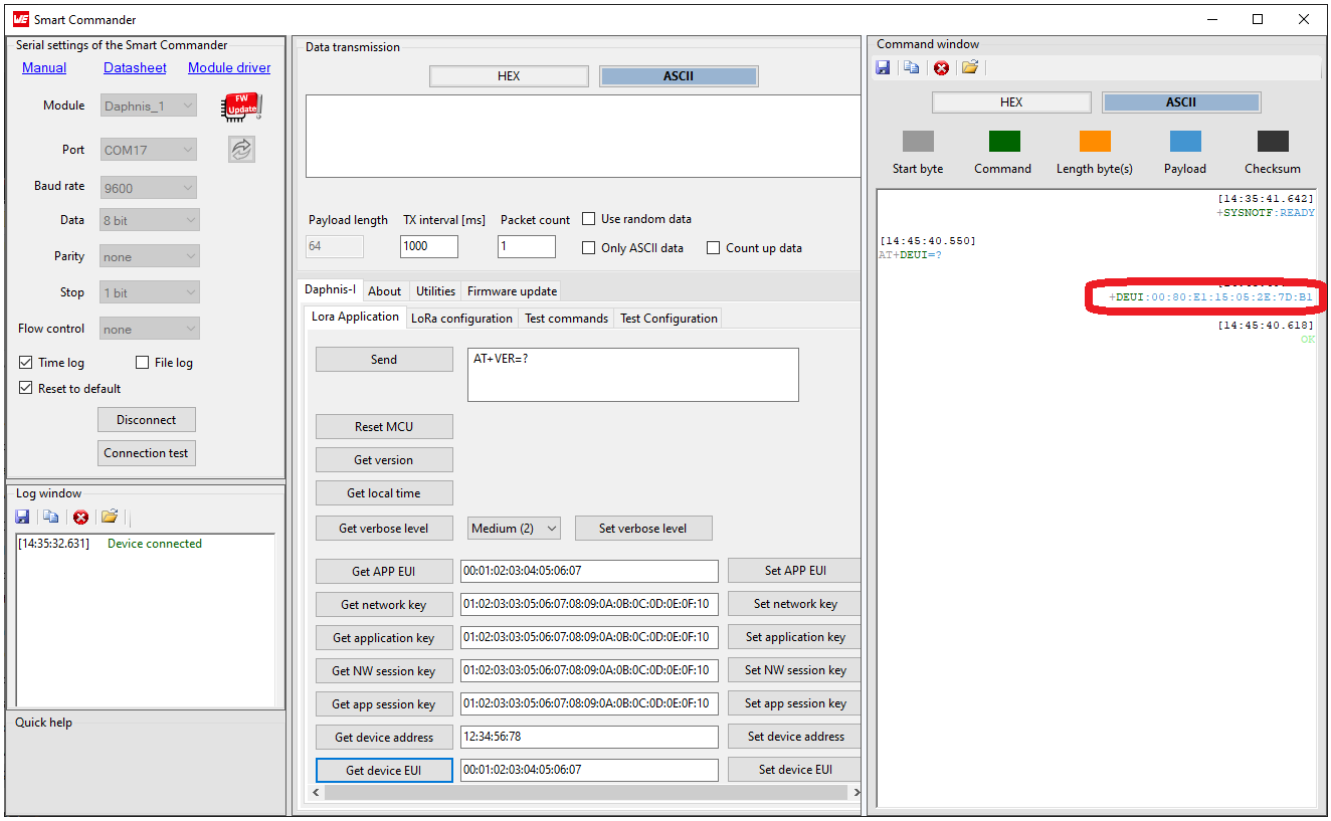

Figure 18: Smart Commander `AT+DEUI` command

The DevEUI is 00:80:E1:15:05:2E:7D:B1, as remarked in red in the command window.

6.4.2 Register module to application on network server

The next step is to register the module on the network server.

TTN community (*https://www.thethingsnetwork.org/*) will be used as the network server but the steps should be similar on all network servers.

1. Enter the end device specifications manually and choose the options as specified below:

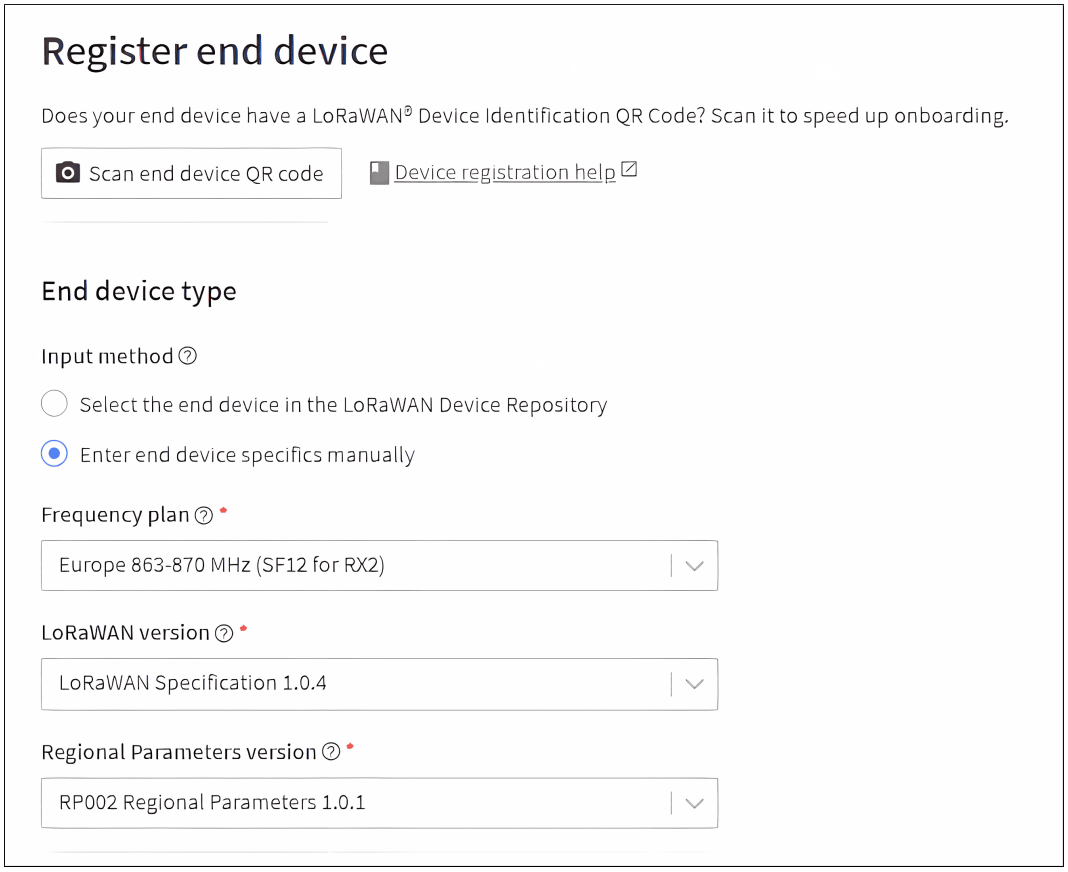

Figure 19: TTN device specifications

- Frequency plan: Europe 863-870 MHz.
- Long-Range-WAN version: 1.0.4.
- Regional parameters Version: 2-1.0.1.

2. Choose the preferred activation mode:

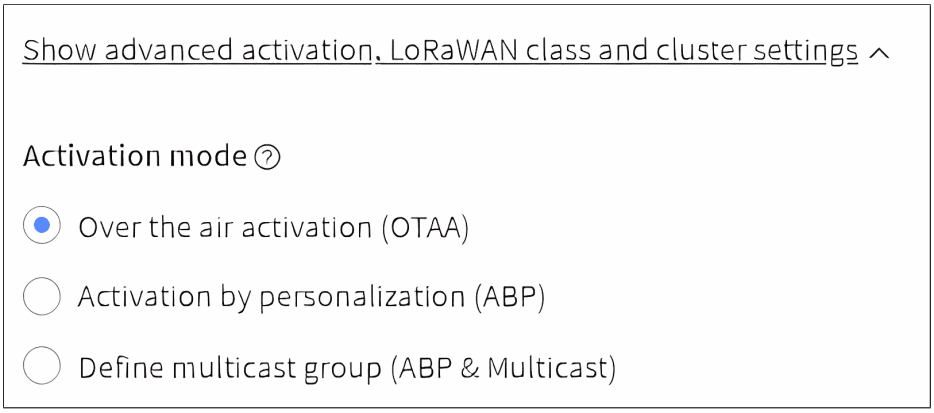

Figure 20: TTN activation mode

3. Choose the provisioning information based on the selection in previous step:

- **For OTAA joining process:**

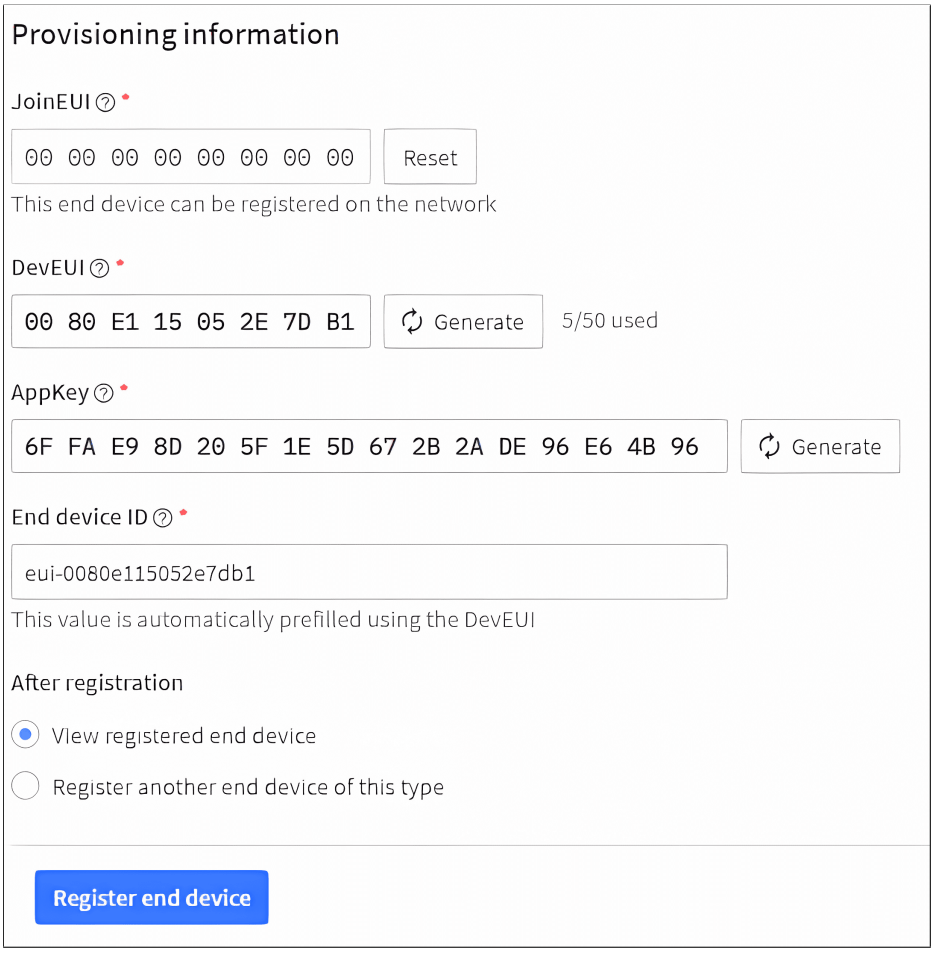

Figure 21: TTN provisioning information OTAA

– JoinEUI: set to 0s.
– DevEUI: use the default DevEUI read out in the previous chapter.
– AppKey: generate a random key.

For using OTAA during development the following option can be used so that the DevNonce on the network server resets each time on join. The Network Server uses the DevNonce of each end-device to keep track of their join requests.

– The following can be enabled to reset the DevNonce[1] on join in TTN, in the registered device under General settings, and then under Join settings.

[1] DevNonce is defined in the Long-Range-WAN specification.

Figure 22: TTN OTAA reset DevNonce

– Click register end device.

- **For ABP joining process:**

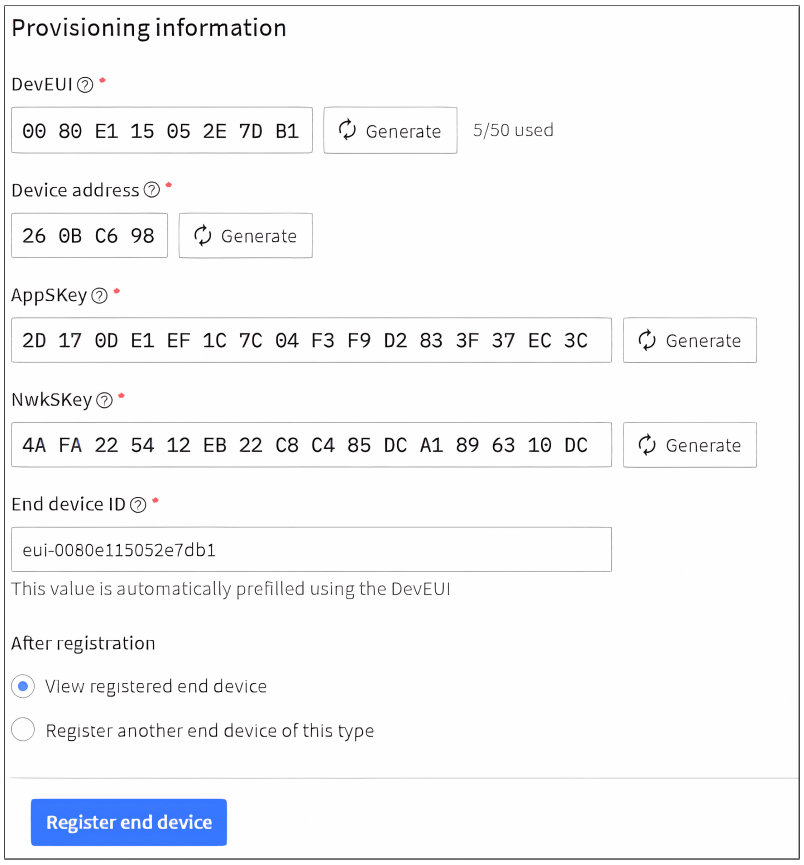

Figure 23: TTN provisioning information ABP

– DevEUI: use the default DevEUI read out in the previous chapter.
– Device Address: generate a random key.
– AppSKey: generate a random key.
– NwkSKey: generate a random key.

For using ABP during development the following option can be used so that the frame counters on the network server reset each time on join.

– The following can be enabled to reset frame counters on join in TTN, in the registered device under General settings, and then under Network layer.

Figure 24: TTN ABP reset frame counters

– Click register end device.

6.4.3 Joining the network

After the device has been registered at the network server, it can join the network.

