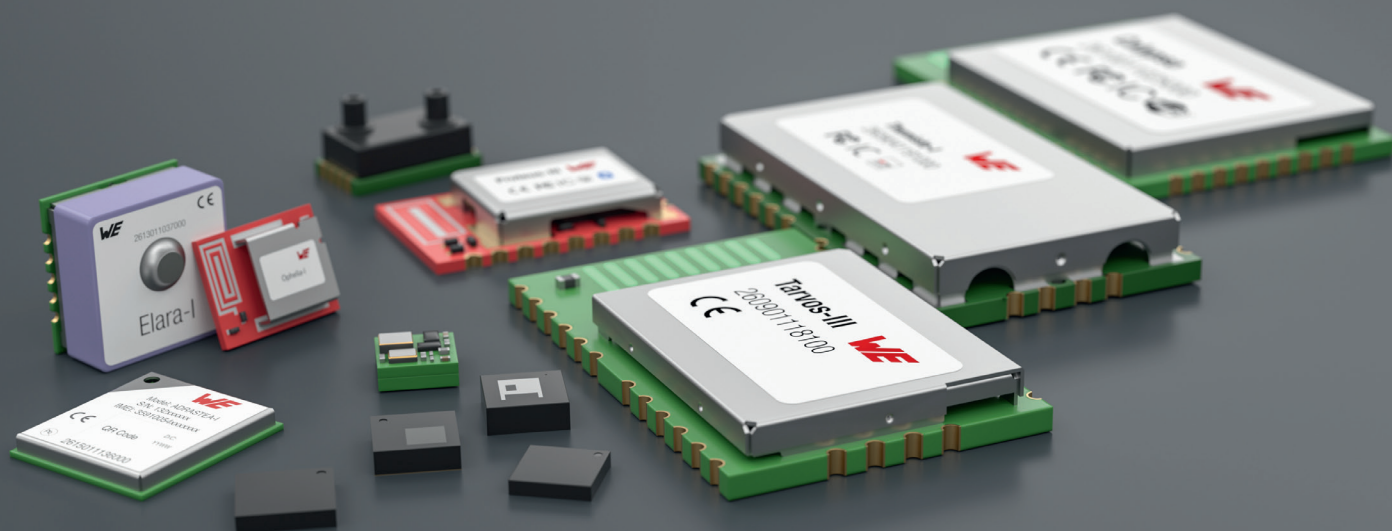




# USER MANUAL

OPHELIA-III

2611011022000

VERSION 1.2

OCTOBER 31, 2025

**WÜRTH ELEKTRONIK** MORE THAN YOU EXPECT

# Contents

|                                                                          |           |
|--------------------------------------------------------------------------|-----------|
| <b>Overview of helpful application notes</b>                             | <b>3</b>  |
| <b>1 Revision history</b>                                                | <b>5</b>  |
| <b>2 Abbreviations</b>                                                   | <b>6</b>  |
| <b>3 Introduction</b>                                                    | <b>7</b>  |
| 3.1 Operational description . . . . .                                    | 7         |
| 3.1.1 Key features . . . . .                                             | 8         |
| 3.2 Block diagram . . . . .                                              | 9         |
| 3.3 Ordering information . . . . .                                       | 9         |
| <b>4 Electrical specifications</b>                                       | <b>10</b> |
| 4.1 Operating conditions . . . . .                                       | 10        |
| 4.2 Absolute maximum ratings . . . . .                                   | 11        |
| 4.3 Power consumption . . . . .                                          | 12        |
| 4.3.1 Static . . . . .                                                   | 12        |
| 4.4 Radio characteristics . . . . .                                      | 13        |
| 4.5 Pin characteristics . . . . .                                        | 14        |
| <b>5 Pinout</b>                                                          | <b>15</b> |
| <b>6 Development</b>                                                     | <b>17</b> |
| <b>7 Certification of the end device</b>                                 | <b>18</b> |
| <b>8 Antenna connection</b>                                              | <b>19</b> |
| 8.1 On-board PCB antenna . . . . .                                       | 19        |
| 8.2 External antenna . . . . .                                           | 19        |
| <b>9 Hardware history</b>                                                | <b>20</b> |
| <b>10 Design in guide</b>                                                | <b>21</b> |
| 10.1 Advice for schematic and layout . . . . .                           | 21        |
| 10.2 Designing the antenna connection . . . . .                          | 23        |
| 10.3 Antenna solutions . . . . .                                         | 24        |
| 10.3.1 Wire antenna . . . . .                                            | 24        |
| 10.3.2 Chip antenna . . . . .                                            | 24        |
| 10.3.3 PCB antenna . . . . .                                             | 25        |
| 10.3.4 Antennas provided by Würth Elektronik eiSos . . . . .             | 25        |
| 10.3.4.1 2600130021 - Hmalia dipole antenna . . . . .                    | 26        |
| <b>11 Reference design</b>                                               | <b>27</b> |
| 11.1 EV-Board . . . . .                                                  | 28        |
| 11.2 Radiation characteristic of the module's internal antenna . . . . . | 31        |
| <b>12 Manufacturing information</b>                                      | <b>32</b> |
| 12.1 Moisture sensitivity level . . . . .                                | 32        |

|           |                                                            |           |
|-----------|------------------------------------------------------------|-----------|
| 12.2      | Soldering . . . . .                                        | 32        |
| 12.2.1    | Reflow soldering . . . . .                                 | 32        |
| 12.2.2    | Cleaning . . . . .                                         | 33        |
| 12.2.3    | Potting and coating . . . . .                              | 34        |
| 12.2.4    | Other notations . . . . .                                  | 34        |
| 12.3      | ESD handling . . . . .                                     | 34        |
| 12.4      | Safety recommendations . . . . .                           | 35        |
| <b>13</b> | <b>Product testing</b>                                