6.4.3.1 Join via OTAA

1. Set the AppEUI/JoinEUI using `AT+APPEUI`:

```
> AT+APPEUI=00:00:00:00:00:00:00:00
< OK
```

2. Set the AppKey using `AT+APPKEY`:

```
> AT+APPKEY=3F:76:A8:2B:97:E9:44:5B:4B:8D:F8:24:5F:A4:5A:20
< OK
```

3. Set the DevEUI using `AT+DEUI`, in case the default DevEUI has not been used during device registration process on the network server:

```
> AT+DEUI=00:80:E1:15:05:2E:7D:B1
< OK
```

This step is not required if the DevEUI that was used during network registration was obtained using `AT+DEUI`.

4. Join the network using `AT+JOIN` and wait for the `+JOIN` event:

```
> AT+JOIN=1
< OK
< +JOIN:JOINED
```

To confirm that the module joined the network successfully, the following messages should appear on the TTN console of the end device.

After the network has been joined, the `AT+CS` command can be used to store the Long-Range-WAN context on non-volatile memory.

Figure 25: TTN OTAA join

6.4.3.2 Join via ABP

1. Set the NwkSKey using `AT+NWKSKEY`:

```
> AT+NWKSKEY=31:ED:AC:79:D6:DB:98:E2:95:A4:B4:00:5C:01:47:1D
< OK
```

2. Set the AppSKey using `AT+APPSKEY`:

```
> AT+APPSKEY=F6:C5:4C:61:17:2B:56:2E:1C:E1:4A:3D:76:C6:1E:1D
< OK
```

3. Set the device address using `AT+DADDR`:

```
> AT+DADDR=26:0B:0D:9B
< OK
```

4. Set the DevEUI using `AT+DEUI`, in case the default DevEUI has not been used during device registration process on the network server:

```
> AT+DEUI=00:80:E1:15:05:2E:7D:B1
< OK
```

5. Join the network using `AT+JOIN` and wait for the `+JOIN` event:

```
> AT+JOIN=0
< OK
< +JOIN:JOINED
```

After the network has been joined, the `AT+CS` command can be used to store the Long-Range-WAN context on non-volatile memory.

6.4.4 Data exchange with the Long-Range-WAN network

6.4.4.1 Sending data to the network in unconfirmed mode

1. Join the network via OTAA `6.4.3.1` or ABP `6.4.3.2`.
2. Send payload 0x1A in unconfirmed mode using `AT+SEND`:

```
> AT+SEND=1:0:1A
< OK
```

To confirm that the payload was received by the network successfully, the following messages should appear on the TTN console of the end device.

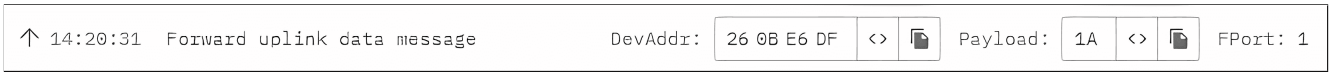

Figure 26: TTN payload received

6.4.4.2 Sending data to the network in confirmed mode

1. Join the network via OTAA `6.4.3.1` or ABP `6.4.3.2`.
2. Send payload 0x1A in confirmed mode using `AT+SEND` and wait for `+TXCONF` event:

```
> AT+SEND=1:1:1A
< OK
< +TXCONF
```

To confirm that the payload was received successfully by the network, the following messages should appear on the TTN console of the end device.

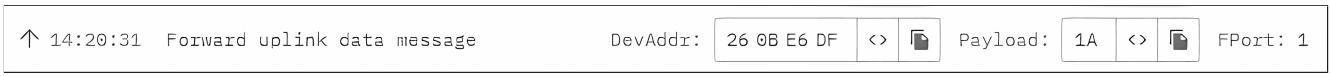

Figure 27: TTN payload received

6.4.4.3 Receiving data from the network unconfirmed mode

1. Join the network via OTAA `6.4.3.1` or ABP `6.4.3.2`.
2. Schedule downlink via TTN console:

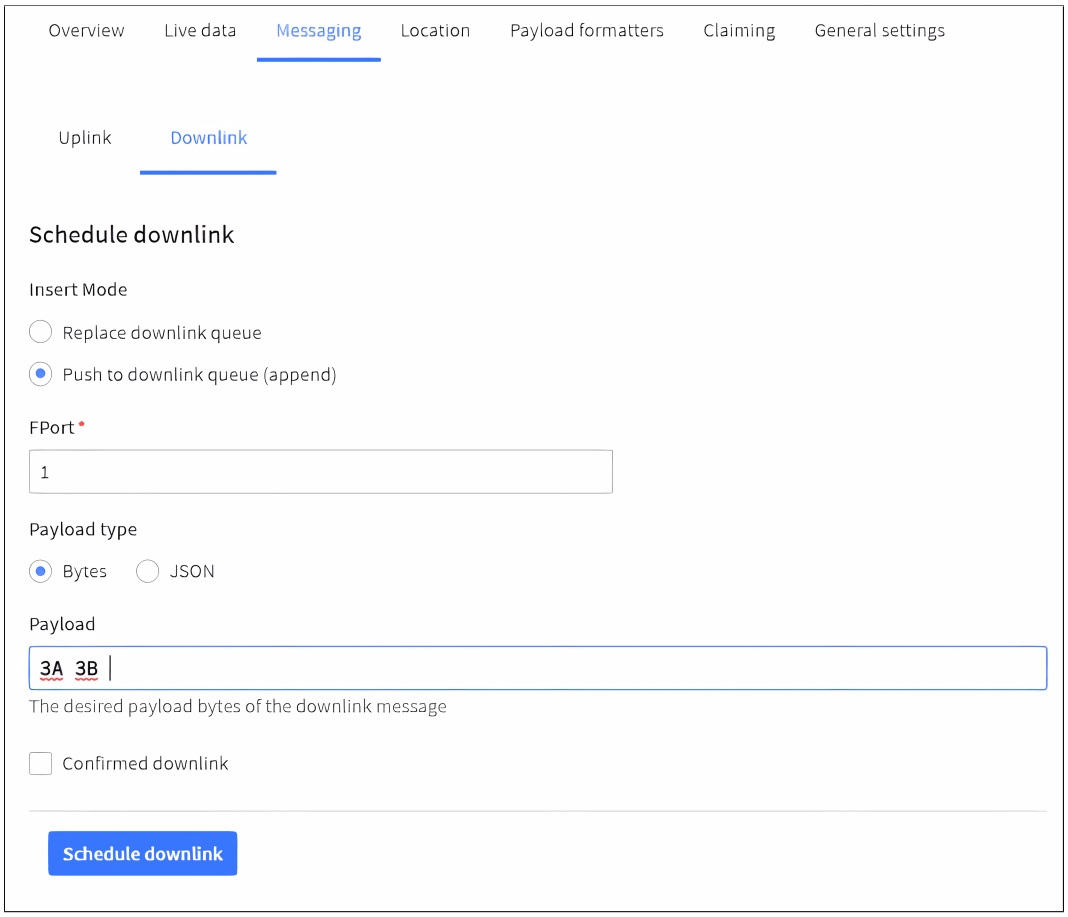

Figure 28: TTN payload schedule

To confirm that the payload was scheduled successfully, the following messages should appear on the TTN console of the end device.

Figure 29: TTN payload sent

3. The payload is received on the module depending on the selected class, in case of Class A an uplink is required first using `AT+SEND` and then wait for the `+RXDATA` event:

```
> AT+SEND=1:0:1A
< OK
< +RXDATA:1,02,3A3B
```

6.4.5 Switch the Long-Range-WAN class

The default class for the Daphnis-I is Long-Range-WAN Class A. It can be changed to Class B or Class C. The following lines show how to update it to Class B. For Class C, run the same steps with C instead of B.

1. Enable Class B support in TTN for the end device and save the changes:

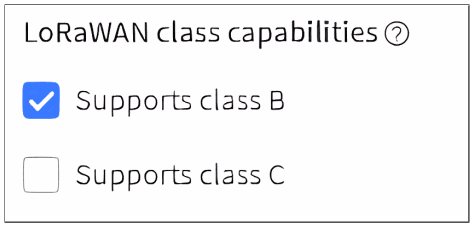

Figure 30: TTN enable Class B

2. Join the network via OTAA `6.4.3.1` or ABP `6.4.3.2`.
3. Run the switch class command `AT+CLASS`:

```
> AT+CLASS=B
< OK
```

4. Send an uplink with any payload using `AT+SEND`:

```
> AT+SEND=1:0:1A
< OK
```

5. Wait for the `+CLASSUPDATE` event:

```
< +CLASSUPDATE:B
```

6. Send an uplink with any payload using `AT+SEND`:

```
> AT+SEND=1:0:1A
< OK
```

7 AT commands

7.1 AT command syntax and types

The command set consists of a series of short text strings for performing operations such as parameters setting and reading data from the Daphnis-I module. AT commands are sent through the UART interface.

The AT commands are sent to the Daphnis-I module with the following generic syntax:

AT+<command_name>=<param1>,<param2>,. . . ,[<paramX>]<CR><LF>

Following syntactical definitions apply for AT command syntax.

- AT+: Command line prefix for AT commands.
- <command_name>: It represents the name of the AT command.
- <param1>,<param2>: Name enclosed in <angle brackets> is a syntactical element. Brackets themselves do not appear in the command line.
- [<paramX>]: Name enclosed in [<square brackets>] is a syntactical element. Brackets themselves do not appear in the command line. And it indicates an optional value (will not always be returned).

AT commands in Daphnis-I are case sensitive.

When an AT command has more than 1 parameter, then a comma (,) is used as delimiter to separate each parameter.

- Additional whitespaces in an AT command are not allowed. Additional whitespaces will return ERROR by the module.
- <CR><LF>: Mandatory command line termination characters <CR><LF>. For readers convenience the example sections will not display these characters.

The following command types are available:

- AT+<command_name>? provides a short help of the given command.
- AT+<command_name>=? is used to get the value of a given command.
- AT+<command_name> is used to run a command.
- AT+<command_name>=<param1>,<param2>,. . . ,[<paramX>] is used to provide a value to a command.

  Output of the commands is provided on the UART. The output format is typically:

  ```
  +<command_name>:<param1>,<param2>,...,<paramX><CR><LF>
  <Status<CR><LF>
  ```

  Considerations:

  – <CR> and <LF> stand for carriage return and line feed.
  – When no value is returned, then only <Status<CR><LF> .
  – Every command returns a status string, which is followed by <CR><LF>.

    Possible values for <Status> are:

    ○ OK: command run correctly without error.
    ○ AT_ERROR: generic error. This is returned when a command is not recognized.
    ○ AT_PARAM_ERROR: parameter of the command is wrong.
    ○ AT_BUSY_ERROR: Long-Range network is busy, so the command could not complete.
    ○ AT_TEST_PARAM_OVERFLOW: parameter is too long.
    ○ AT_NO_NETWORK_JOINED: Long-Range network is not joined.
    ○ AT_RX_ERROR: error detection during the reception of the command.
    ○ AT_DUTYCYCLE_RESTRICTED: duty cycle restriction is reached.
    ○ AT_CRYPTO_ERROR: error occurred during encryption / decryption.

7.2 General AT commands

7.2.1 AT

Description: Check communication via UART with Daphnis-I.

Command	Parameters	Return Value	Return Code
AT	None	None	OK

Table 15: AT command

Example:

```
> AT
< OK
```

7.2.2 ATZ

Description: Reset Daphnis-I.

Command	Parameters	Return Value	Return Code
ATZ	None	None	OK

Table 16: ATZ command

Example:

```
> ATZ
< OK
```

7.2.3 AT+LTIME

Description: Get the local time.

Command	Parameters	Return Value	Return Code
AT+LTIME=?	None	<param1>: Time following format XXhXXmXXs <param2>: Date in the following format dd/MM/yyyy	OK

Table 17: AT+LTIME command

Example:

```
> AT+LTIME=?
< +LTIME:16h45m25s,15/05/2023
< OK
```

The returned time is valid if you are in Class B or have at least once switched to Class B without resetting the module.

7.2.4 AT+BAT

Description: Get the battery level in mV.

Command	Parameters	Return Value	Return Code
AT+BAT=?	None	<param1>: Battery level in mV	OK

Table 18: AT+BAT command

Example:

```
> AT+BAT=?
< +BAT:3155
< OK
```

7.2.5 AT+SLEEP

Description: Put Daphnis-I into `Sleep mode`.

Command	Parameters	Return Value	Return Code
AT+SLEEP	None	None	OK

Table 19: AT+SLEEP command

Example:

```
> AT+SLEEP
< OK
```

7.3 General events

7.3.1 +SYSNOTF

Description: Daphnis-I ready to receive commands (boot up finished).

Event	Parameters
+SYSNOTF	<param1>: READY

Table 20: +SYSNOTF Event

Example:

```
< +SYSNOTF:READY
```

7.3.2 +CS

Description: Long-Range-WAN context storage event.

Event	Parameters
+CS	<param1>: NVM_DATA_STORED NVM_DATA_RESTORED

Table 21: +CS Event

Example:

```
< +CS:NVM_DATA_RESTORED
```

7.4 UserSettings AT commands

7.4.1 AT+UARTBAUDRATE

Description: Get or set the UART baud rate of Daphnis-I.

Command	Parameters	Return Value	Return Code
AT+UARTBAUDRATE	<param1>: Baud rate 0: 9600 1: 57600 2: 115200	None	OK AT_PARAM_ERROR
AT+UARTBAUDRATE=?	None	<param1>: Baud rate Default value 0 0: 9600 1: 57600 2: 115200	OK

Table 22: AT+UARTBAUDRATE command

Example:

```
> AT+UARTBAUDRATE=0
< OK

> AT+UARTBAUDRATE=?
< +UARTBAUDRATE:0
< OK
```

The newly selected baud rate is only applied after the module has been reset.

7.4.2 AT+RUS

Description: Restore UserSettings to their default values.

Command	Parameters	Return Value	Return Code
AT+RUS	None	None	OK

Table 23: AT+RUS command

Example:

```
> AT+RUS
< OK
```

The default UserSettings are only applied after the module has been reset.

7.5 Long-Range-WAN stack context AT commands

7.5.1 AT+CS

Description: Store Long-Range-WAN context to flash memory.

Command	Parameters	Return Value	Return Code
AT+CS	None	<param1>: NVM_DATA_STORED	OK AT_ERROR

Table 24: AT+CS command

Example:

```
> AT+CS
< +CS:NVM_DATA_STORED
< OK
```

7.5.2 AT+RFS

Description: Erase Long-Range-WAN context stored in flash memory.

Command	Parameters	Return Value	Return Code
AT+RFS	None	None	OK

Table 25: AT+RFS command

Example:

```
> AT+RFS
< OK
```

This command restarts Daphnis-I after execution.

7.6 Long-Range-WAN keys, IDs and EUIs AT commands

7.6.1 AT+APPEUI

Description: Get or set the application identifier (also known as join identifier).

Command	Parameters	Return Value	Return Code
AT+APPEUI	<param1>: APPEUI 8 byte value separated by ':' in hex string format XX:XX:XX:XX:XX:XX:XX:XX	None	OK AT_PARAM_ERROR AT_ERROR
AT+APPEUI=?	None	<param1>: APPEUI 8 byte value separated by ':' in hex string format XX:XX:XX:XX:XX:XX:XX:XX	OK AT_ERROR

Table 26: AT+APPEUI command

Example:

```
> AT+APPEUI=00:00:00:00:00:00:00:00
< OK

> AT+APPEUI=?
< +APPEUI:00:00:00:00:00:00:00:00
< OK
```

7.6.2 AT+APPKEY

Description: Set the application key.

Command	Parameters	Return Value	Return Code
AT+APPKEY	<param1>: APPKEY in the following format 16 byte value separated by ':' in hex string format XX:XX:...:XX	None	OK AT_PARAM_ERROR AT_ERROR

Table 27: AT+APPKEY command

Example:

```
> AT+APPKEY=3F:76:A8:2B:97:E9:44:5B:4B:8D:F8:24:5F:A4:5A:20
< OK
```

This key can only be set but not read back due to security reasons.

7.6.3 AT+APPSKEY

Description: Set the application session key.

Command	Parameters	Return Value	Return Code
AT+APPSKEY	<param1>: APPSKEY in the following format 16 byte value separated by ':' in hex string format XX:XX:...:XX	None	OK AT_PARAM_ERROR AT_ERROR

Table 28: AT+APPSKEY command

Example:

```
> AT+APPSKEY=81:CD:59:B3:0E:E8:75:3F:B7:F7:CC:FE:4B:D3:E9:66
< OK
```

This key can only be set but not read back due to security reasons.

7.6.4 AT+NWKSKEY

Description: Set the network session key.

Command	Parameters	Return Value	Return Code
AT+NWKSKEY	<param1>: NWKSKEY in the following format 16 byte value separated by ':' in hex string format XX:XX:...:XX	None	OK AT_PARAM_ERROR AT_ERROR

Table 29: AT+NWKSKEY command

Example:

```
> AT+NWKSKEY=54:44:A3:15:76:CE:6A:71:BC:B7:5A:DF:B1:DB:03:D0
< OK
```

This key can only be set but not read back due to security reasons.

7.6.5 AT+DADDR

Description: Get or set the device address.

Command	Parameters	Return Value	Return Code
AT+DADDR	<param1>: DADDR 4 byte value separated by ':' in hex string format XX:XX:XX:XX	None	OK AT_PARAM_ERROR AT_ERROR
AT+DADDR=?	None	<param1>: DADDR 4 byte value separated by ':' in hex string format XX:XX:XX:XX	OK AT_ERROR

Table 30: AT+DADDR command

Example:

```
> AT+DADDR=30:92:45:D2
< OK

> AT+DADDR=?
< +DADDR:30:92:45:D2
< OK
```

7.6.6 AT+DEUI

Description: Get or set the device identifier.

Command	Parameters	Return Value	Return Code
AT+DEUI	<param1>: DEUI 8 byte value separated by ':' in hex string format XX:XX:XX:XX:XX:XX:XX:XX	None	OK AT_PARAM_ERROR AT_ERROR
AT+DEUI=?	None	<param1>: DEUI 8 byte value separated by ':' in hex string format XX:XX:XX:XX:XX:XX:XX:XX	OK AT_ERROR

Table 31: AT+DEUI command

Example:

```
> AT+DEUI=32:E4:5F:7D:50:4A:E6:8A
< OK

> AT+DEUI=?
< +DEUI:32:E4:5F:7D:50:4A:E6:8A
< OK
```

7.6.7 AT+NWKID

Description: Get or set the network ID.

Command	Parameters	Return Value	Return Code
AT+NWKID	<param1>: NWKID Integer value from 0 to 127	None	OK AT_PARAM_ERROR AT_ERROR
AT+NWKID=?	None	<param1>: NWKID Integer value from 0 to 127	OK AT_ERROR

Table 32: AT+NWKID command

Example:

```
> AT+NWKID=64
< OK

> AT+NWKID=?
< +NWKID:64
< OK
```

7.7 Long-Range-WAN network AT commands

7.7.1 AT+VER

Description: Get the firmware version, Long-Range-WAN link layer and regional parameters specifications.

Command	Parameters	Return Value	Return Code
AT+VER=?	None	<param1>: Firmware version in the following format VX.X.X <param2>: Link layer specification in the following format VX.X.X <param3>: Regional parameters specification in the following format VX-X.X.X	OK

Table 33: AT+VER command

Example:

```
> AT+VER=?
< +VER:V1.3.0,V1.0.4,V2−1.0.1
< OK
```

7.7.2 AT+ADR

Description: Get or set adaptive data rate functionality.

Command	Parameters	Return Value	Return Code
AT+ADR	<param1>: ADR 0: ADR off 1: ADR on	None	OK AT_PARAM_ERROR
AT+ADR=?	None	<param1>: ADR Default value 1 0: ADR off 1: ADR on	OK

Table 34: AT+ADR command

Example:

```
> AT+ADR=1
< OK

> AT+ADR=?
< +ADR:1
< OK
```

7.7.3 AT+DR

Description: Get or set TX data rate.

Command	Parameters	Return Value	Return Code
AT+DR	<param1>: Data rate Integer value from 0 to 7	None	OK AT_PARAM_ERROR AT_ERROR
AT+DR=?	None	<param1>: Data rate Default value 0 Integer value from 0 to 7	OK AT_ERROR

Table 35: AT+DR command

Example:

```
> AT+DR=2
< OK

> AT+DR=?
< +DR:2
< OK
```

This command can be used only if adaptive data rate is off.

7.7.4 AT+DCS

Description: Get or set duty cycle restriction.

Command	Parameters	Return Value	Return Code
AT+DCS	<param1>: DCS 0: DCS off 1: DCS on	None	OK AT_PARAM_ERROR AT_ERROR
AT+DCS=?	None	<param1>: DCS Default value 1 0: DCS off 1: DCS on	OK AT_ERROR

Table 36: AT+DCS command

Resetting the module or entering `Sleep mode` will cause the module to reset the calculated time on air.

Example:

```
> AT+DCS=1
< OK

> AT+DCS=?
< +DCS:1
< OK
```

7.7.5 AT+JN1DL

Description: Get or set the join accept delay between the end of the join request TX and the first join receive window (RX1).

Command	Parameters	Return Value	Return Code
AT+JN1DL	<param1>: Delay in ms Integer value	None	OK AT_PARAM_ERROR AT_ERROR
AT+JN1DL=?	None	<param1>: Delay in ms Default value 5000 Integer value	OK AT_ERROR

Table 37: AT+JN1DL command

Example:

```
> AT+JN1DL=7000
< OK

> AT+JN1DL=?
< +JN1DL:7000
< OK
```

7.7.6 AT+JN2DL

Description: Get or set the join accept delay between the end of the join request TX and the second join receive window (RX2).

Command	Parameters	Return Value	Return Code
AT+JN2DL	<param1>: Delay in ms Integer value	None	OK AT_PARAM_ERROR AT_ERROR
AT+JN2DL=?	None	<param1>: Delay in ms Default value 6000 Integer value	OK AT_ERROR

Table 38: AT+JN2DL command

Example:

```
> AT+JN2DL=8000
< OK

> AT+JN2DL=?
< +JN2DL:8000
< OK
```

7.7.7 AT+RX1DL

Description: Get or set the delay between the end of the TX and the first receive window (RX1).

Command	Parameters	Return Value	Return Code
AT+RX1DL	<param1>: Delay in ms Integer value	None	OK AT_PARAM_ERROR AT_ERROR
AT+RX1DL=?	None	<param1>: Delay in ms Default value 1000 Integer value	OK AT_ERROR

Table 39: AT+RX1DL command

Example:

```
> AT+RX1DL=2000
< OK

> AT+RX1DL=?
< +RX1DL:2000
< OK
```

7.7.8 AT+RX2DL

Description: Get or set the delay between the end of the TX and the second receive window (RX2).

Command	Parameters	Return Value	Return Code
AT+RX2DL	<param1>: Delay in ms Integer value	None	OK AT_PARAM_ERROR AT_ERROR
AT+RX2DL=?	None	<param1>: Delay in ms Default value 2000 Integer value	OK AT_ERROR

Table 40: AT+RX2DL command

Example:

```
> AT+RX2DL=3000
< OK

> AT+RX2DL=?
< +RX2DL:3000
< OK
```

7.7.9 AT+RX2DR

Description: Get or set the data rate of the second receive window (RX2).

Command	Parameters	Return Value	Return Code
AT+RX2DR	<param1>: Data rate Integer value from 0 to 7	None	OK AT_PARAM_ERROR AT_ERROR
AT+RX2DR=?	None	<param1>: Data rate Default value 0 Integer value from 0 to 7	OK AT_ERROR

Table 41: AT+RX2DR command

Example:

```
> AT+RX2DR=4
< OK

> AT+RX2DR=?
< +RX2DR:4
< OK
```

7.7.10 AT+RX2FQ

Description: Get or set the frequency of the second receive window (RX2).

Command	Parameters	Return Value	Return Code
AT+RX2FQ	<param1>: Frequency in Hz Integer value	None	OK AT_PARAM_ERROR AT_ERROR
AT+RX2FQ=?	None	<param1>: Frequency in Hz Default value 869525000 Integer value	OK AT_ERROR

Table 42: AT+RX2FQ command

Example:

```
> AT+RX2FQ=869535000
< OK

> AT+RX2FQ=?
< +RX2FQ:869535000
< OK
```

7.7.11 AT+TXP

Description: Get or set the transmit power according to the regional parameters.

Command	Parameters	Return Value	Return Code
AT+TXP	<param1>: Transmit power Integer value from 0 to 7	None	OK AT_PARAM_ERROR AT_ERROR
AT+TXP=?	None	<param1>: Transmit power Default value 0 Integer value from 0 to 7	OK AT_ERROR

Table 43: AT+TXP command

Example:

```
> AT+TXP=4
< OK

> AT+TXP=?
< +TXP:4
< OK
```

7.7.12 AT+PGSLOT

Description: Get or set the periodicity factor of the ping slot.

Command	Parameters	Return Value	Return Code
AT+PGSLOT	<param1>: Periodicity factor Integer value from 0 to 7	None	OK AT_PARAM_ERROR AT_ERROR
AT+PGSLOT=?	None	<param1>: Periodicity factor Default value 4 Integer value from 0 to 7	OK AT_ERROR

Table 44: AT+PGSLOT command

Example:

```
> AT+PGSLOT=5
< OK

> AT+PGSLOT=?
< +PGSLOT:5
< OK
```

Ping slot periodicity is calculated as $Periodicity = 2^{<param1>}$ seconds.

7.7.13 AT+JOIN

Description: Join the Long-Range-WAN network.

Command	Parameters	Return Value	Return Code
AT+JOIN	<param1>: Join mode 0: ABP 1: OTAA	None	OK AT_PARAM_ERROR

Table 45: AT+JOIN command

Example:

```
> AT+JOIN=0
< OK

> AT+JOIN=1
< OK
```

This command triggers the `+JOIN` event.

7.7.14 AT+LINKC

Description: Piggyback LinkCheckReq MAC command on the next uplink.

Command	Parameters	Return Value	Return Code
AT+LINKC	None	None	OK AT_PARAM_ERROR

Table 46: AT+LINKC command

Example:

```
> AT+LINKC
< OK
```

This command affects the output of the +RXINFO event.

7.7.15 AT+SEND

Description: Send a packet to the Long-Range-WAN network.

Command	Parameters	Return Value	Return Code
AT+SEND	<param1>: Frame port Integer value from 0 to 255 <param2>: Uplink confirmation 0: Unconfirmed 1: Confirmed <param3>: Payload in hex string format Max length is up to 242 bytes depending on the data rate XXXX...XX	None	OK AT_PARAM_ERROR AT_DUTYCYLE_RESTRICTED AT_NO_NET_JOINED AT_BUSY_ERROR AT_CRYPTO_ERROR AT_ERROR

Table 47: AT+SEND command

Example:

```
> AT+SEND=1:0:1A2B
< OK

> AT+SEND=1:1:1A2B
< OK
```

This command triggers the +TXCONF event.

7.7.16 AT+CLASS

Description: Get or set Daphnis-I Long-Range-WAN class.

Command	Parameters	Return Value	Return Code
AT+CLASS	<param1>: Class A: Class A B: Class B C: Class C	None	OK AT_ERROR AT_PARAM_ERROR AT_NO_NET_JOINED
AT+CLASS=?	None	<param1>: Class A: Class A B0,B1,B2: Switch Class A to Class B in progress B: Class B C: Class C	OK

Table 48: AT+CLASS command

Example:

```
> AT+CLASS=C
< OK

> AT+CLASS=?
< +CLASS:C
< OK
```

The class can be changed only after a network has been joined. In order to switch to Class B or Class C, the module needs to be in Class A.

This command triggers the `+CLASSUPDATE` event.

7.8 Long-Range-WAN certification AT commands

7.8.1 AT+CERTIF

Description: Start Long-Range-WAN certification mode.

Command	Parameters	Return Value	Return Code
AT+CERTIF	<param1>: Join mode 0: ABP 1: OTAA	None	OK AT_PARAM_ERROR AT_ERROR

Table 49: AT+CERTIF command

Example:

```
> AT+CERTIF=0
< OK

> AT+CERTIF=1
< OK
```

This command triggers `+JOIN` event.

7.9 Long-Range-WAN network events

7.9.1 +JOIN

Description: Join Long-Range-WAN network event.

Event	Parameters
+JOIN	<param1>: Join status JOINED: Successfully joined the network JOIN_FAILED: Failed to join the network

Table 50: +JOIN Event

Example:

```
< +JOIN:JOINED
```

7.9.2 +RXDATA

Description: Data received event.

Event	Parameters
+RXDATA	<param1>: Application port Integer value from 1 to 223 <param2>: Size in bytes in hex format Up to 242 bytes <param3>: Payload in hex string format XXXX...XX

Table 51: +RXDATA Event

Example:

```
< +RXDATA:223,01,65
```

7.9.3 +RXINFO

Description: Receive window slot information event.

Event	Parameters
+RXINFO	<param1>: Receive slot window RX_1: Received on first Class A window RX_2: Received on second Class A window RX_C: Received on continuous Class C window RX_B: Received on ping Class B window <param2>: Frame port Integer value from 0 to 255 <param3>: Data rate Integer value from 0 to 7 <param4>: RSSI Received signal strength indicator Integer value 1 byte <param5>: SNR Signal-to-noise ratio Integer value 1 byte [<param6>]: Demodulated margin indicating the link margin in db of the last successfully received LinkCheckReq MAC command Integer value from 0 to 254 [<param7>]: Number of gateways that successfully received the last LinkCheckReq MAC command Integer value 1 byte

Table 52: +RXINFO Event

Example:

```
< +RXINFO:RX_1,0,5,−25,9

< +RXINFO:RX_C,223,0,−17,5

< +RXINFO:RX_1,0,5,−25,9,21,1
```

<param6> and <param7> are optional and only available after the `AT+LINKC` command was executed and an uplink was sent.

7.9.4 +TXCONF

Description: Uplink confirmation event.

Event	Parameters
+TXCONF	None

Table 53: +TXCONF Event

Example:

```
< +TXCONF
```

7.9.5 +CLASSUPDATE

Description: Successfully switch to class event.

Event	Parameters
+CLASSUPDATE	<param1>: Class A: Class A B: Class B C: Class C

Table 54: +CLASSUPDATE Event

Example:

```
< +CLASSUPDATE:C
```

7.9.6 +BEACONINFO

Description: Received beacon information event.

Event	Parameters
+BEACONINFO	<param1>: Beacon window RX_BC <param2>: Data rate Integer value from 0 to 7 <param3>: RSSI Received signal strength indicator Integer value 1 byte <param4>: SNR Signal-to-noise ratio Integer value 1 byte <param5>: Frequency in Hz Integer value <param6>: Timestamp in seconds GPS Epoch Integer value <param7>: Info descriptor Integer value 1 byte, refer to [1] Section 13.3 <param8>: Info first 3 bytes in hex string format XXXXXX, refer to [1] Section 13.3 <param9>: Info second 3 bytes in hex string format XXXXXX, refer to [1] Section 13.3

Table 55: +BEACONINFO Event

Example:

```
< +BEACONINFO:RX_BC,3,−45,12,869525000,1368197120,0,000000,000000
```

7.9.7 +BEACONLOST

Description: No beacon was received in the past 120 minutes event. It will also revert to Class A from Class B and try to acquire a new beacon.

Event	Parameters
+BEACONLOST	None

Table 56: +BEACONLOST Event

Example:

```
< +BEACONLOST
```

7.9.8 +BEACONNOTRECEIVED

Description: The beacon receive window did not receive any beacons within the beacon period.

Event	Parameters
+BEACONNOTRECEIVED	None

Table 57: +BEACONNOTRECEIVED Event

Example:

```
< +BEACONNOTRECEIVED
```

7.10 Radio test AT commands

7.10.1 AT+TTONE

Description: Start RF tone test.

Command	Parameters	Return Value	Return Code
AT+TTONE	None	None	OK AT_BUSY_ERROR AT_ERROR

Table 58: AT+TTONE command

Example:

```
> AT+TTONE
< OK
```

7.10.2 AT+TRSSI

Description: Start RF RSSI tone test.

Command	Parameters	Return Value	Return Code
AT+TRSSI	None	<param1>: RSSI Integer value 1 byte	OK AT_BUSY_ERROR AT_ERROR

Table 59: AT+TRSSI command

Example:

```
> AT+TRSSI
< +TRSSI:-114
< OK
```

7.10.3 AT+TCONF

Description: Get or set the test configuration.

Command	Parameters	Return Value	Return Code
AT+TCONF	<param1>: Frequency in Hz Integer value <param2>: Transmit power in dBm Integer value from 0 to 14 <param3>: Bandwidth • FSK in Hz Integer value from 4800 to 467000 • Long-Range in kHz 0: 7.8125 1: 15.625 2: 31.25 3: 62.5 4: 125 5: 250 6: 500 • BPSK in Hz Not used • MSK in Hz Integer value from 4800 to 467000 <param4>: • FSK data rate in bps Integer value from 600 to 300000 • Long-Range spreading factor Integer value from 5 to 12	None	OK AT_PARAM_ERROR

AT+TCONF	• BPSK data rate in bps Integer value from 1 to 1000 • MSK data rate in bps Integer value from 100 to 300000 <param5>: Coding rate • FSK Not used • Long-Range 4/5 4/6 4/7 4/8 • BPSK Not used • MSK Not used <param6>: Low-noise amplifier 0: off 1: on <param7>: PA boost 0: off 1: on <param8>: Modulation 0: FSK 1: Long-Range 2: BPSK (TX) 3: MSK <param9>: Payload length in bytes Integer value from 1 to 255	None	OK AT_PARAM_ERROR

AT+TCONF	<param10>: Frequency deviation • FSK frequency in MHz Integer value from 600 to 200000 • Long-Range Not used • BPSK Not used • MSK Not used <param11>: Low DR optimization • FSK Not used • Long-Range 0: 0ff 1: on 2: Auto (1 when SF11 or SF12, 0 otherwise) • BPSK Not used • MSK Not used <param12>: Gaussian BT product • FSK, MSK 0: No filter applied 1: BT = 0.3 2: BT = 0.5 3: BT = 0.7 4: BT = 1 • Long-Range Not used • BPSK Not used	None	OK AT_PARAM_ERROR

AT+TCONF=?	None	<param1>: Frequency in Hz Integer value <param2>: Transmit power in dBm Integer value from 0 to 14 [<param3>]: Bandwidth • FSK Integer value • Long-Range 0(7812) 1(15625) 2(31250) 3(62500) 4(125000) 5(250000) 6(500000) • BPSK Not returned • MSK Integer value <param4>: • FSK data rate in bps Integer value • Long-Range spreading factor Integer value from 5 to 12 • BPSK data rate in bps Integer value • MSK data rate in bps Integer value	OK

AT+TCONF=?	None	[<param5>]: Coding rate • FSK NA • Long-Range 1(=4/5) 2(=4/6) 3(=4/7) 4(=4/8) • BPSK Not returned • MSK NA [<param6>]: Low-noise amplifier • FSK, Long-Range, MSK 0: off 1: on • BPSK Not returned [<param7>]: PA boost • FSK, Long-Range, MSK 0: off 1: on • BPSK Not returned [<param8>]: Modulation • FSK FSK • Long-Range Long-Range • BPSK Not returned • MSK MSK	OK

AT+TCONF=?	None	[<param9>]: Payload length in bytes • FSK, Long-Range, MSK Integer value • BPSK Not returned [<param10>]: Frequency deviation • FSK Integer value • Long-Range NA • BPSK Not returned • MSK FSK_DR/4 [<param11>]: Low DR optimization • FSK NA • Long-Range 0: 0ff 1: on 2: Auto (1 when SF11 or SF12, 0 otherwise) • BPSK Not returned • MSK NA [<param12>]: Gaussian BT product • FSK, MSK 0: No filter applied 1: BT = 0.3 2: BT = 0.5 3: BT = 0.7 4: BT = 1	OK

AT+TCONF=?	None	• Long-Range Not used • BPSK Not used	OK

Table 60: AT+TCONF command

Example:

```
> AT+TCONF=868000000:14:50000:50000:4/5:0:0:0:16:25000:2:3 // FSK
< OK

> AT+TCONF=868000000:14:4:12:4/5:0:0:1:16:25000:2:3 // Long−Range
< OK

> AT+TCONF=868000000:14:10000:1000:4/5:0:0:2:16:25000:2:3 // BPSK
< OK

> AT+TCONF=868000000:14:10000:10000:4/5:0:0:3:16:25000:2:3 // MSK
< OK

> AT+TCONF=?
< +TCONF:868000000,14,4(125000),12,1(=4/5),0,0,LORA,16,NA,2,NA
< OK
```

When setting the test configuration, unused parameters still need to be defined as shown in the example.

7.10.4 AT+TTX

Description: Start RF TX test with the specified number of packets.

Command	Parameters	Return Value	Return Code
AT+TTX	<param1>: Number of packets Integer value	<param1>: Success rate Integer value from 0 to 100	OK AT_BUSY_ERROR AT_ERROR

Table 61: AT+TTX command

Example:

```
> AT+TTX=3
< +TTX:100
< OK
```

This command will only respond after all packets have been sent.

7.10.5 AT+TRX

Description: Start RF RX test with the specified number of expected packets (to be used with `AT+TTX`).

Command	Parameters	Return Value	Return Code
AT+TRX	<param1>: Number of packets Integer value	<param1>: Success rate Integer value from 0 to 100 <param2>: Average RSSI Integer value <param3>: Average SNR Integer value <param4>: Average Sensitivity Integer value	OK AT_BUSY_ERROR AT_ERROR

Table 62: AT+TRX command

Example:

```
> AT+TRX=3
< +TRX:100,-7,5,-2
< OK
```

This command will only respond after all packets have been either received or timed out.

7.10.6 AT+TTH

Description: Start RF TX hopping test.

Command	Parameters	Return Value	Return Code
AT+TTH	<param1>: Start frequency in Hz Integer value <param2>: Stop frequency in Hz Integer value <param3>: Frequency delta in Hz Integer value <param4>: Number of packets Integer value	<param1>: Success rate Integer value from 0 to 100	OK AT_BUSY_ERROR AT_ERROR

Table 63: AT+TTH command

Example:

```
> AT+TTH=868000000,868500000,100000,6
< +TTH:100
< OK
```

7.10.7 AT+TOFF

Description: Stop RF tone test.

Command	Parameters	Return Value	Return Code
AT+TOFF	None	None	OK AT_BUSY_ERROR AT_ERROR

Table 64: AT+TOFF command

Example:

```
> AT+TOFF
< OK
```

Other radio tests once started cannot be stopped using this command.

8 Firmware update

The firmware on the Daphnis-I consists of two components:

- The bootloader that implements the secure firmware update over UART.
- The application firmware that provides the module functionality.

Only the application firmware can be updated over the UART interface (see section 8.1)

8.1 Firmware update using the Daphnis-I UART bootloader

The firmware update of the module over the UART interface is managed by the secure bootloader implemented as a part of the standard firmware. The update process can only be performed in the bootloader mode. If the firmware update process is interrupted, the application firmware will be invalidated and the module will always go to bootloader mode, regardless of the *BOOT* pin level. Once a successful update occurs, the module will boot depending on the level of the *BOOT* pin. A connection of *UTXD1* and *URXD1* over a suiting level and/or interface converter (e.g. FTDI cable or converter) is required.

The firmware update process requires exclusive access on the following pins of the Daphnis-I: *UTXD1*, *URXD1*.
The user is required to use the *BOOT* pin and */RESET* pin during this process.

A stable power supply is assumed to be available during any firmware update process. Battery operated firmware updates are not recommended.

- The module can be switched to the bootloader mode by holding the *BOOT* pin HIGH during the boot-up process to activate the secure UART bootloader.
- The *LED_1* pin will toggle to indicate that the module is in the bootloader mode and waiting for the firmware file to be sent.
- The secure UART bootloader runs at a fixed baud rate of 115200 Baud.

8.1.1 Update using Daphnis-I updater tool for Windows PC

It is recommended to download the updater tool from the Daphnis-I homepage in the *Daphnis-I specific area for software downloads*.

The encrypted firmware update package (sfb) file is only available on request by contacting support [4].

Requirements for running the PC tool:

- Windows 10
- .NET 6.0 or newer (download available via Microsoft Homepage and in the Windows Features section)
- A folder with write and read access for the current user.

Steps to update the firmware using the tool:

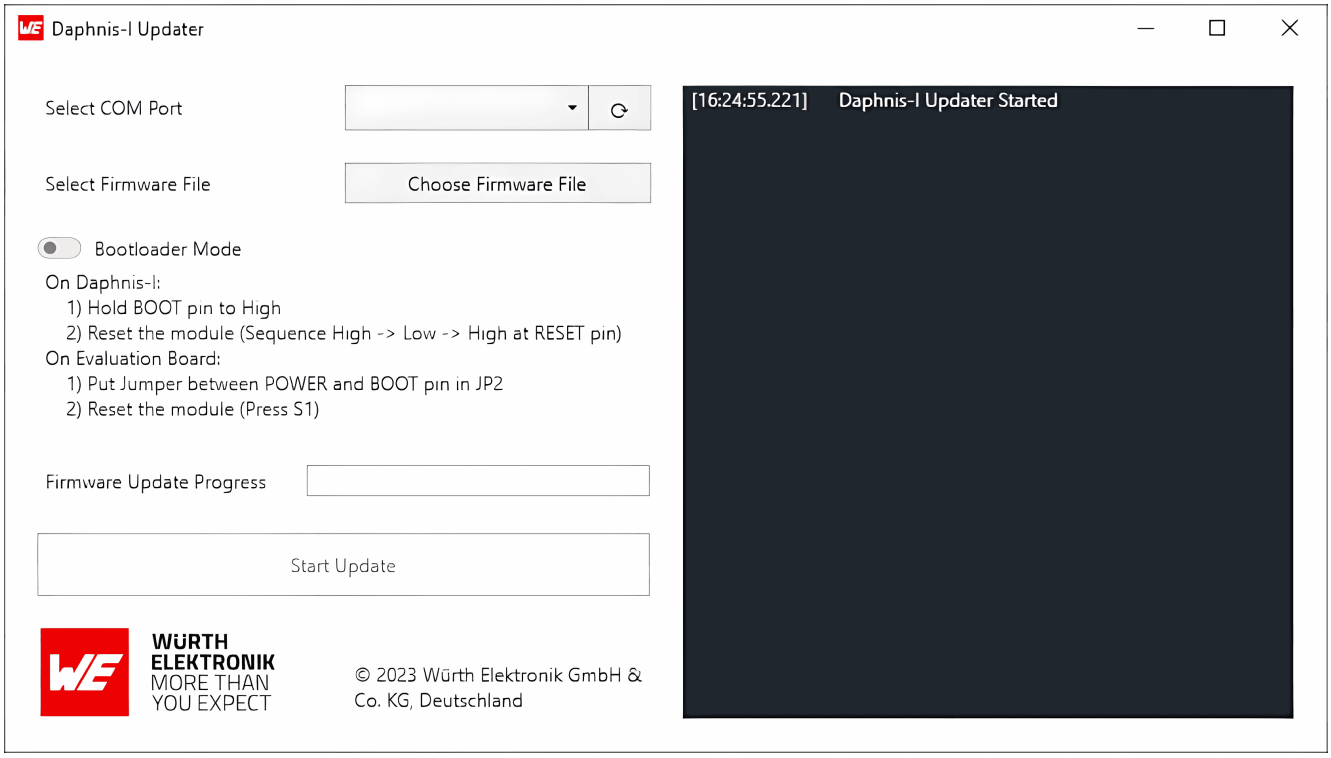

Figure 31: Daphnis-I Updater

1. Unzip the contents of the updater tool zip to any folder on your hard drive with read and write access. Network paths are not allowed.
2. Execute the GUI tool named Daphnis-I Updater.exe.
3. Connect the module to the PC and select the COM port of Daphnis-I.
4. Choose the encrypted and signed firmware update image package (sfb) file.
5. Follow the steps to put the module into bootloader mode according to the tool and after that set it to on.

6. The start update button should now be enabled. Click it to start the update.
7. The log on the right should show a green success message, if the update was successful or a red failure message if the update failed.

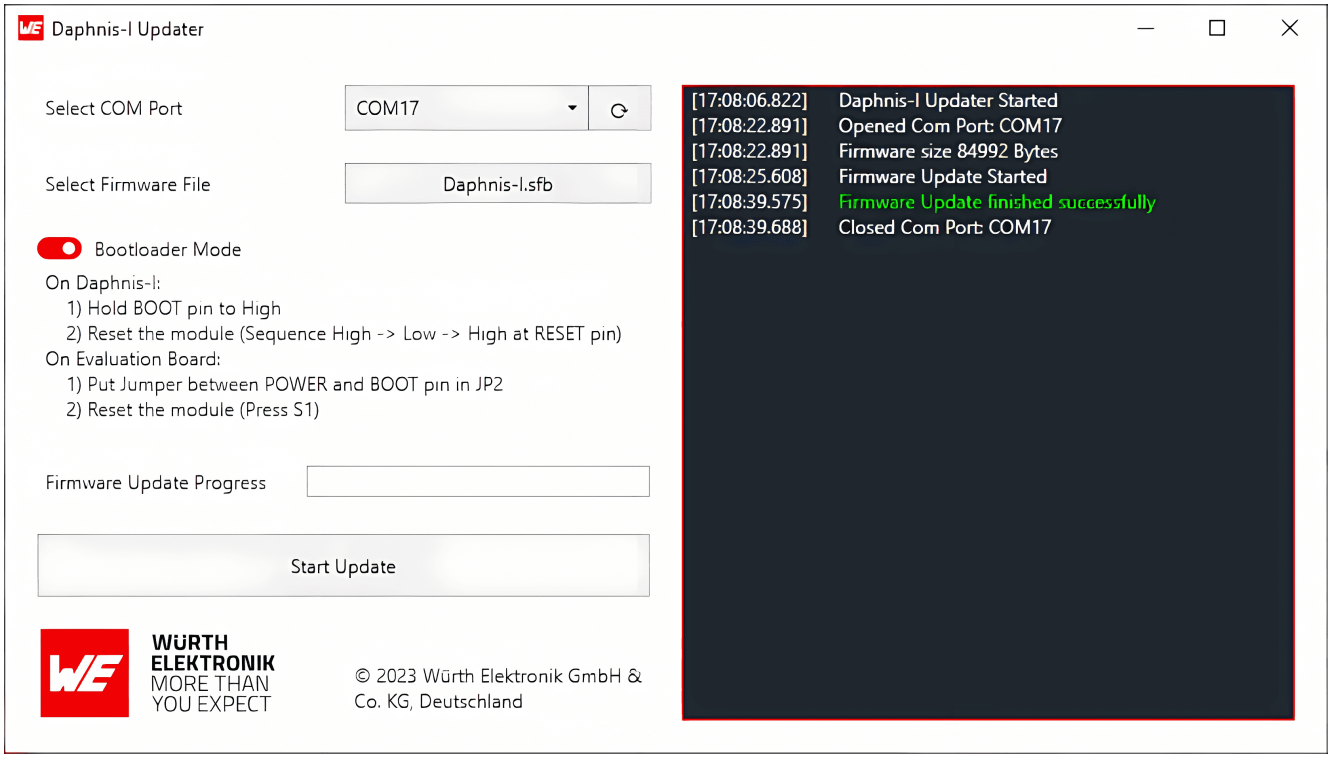

Figure 32: Daphnis-I Updater success

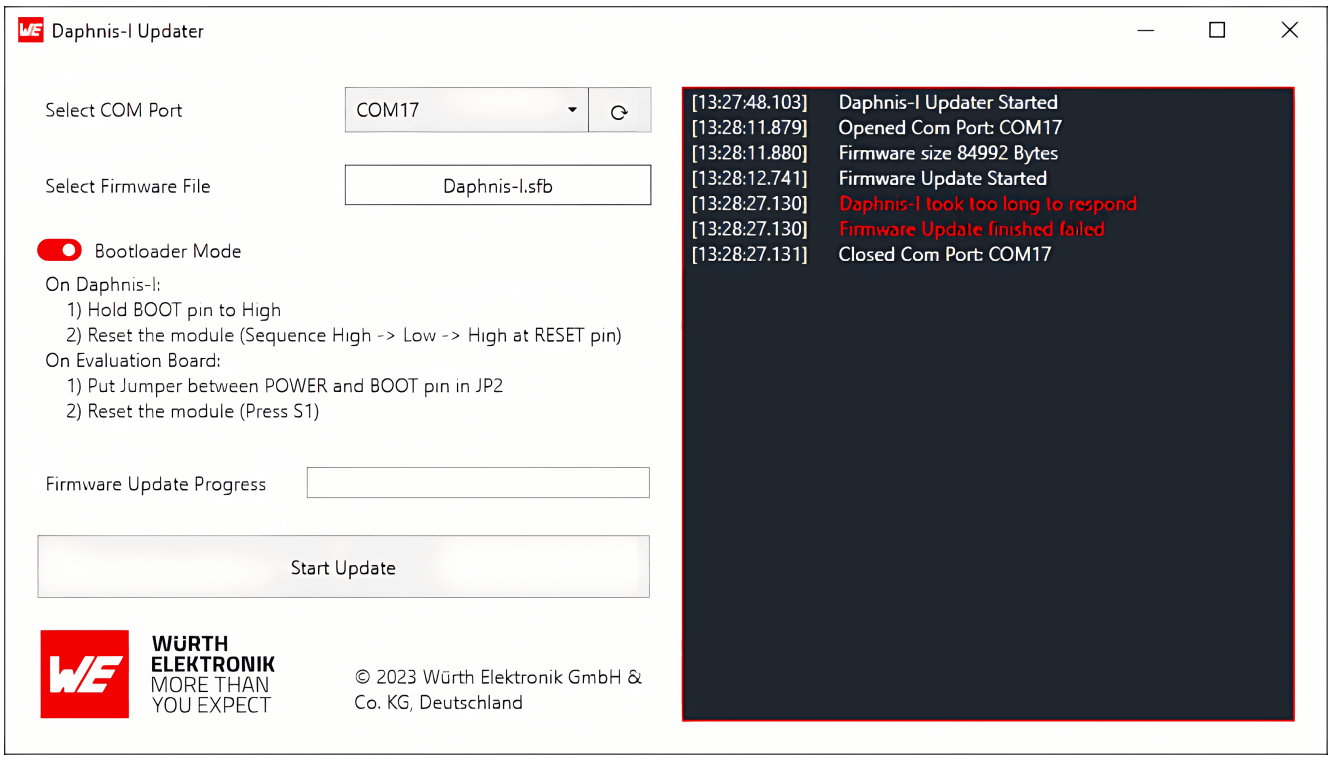

Figure 33: Daphnis-I Updater failure

The update will take some time. Make sure the command window stays top-most and is in focus during the entire update procedure. Watch carefully for any message displayed in the log window of the tool and keep the log in case of errors or if you require support.

The firmware update image used for this update process needs to be signed by Würth Elektronik eiSos, which means that the bootloader can't be used to install custom firmwares.

A firmware update will revert to the default factory settings of Daphnis-I.

The process and tools described here were tested and verified on a 64 bit Windows 10 (build 19044.2965) machine using a Daphnis-I EV board.

8.1.2 Update via host

In case you want to enable your own host to perform UART firmware updates, the bootloader implements the YMODEM protocol. This protocol must be implemented in the host. Refer to the chapter `Bootloader UART` for more information regarding the UART interface. The firmware

update image of Daphnis-I itself may take up to 190 KB of memory in the host.

9 Firmware history

The Daphnis-I firmware is based on the STM32CubeWL software development kit (SDK) from STMicroelectronics with the corresponding features. A list of the versions of different components used for the current Daphnis-I firmware version is shown below.

Description	Version
STM32CubeWL	1.3.0
LoRaMac-node	4.6.0
Long-Range-WAN	1.0.4
Regional Parameters	2-1.0.1

9.1 Release notes

Version 1.3.0 "Release"

- First release of the product.
- Long-Range-WAN version: 1.0.4
- Regional parameters version: 2-1.0.1

10 Custom firmware

Daphnis-I offers a production interface (e.g. JTAG, SWD) for module flash access. This interface can be used by customers to erase the entire chip and install their own firmware.

Using the production interface is not intended to perform updates of Würth Elektronik eiSos standard product firmware.

Production firmware images and binary files for Würth Elektronik eiSos wireless connectivity modules are not publicly available.

Any certification, declaration, listing and qualification becomes invalid if the production interface is used by a customer. Some products, in their documentation, state exceptions to this invalidation under certain conditions.

Customers shall make the product specific firmware update interface available to their application. These methods will use a wired (UART, SPI, etc.) communication interface of the module to allow updating the product's firmware.

11 Design in guide

11.1 Advice for schematic and layout

For users with less RF experience it is advisable to closely copy the relating EV board with respect to schematic and layout, as it is a proven design. The layout should be conducted with particular care, because even small deficiencies could affect the radio performance and its range or even the conformity.
The following general advice should be taken into consideration:

- A clean, stable power supply is strongly recommended. Interference, especially oscillation can severely restrain range and conformity.
- Variations in voltage level should be avoided.
- LDOs, properly designed in, usually deliver a proper regulated voltage.
- Blocking capacitors and a ferrite bead in the power supply line can be included to filter and smoothen the supply voltage when necessary.

No fixed values can be recommended, as these depend on the circumstances of the application (main power source, interferences etc.).

STOP

The use of an external reset IC should be considered if one of the following points is relevant:

- The slew rate of the power supply exceeds the electrical specifications.
- The effect of different current consumptions on the voltage level of batteries or voltage regulators should be considered. The module draws higher currents in certain scenarios like start-up or radio transmit which may lead to a voltage drop on the supply. A restart under such circumstances should be prevented by ensuring that the supply voltage does not drop below the minimum specifications.
- Voltage levels below the minimum recommended voltage level may lead to malfunction. The reset pin of the module shall be held on LOW logic level whenever the VDD is not stable or below the minimum operating Voltage.
- Special care must be taken in case of battery powered systems.

- Elements for ESD protection should be placed on all pins that are accessible from the outside and should be placed close to the accessible area. For example, the RF-pin is accessible when using an external antenna and should be protected.
- ESD protection for the antenna connection must be chosen such as to have a minimum effect on the RF signal. For example, a protection diode with low capacitance such as the 8231606A or a 68 nH air-core coil connecting the RF-line to ground give good results.
- Placeholders for optional antenna matching or additional filtering are recommended.
- The antenna path should be kept as short as possible.

Again, no fixed values can be recommended, as they depend on the influencing circumstances of the application (antenna, interferences etc.).

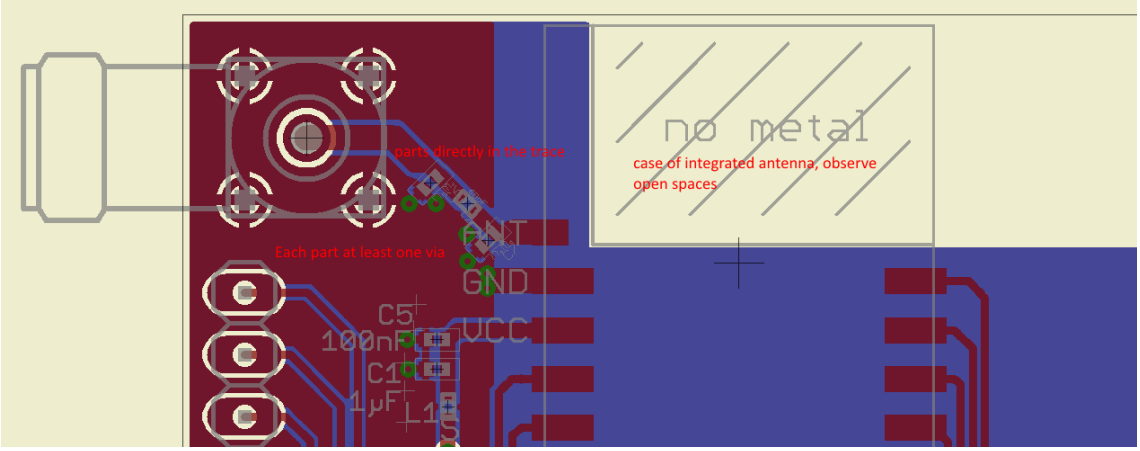

Figure 34: Layout

- To avoid the risk of short circuits and interference there should be no routing underneath the module on the top layer of the baseboard.
- On the second layer, a ground plane is recommended, to provide good grounding and shielding to any following layers and application environment.
- In case of integrated antennas it is required to have areas free from ground. This area should be copied from the EV board.
- The area with the integrated antenna must overlap with the carrier board and should not protrude, as it is matched to sitting directly on top of a PCB.
- Modules with integrated antennas should be placed with the antenna at the edge of the main board. It should not be placed in the middle of the main board or far away from the edge. This is to avoid tracks beside the antenna.

- Filter and blocking capacitors should be placed directly in the tracks without stubs, to achieve the best effect.
- Antenna matching elements should be placed close to the antenna / connector, blocking capacitors close to the module.
- Ground connections for the module and the capacitors should be kept as short as possible and with at least one separate through hole connection to the ground layer.
- ESD protection elements should be placed as close as possible to the exposed areas.

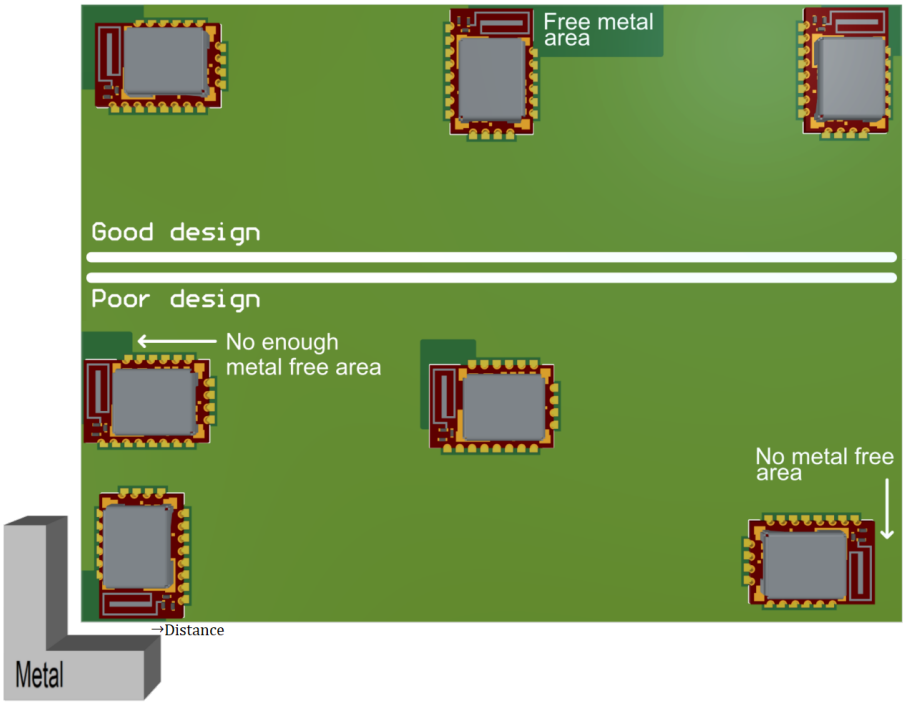

Figure 35: Placement of the module with integrated antenna

11.2 Designing the antenna connection

The antenna should be connected with a 50 Ω line. This is needed to obtain impedance matching to the module and avoids reflections. Here we show as an example how to calculate the dimensions of a 50 Ω line in form of a micro strip above ground, as this is easiest to calculate. Other connections like coplanar or strip line are more complicated to calculate but can offer more robustness to EMC. There are free calculation tools available in the internet.

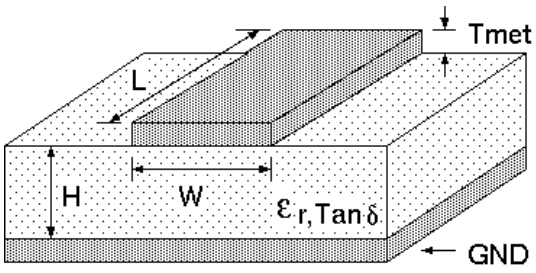

Figure 36: Dimensioning the antenna connection as micro strip

The width W for a micro strip can be calculated using the following equation:

$$W = 1.25 \times \left(\frac{5.98 \times H}{e^{\frac{50 \times \sqrt{\epsilon_r} + 1.41}{87}}} - T_{met} \right) \quad (1)$$

Example:
A FR4 material with ε_r = 4.3, a height H = 1000 µm and a copper thickness of T_{met} = 18 µm will lead to a trace width of W ~ 1.9 mm. To ease the calculation of the micro strip line (or e.g. a coplanar) many calculators can be found in the internet.

- As rule of thumb a distance of about 3×W should be observed between the micro strip and other traces / ground.
- The micro strip refers to ground, therefore there has to be the ground plane underneath the trace.
- Keep the feeding line as short as possible.

11.3 Antenna solutions

There exist several kinds of antennas, which are optimized for different needs. Chip antennas are optimized for minimal size requirements but at the expense of range, PCB antennas are optimized for minimal costs, and are generally a compromise between size and range. Both usually fit inside a housing.
Range optimization in general is at the expense of space. Antennas that are bigger in size, so that they would probably not fit in a small housing, are usually equipped with a RF connector. A benefit of this connector may be to use it to lead the RF signal through a metal plate (e.g. metal housing, cabinet).
As a rule of thumb a minimum distance of λ /10 (which is 3.5 cm @ 868 MHz and 1.2 cm @ 2.44 GHz) from the antenna to any other metal should be kept. Metal placed further away will not directly influence the behavior of the antenna, but will anyway produce shadowing.

Keep the antenna as far as possible from large metal objects to avoid electromagnetic field blocking.

The choice of antenna might have influence on the safety requirements.

In the following chapters, some special types of antenna are described.

11.3.1 Wire antenna

An effective antenna is a λ /4 radiator with a suiting ground plane. The simplest realization is a piece of wire. It's length is depending on the used radio frequency, so for example 8.6 cm 868.0 MHz and 3.1 cm for 2.440 GHz as frequency. This radiator needs a ground plane at its feeding point. Ideally, it is placed vertically in the middle of the ground plane. As this is often not possible because of space requirements, a suitable compromise is to bend the wire away from the PCB respective to the ground plane. The λ/4 radiator has approximately 40 Ω input impedance. Therefore, matching is not required.

11.3.2 Chip antenna

There are many chip antennas from various manufacturers. The benefit of a chip antenna is obviously the minimal space required and reasonable costs. However, this is often at the expense of range. For the chip antennas, reference designs should be followed as closely as possible, because only in this constellation can the stated performance be achieved.

11.3.3 PCB antenna

PCB antenna designs can be very different. The special attention can be on the miniaturization or on the performance. The benefits of the PCB antenna are their small / not existing (if PCB space is available) costs, however the EV of a PCB antenna holds more risk of failure than the use of a finished antenna. Most PCB antenna designs are a compromise of range and space between chip antennas and connector antennas.

11.3.4 Antennas provided by Würth Elektronik eiSos

11.3.4.1 2600130081 - Hyperion-I dipole antenna

Figure 37: Hyperion-I dipole antenna

Ideally suited for applications where no ground plane is available.

The 2600130081 antenna can be also used for 902 MHz - 928 MHz range.

Specification	Value
Center frequency [MHz]	868
Frequency range [MHz]	853 – 883
Wavelength	0.5 wave
VSWR	$\leq$ 2.0
Impedance [Ω]	50
Connector	SMA (Male)
Dimensions (L x d) [mm]	142 x 10
Peak gain [dBi]	-2.3
Operating temp. [℃]	-30 – +80

11.3.4.2 2600130086 - Hermippe-III dipole antenna

Well suited for applications where the RF is lead through a metal wall that could serve as ground plane to the antenna.

Figure 38: Hermippe-III dipole antenna

Specification	Value
Frequency range [MHz]	855 – 915
VSWR (free space,without ground plane)	$\leq$ 2.0
Polarisation	Linear
Impedance [Ω]	50±5
Connector	SMA (Male)
Dimensions (L x d) [mm]	50±3 x 7.92±0.2
Weight [g]	4.5
Operating temp. [°C]	-40 – +85

11.3.4.3 2600130082 - Hyperion-II magnetic base antenna

Well suited for applications where the RF is lead through a metal wall that could serve as ground plane to the antenna.

Figure 39: Hyperion-II magnetic base antenna with 1.5 m antenna cable

The 2600130082 is an antenna in form of $\lambda/4$ and therefore needs a ground plane at the feeding point.

Specification	Value
Frequency range [MHz]	824 – 894
VSWR	$\leq$ 2.0
Polarisation	Vertical
Impedance [Ω]	50±5
Connector	SMA (Male)
Dimensions (L x d) [mm]	89.8 x 27
Weight [g]	50±5
Operating temp. [℃]	-30 – +60

12 Reference design

Daphnis-I was tested and certified on the corresponding Daphnis-I EV board. For the compliance with the EU directive 2014/53/EU Annex I, the EV board serves as reference design. This is no discrepancy due to the fact that the EV board itself does not fall within the scope of the EU directive 2014/53/EU Annex I as the module is tested on the EV board, which is also the recommended use.

Further information concerning the use of the EV board can be found in the manual of the Daphnis-I EV board.

12.1 EV-Board

12.1.1 Schematic

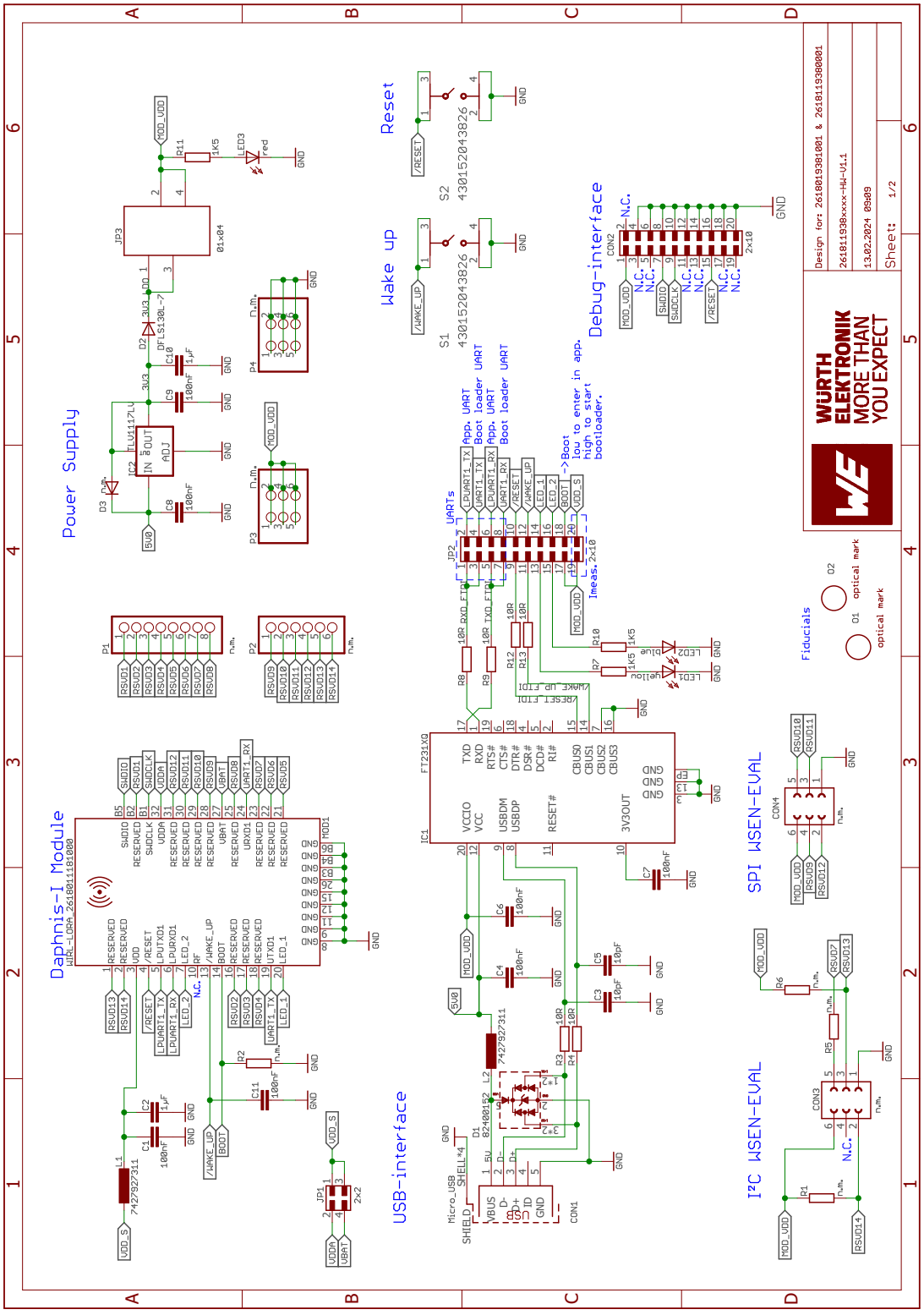

Figure 40: Reference design: Schematic diagram

12.1.2 Layout

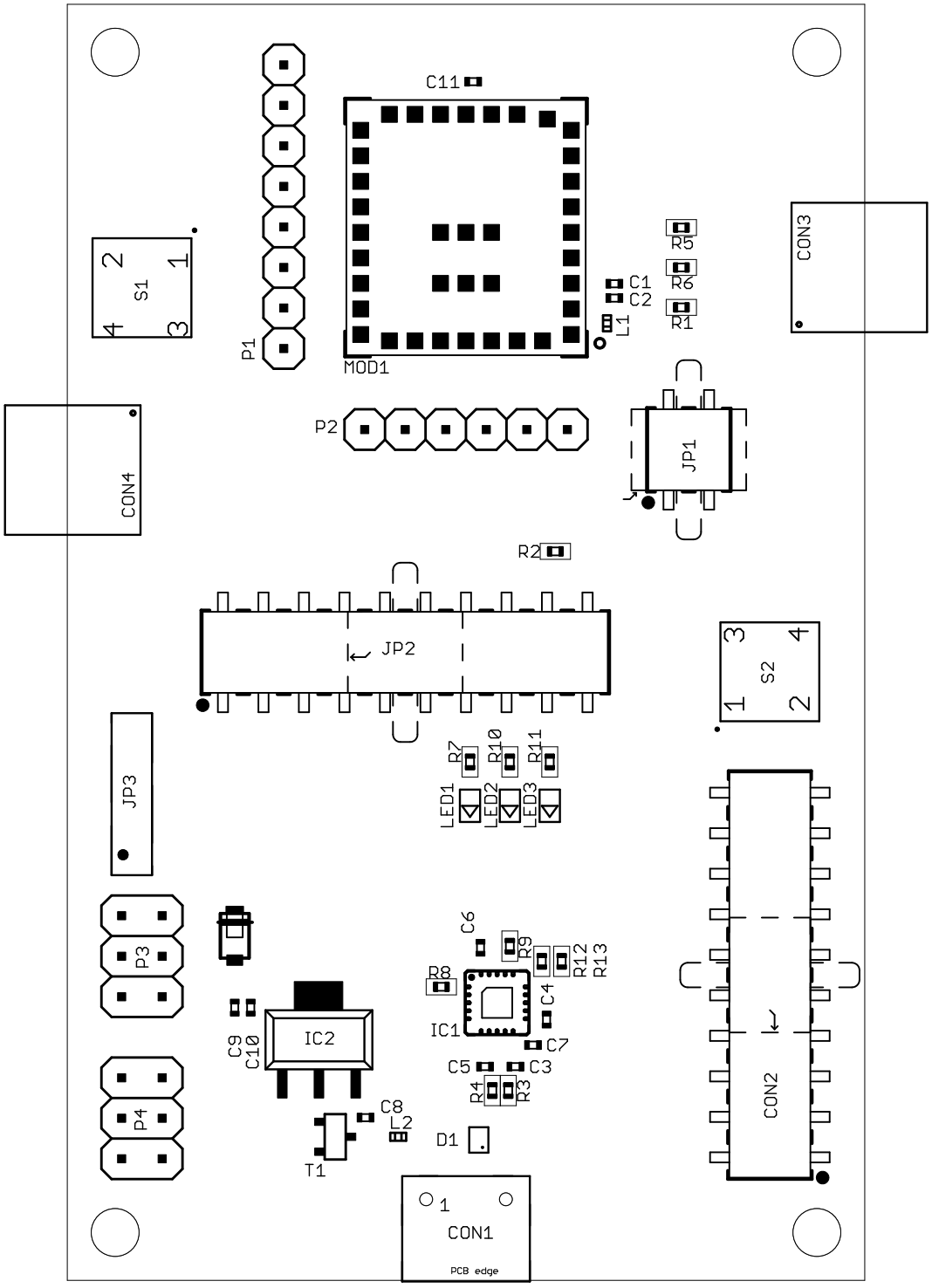

Figure 41: Reference design: Assembly diagram

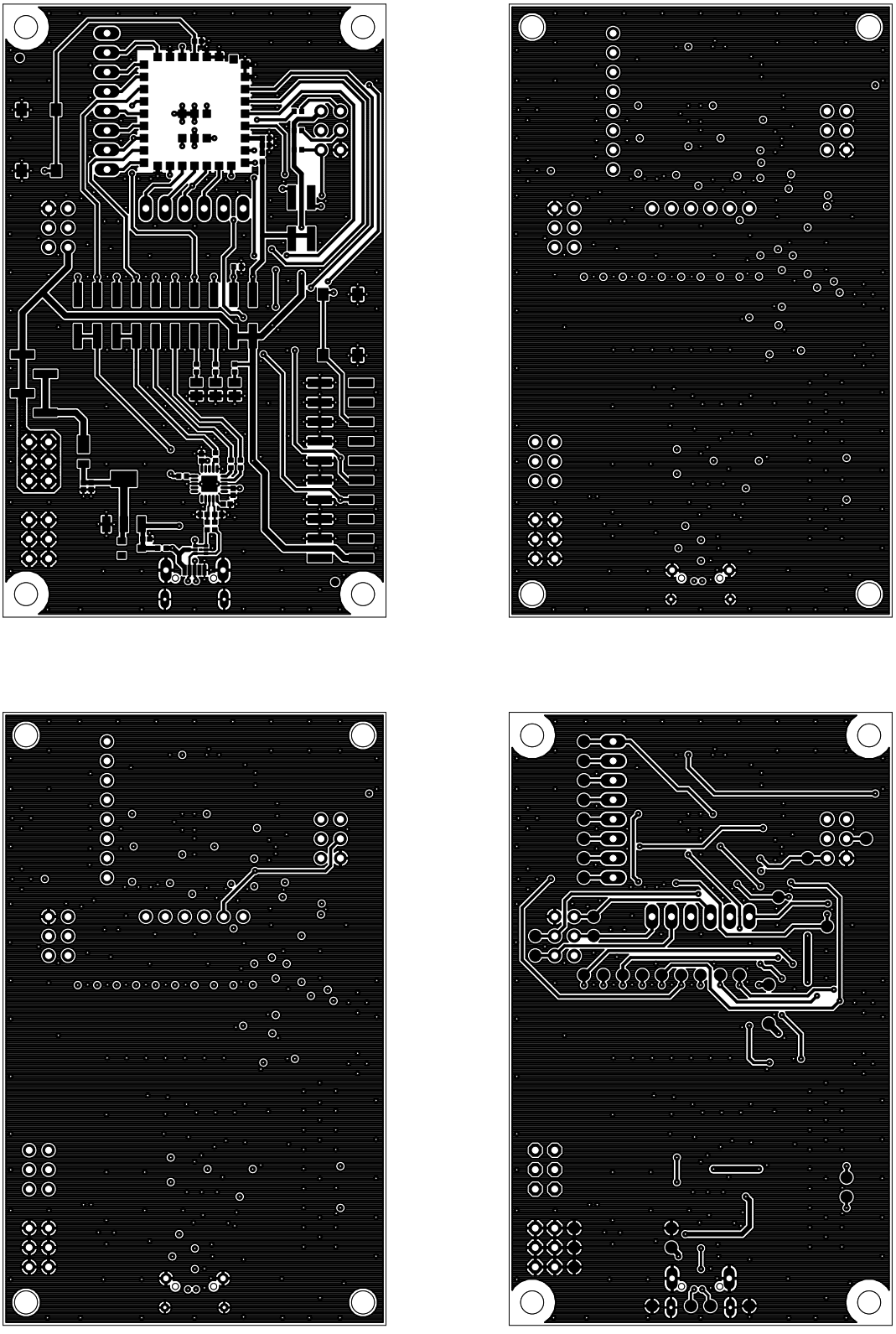

Figure 42: Top layer (upper left), second layer (upper right), third layer (bottom left), fourth layer (bottom right)

13 Manufacturing information

13.1 Moisture sensitivity level

This wireless connectivity product is categorized as JEDEC Moisture Sensitivity Level 3 (MSL3), which requires special handling.

More information regarding the MSL requirements can be found in the IPC/JEDEC J-STD-020 standard on *www.jedec.org*.

More information about the handling, picking, shipping and the usage of moisture/reflow and/or process sensitive products can be found in the IPC/JEDEC J-STD-033 standard on *www.jedec.org*.

13.2 Soldering

13.2.1 Reflow soldering

Attention must be paid on the thickness of the solder resist between the host PCB top side and the modules bottom side. Only lead-free assembly is recommended according to JEDEC J-STD020.

Profile feature		Value
Preheat temperature Min	$T_{S\ Min}$	150 °C
Preheat temperature Max	$T_{S\ Max}$	200 °C
Preheat time from $T_{S\ Min}$ to $T_{S\ Max}$	t_S	60 - 120 seconds
Ramp-up rate (T_L to T_P)		3 °C / second max.
Liquidous temperature	T_L	217 °C
Time t_L maintained above T_L	t_L	60 - 150 seconds
Peak package body temperature	T_P	260 °C
Time within 5 °C of actual peak temperature	t_P	20 - 30 seconds
Ramp-down Rate (T_P to T_L)		6 °C / second max.
Time 20 °C to T_P		8 minutes max.

Table 65: Classification reflow soldering profile, Note: refer to IPC/JEDEC J-STD-020E

It is recommended to solder this module on the last reflow cycle of the PCB. For solder paste use a LFM-48W or Indium based SAC 305 alloy (Sn 96.5 / Ag 3.0 / Cu 0.5 / Indium 8.9HF / Type 3 / 89%) type 3 or higher.

The reflow profile must be adjusted based on the thermal mass of the entire populated PCB, heat transfer efficiency of the reflow oven and the specific type of solder paste used. Based on the specific process and PCB layout the optimal soldering profile must be adjusted and verified. Other soldering methods (e.g. vapor phase) have not been verified and have to be validated

by the customer at their own risk. Rework is not recommended.

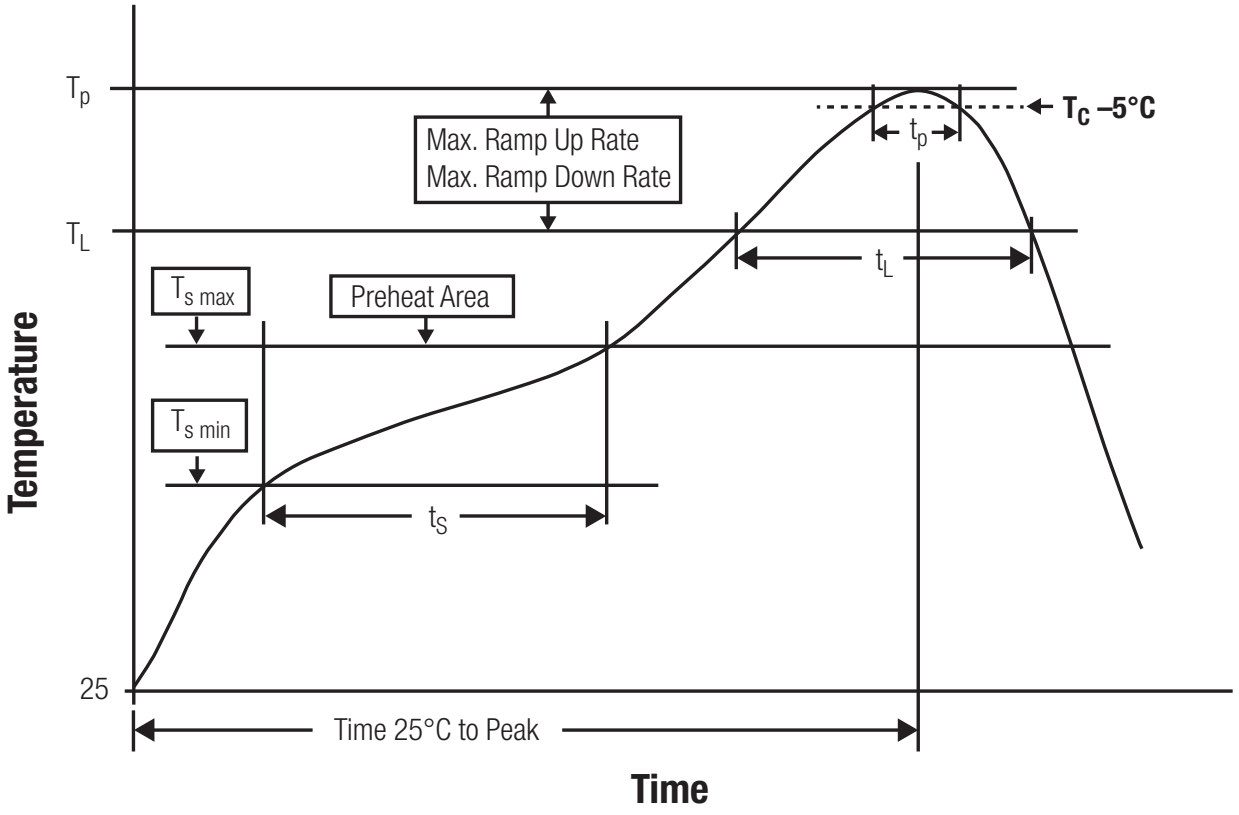

Figure 43: Reflow soldering profile

After reflow soldering, visually inspect the board to confirm proper alignment

13.2.2 Cleaning

Do not clean the product. Any residue cannot be easily removed by washing. Use a "no clean" soldering paste and do not clean the board after soldering.

- Do not clean the product with water. Capillary effects can draw water into the gap between the host PCB and the module, absorbing water underneath it. If water is trapped inside, it may short-circuit adjoining pads. The water may also destroy the label and ink-jet printed text on it.
- Cleaning processes using alcohol or other organic solvents may draw solder flux residues into the housing, which won't be detected in a post-wash inspection. The solvent may also destroy the label and ink-jet printed text on it.
- Do not use ultrasonic cleaning as it will permanently damage the part, particularly the crystal oscillators.

13.2.3 Potting and coating

- If the product is potted in the customer application, the potting material might shrink or expand during and after hardening. Shrinking could lead to an incomplete seal, allowing contaminants into the component. Expansion could damage components. We recommend a manual inspection after potting to avoid these effects.
- Conformal coating or potting results in loss of warranty.
- The RF shield will not protect the part from low-viscosity coatings and potting. An undefined amount of coating and potting will enter inside the shielding.
- Conformal coating and potting will influence the parts of the radio front end and consequently influence the radio performance.
- Potting will influence the temperature behaviour of the device. This might be critical for components with high power.

13.2.4 Other notations

- Do not attempt to improve the grounding by forming metal strips directly to the EMI covers or soldering on ground cables, as it may damage the part and will void the warranty.
- Always solder every pad to the host PCB even if some are unused, to improve the mechanical strength of the module.
- The part is sensitive to ultrasonic waves, as such do not use ultrasonic cleaning, welding or other processing. Any ultrasonic processing will void the warranty.

13.3 ESD handling

This product is highly sensitive to electrostatic discharge (ESD). As such, always use proper ESD precautions when handling. Make sure to handle the part properly throughout all stages of production, including on the host PCB where the module is installed. For ESD ratings, refer to the module series' maximum ESD section. For more information, refer to the relevant chapter 2. Failing to follow the aforementioned recommendations can result in severe damage to the part.

- the first contact point when handling the PCB is always between the local GND and the host PCB GND, unless there is a galvanic coupling between the local GND (for example work table) and the host PCB GND.
- Before assembling an antenna patch, connect the grounds.
- While handling the RF pin, avoid contact with any charged capacitors and be careful when contacting any materials that can develop charges (for example coaxial cable with around 50-80 pF/m, patch antenna with around 10 pF, soldering iron etc.)
- Do not touch any exposed area of the antenna to avoid electrostatic discharge. Do not let the antenna area be touched in a non ESD-safe manner.
- When soldering, use an ESD-safe soldering iron.

13.4 Safety recommendations

It is your duty to ensure that the product is allowed to be used in the destination country and within the required environment. Usage of the product can be dangerous and must be tested and verified by the end user. Be especially careful of:

- Use in areas with risk of explosion (for example oil refineries, gas stations).
- Use in areas such as airports, aircraft, hospitals, etc., where the product may interfere with other electronic components.

It is the customer's responsibility to ensure compliance with all applicable legal, regulatory and safety-related requirements as well as applicable environmental regulations. Disassembling the product is not allowed. Evidence of tampering will void the warranty.

- Compliance with the instructions in the product manual is recommended for correct product set-up.
- The product must be provided with a consolidated voltage source. The wiring must meet all applicable fire and security prevention standards.
- Handle with care. Avoid touching the pins as there could be ESD damage.

Be careful when working with any external components. When in doubt consult the technical documentation and relevant standards. Always use an antenna with the proper characteristics.

Würth Elektronik eiSos radio modules with high output power of up to 500 mW, as for example the radio module Thebe-II, generate a high amount of warmth while transmitting. The manufacturer of the end device must take care of potentially necessary actions for his application.

14 Physical specifications

14.1 Dimensions

Dimensions
15.0 * 16.0 * 3.00 mm

Table 66: Dimensions

Tolerances: see chapter 14.3

14.2 Weight

Weight
1.21 g

Table 67: Weight

Tolerance: ± 0.15 g

14.3 Module drawing

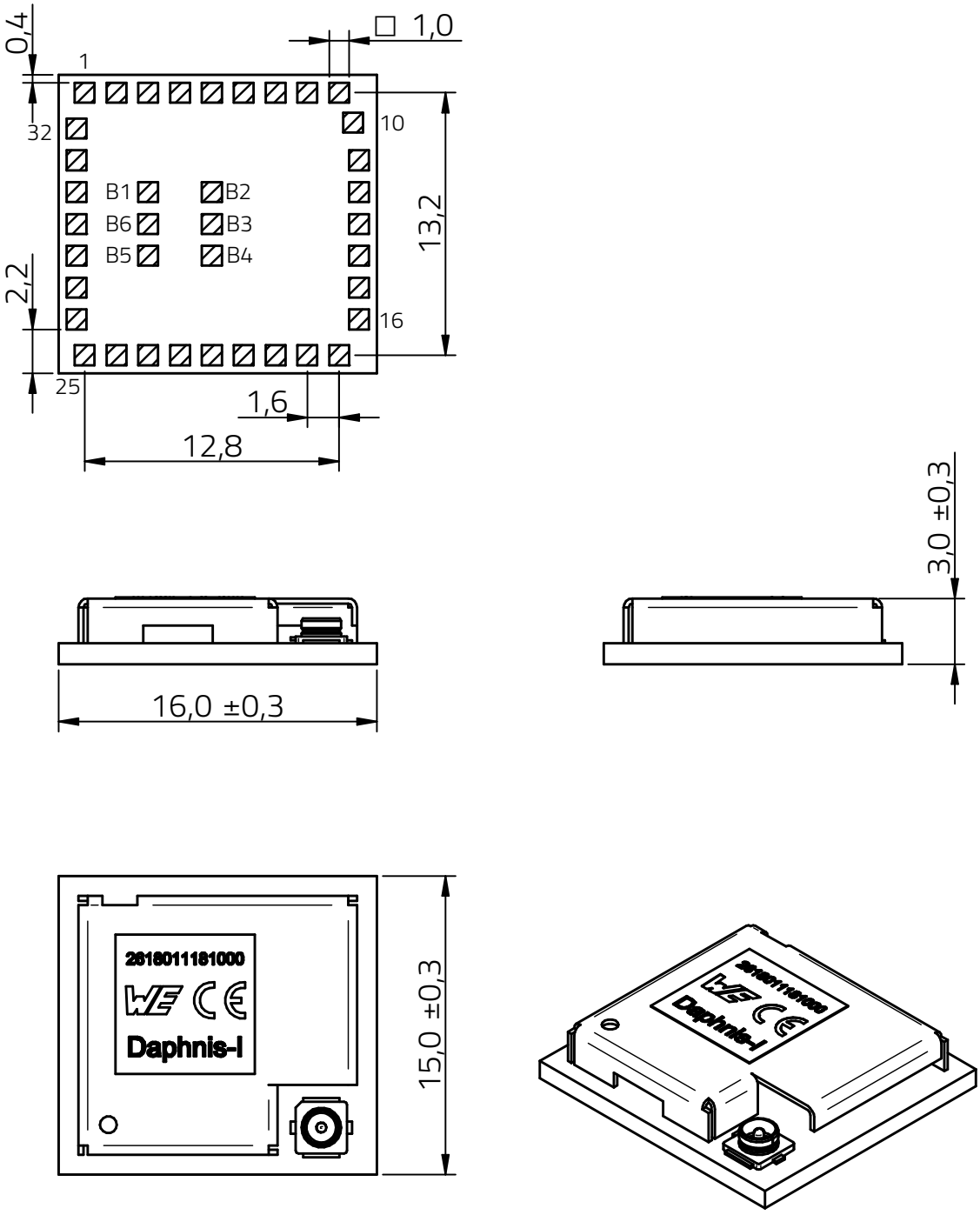

Figure 44: Module dimensions [mm]

14.4 Footprint

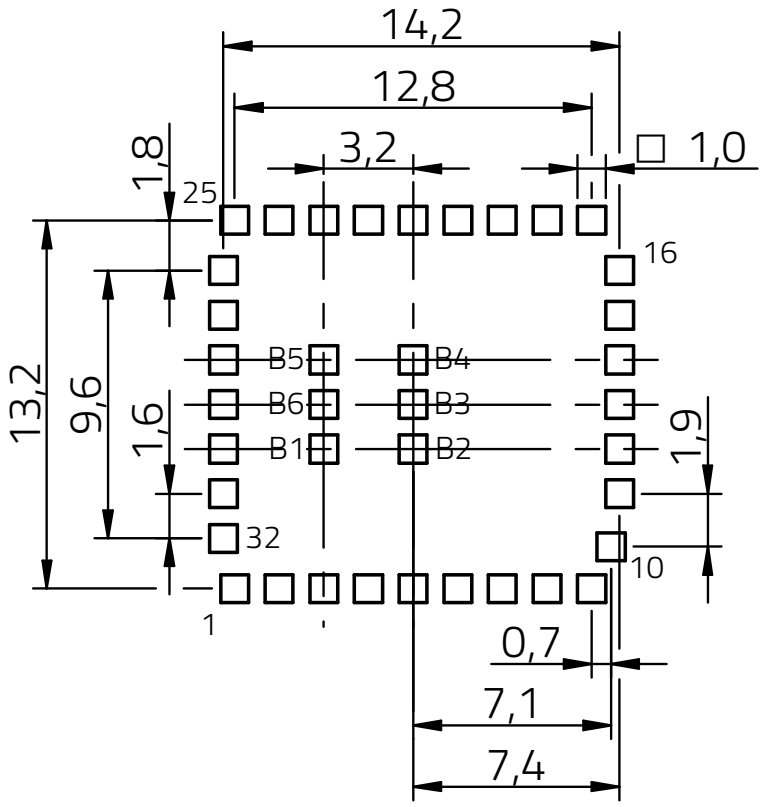

Figure 45: Footprint and dimensions [mm]

15 Marking

15.1 Lot number

The 15 digit lot number is printed in numerical digits as well as in form of a machine readable bar code. It is divided into 5 blocks as shown in the following picture and can be translated according to the following table.

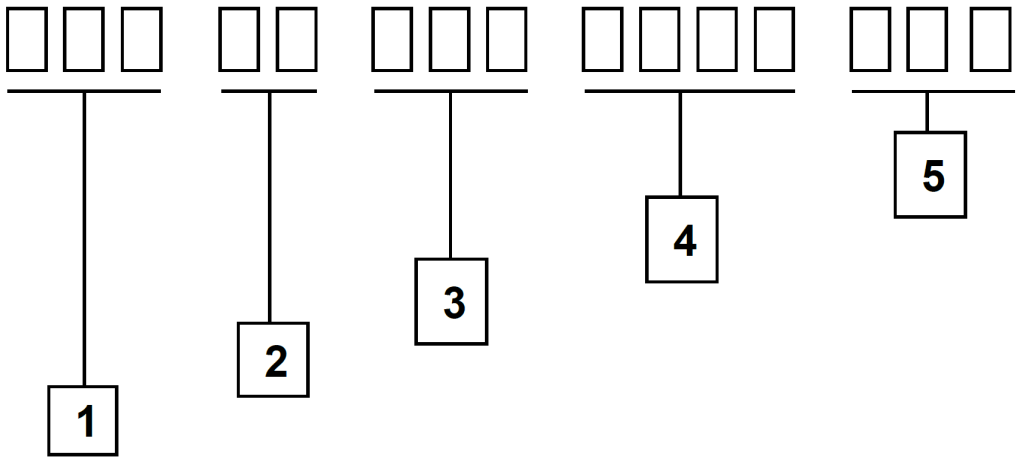

Figure 46: Lot number structure

Block	Information	Example(s)
1	eiSos internal, 3 digits	439
2	eiSos internal, 2 digits	01
3	Hardware version, 3 digits	V2.4 = 024, V12.2 = 122
4	Date code, 4 digits	1703 = week 03 in year 2017, 1816 = week 16 in year 2018
5	Firmware version, 3 digits	V3.2 = 302, V5.13 = 513

Table 68: Lot number details

As the user can perform a firmware update the printed lot number only shows the factory delivery state. The currently installed firmware can be requested from the module using the corresponding product specific command. The firmware version as well as the hardware version are restricted to show only major and minor version not the patch identifier.

15.2 General labeling information

The module labels may include the following fields:

- Manufacturer identification WE, Würth Elektronik or Würth Elektronik eiSos
- WE Order Code and/or article alias
- Serial number or MAC address
- Certification identifiers (CE, FCC ID, IC, TELEC,...)
- Bar code or 2D code containing the serial number or MAC address

If the module is using a serial Number, this serial number includes the product ID (PID) and an 6 digit number. The 6 rightmost digits represent the 6 digit number, followed by the product ID (2 or 3 digits). Some labels indicate the product ID with a "." as marker in-between the 2 fields. The PID and the 6 digit number form together a unique serial number for any wireless connectivity product.
In case of small labels, the 3 byte manufacturer identifier (0x0018DA) of the MAC address is not printed on the labels. The 3 byte counter printed on the label can be used with this 0018DA to produce the full MAC address by appending the counter after the manufacturer identifier.

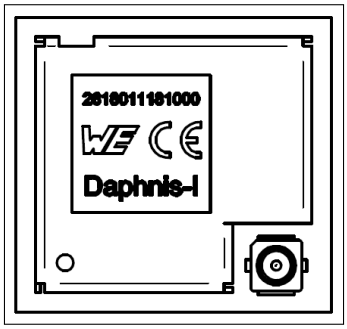

Figure 47: Label of the Daphnis-I

16 References

[1] LoRa Alliance©. LoRaWAN® L2 1.0.4 Specification. https://resources.lora-alliance.org/technical-specifications/ts001-1-0-4-lorawan-l2-1-0-4-specification.

[2] LoRa Alliance©. LoRaWAN® RP002-1.0.1 LoRaWAN Regional Parameters. https://resources.lora-alliance.org/technical-specifications/rp2-1-0-1-lorawan-regional-parameters.

[3] STMicroelectronics. Web page: STM32WLE5CC. https://www.st.com/en/microcontrollers-microprocessors/stm32wle5cc.html.

[4] Würth Elektronik Support. https://we-online.com/wireless-connectivity/support.

[5] Würth Elektronik. DAPHNIS-I EVALUATION BOARD MANUAL. https://we-online.com/katalog/en/manual/2618119380001.

[6] Würth Elektronik. Smart Commander PC tool. https://www.we-online.com/SmartCommander.

17 Regulatory compliance information

17.1 Important notice EU

The use of RF frequencies is limited by national regulations. The Daphnis-I has been designed to comply with the RED directive 2014/53/EU of the European Union (EU).
The Daphnis-I can be operated without notification and free of charge in the area of the European Union. However, according to the RED directive, restrictions (e.g. in terms of duty cycle or maximum allowed RF power) may apply.

Since the module is a built-in equipment its power class according to EN 62368-1 must be specified in the end product.

17.2 Conformity assessment of the final product

The Daphnis-I is a subassembly. It is designed to be embedded into other products (products incorporating the Daphnis-I are henceforward referred to as "final products").
It is the responsibility of the manufacturer of the final product to ensure that the final product is in compliance with the essential requirements of the underlying national radio regulations.
The conformity assessment of the subassembly Daphnis-I carried out by Würth Elektronik eiSos does not replace the required conformity assessment of the final product.

17.3 Exemption clause

Relevant regulation requirements are subject to change. Würth Elektronik eiSos does not guarantee the accuracy of the before mentioned information. Directives, technical standards, procedural descriptions and the like may be interpreted differently by the national authorities. Equally, the national laws and restrictions may vary with the country. In case of doubt or uncertainty, we recommend that you consult with the authorities or official certification organizations of the relevant countries. Würth Elektronik eiSos is exempt from any responsibilities or liabilities related to regulatory compliance.

Notwithstanding the above, Würth Elektronik eiSos makes no representations and warranties of any kind related to their accuracy, correctness, completeness and/or usability for customer applications. No responsibility is assumed for inaccuracies or incompleteness.

17.4 EU Declaration of conformity

CE

EU DECLARATION OF CONFORMITY

Radio equipment: **2618011181000**

The manufacturer: Würth Elektronik eiSos GmbH & Co. KG
Max-Eyth-Straße 1
74638 Waldenburg

This declaration of conformity is issued under the sole responsibility of the manufacturer.

Object of the declaration: 2618011181000

The object of the declaration described above is in conformity with the relevant Union harmonisation legislation Directive 2014/53/EU. Following harmonised norms or technical specifications have been applied:

EN 300 220-1 V3.1.1 (2017-02)
EN 300 220-2 V3.1.1 (2017-02)
EN 301 489-1 V2.2.3 (2019-11)
EN 301 489-3 V2.3.2 (2023-01)
EN 62368-1: 2014/AC: 2015/A11: 2017/AC:2017
EN 62311 : 2010
2011/65/EU with its amending Annex II EU 2015/863.

i.A. G. Erlandt

Trier, 7th of July 2023
Place and date of issue

18 Important notes

The following conditions apply to all goods within the wireless connectivity and sensors product range of Würth Elektronik eiSos GmbH & Co. KG:

General customer responsibility
Some goods within the product range of Würth Elektronik eiSos GmbH & Co. KG contain statements regarding general suitability for certain application areas. These statements about suitability are based on our knowledge and experience of typical requirements concerning the areas, serve as general guidance and cannot be estimated as binding statements about the suitability for a customer application. The responsibility for the applicability and use in a particular customer design is always solely within the authority of the customer. Due to this fact, it is up to the customer to evaluate, where appropriate to investigate and to decide whether the device with the specific product characteristics described in the product specification is valid and suitable for the respective customer application or not. Accordingly, the customer is cautioned to verify that the documentation is current before placing orders.

Customer responsibility related to specific, in particular safety-relevant applications
It has to be clearly pointed out that the possibility of a malfunction of electronic components or failure before the end of the usual lifetime cannot be completely eliminated in the current state of the art, even if the products are operated within the range of the specifications. The same statement is valid for all software source code and firmware parts contained in or used with or for products in the wireless connectivity and sensor product range of Würth Elektronik eiSos GmbH & Co. KG. In certain customer applications requiring a high level of safety and especially in customer applications in which the malfunction or failure of an electronic component could endanger human life or health, it must be ensured by most advanced technological aid of suitable design of the customer application that no injury or damage is caused to third parties in the event of malfunction or failure of an electronic component.

Best care and attention
Any product-specific data sheets, manuals, application notes, PCN's, warnings and cautions must be strictly observed in the most recent versions and matching to the products revisions. This documents can be downloaded from the product specific sections on the wireless connectivity and sensors homepage.

Customer support for product specifications
Some products within the product range may contain substances, which are subject to restrictions in certain jurisdictions in order to serve specific technical requirements. Necessary information is available on request. In this case, the field sales engineer or the internal sales person in charge should be contacted who will be happy to support in this matter.

Product improvements
Due to constant product improvement, product specifications may change from time to time. As a standard reporting procedure of the Product Change Notification (PCN) according to the JEDEC-Standard, we inform about major changes. In case of further queries regarding the PCN, the field sales engineer, the internal sales person or the technical support team in charge should be contacted. The basic responsibility of the customer as per section 18 and 18 remains unaffected.
All software like ¨wireless connectivity SDK¨, ¨Sensor SDK¨ or other source codes as well as all PC software tools are not subject to the Product Change Notification information process.

Product life cycle
Due to technical progress and economical evaluation we also reserve the right to discontinue production and delivery of products. As a standard reporting procedure of the Product Termination Notification (PTN) according to the JEDEC-Standard we will inform at an early stage about inevitable product discontinuance. According to this, we cannot ensure that all products within our product range will always be available. Therefore, it needs to be verified with the field sales engineer or the internal sales person in charge about the current product availability expectancy before or when the product for application design-in disposal is considered. The approach named above does not apply in the case of individual agreements deviating from the foregoing for customer-specific products.

Property rights
All the rights for contractual products produced by Würth Elektronik eiSos GmbH & Co. KG on the basis of ideas, development contracts as well as models or templates that are subject to copyright, patent or commercial protection supplied to the customer will remain with Würth Elektronik eiSos GmbH & Co. KG. Würth Elektronik eiSos GmbH & Co. KG does not warrant or represent that any license, either expressed or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, application, or process in which Würth Elektronik eiSos GmbH & Co. KG components or services are used.

General terms and conditions
Unless otherwise agreed in individual contracts, all orders are subject to the current version of the "General Terms and Conditions of Würth Elektronik eiSos Group", last version available at *www.we-online.com*.

19 Legal notice

Exclusion of liability
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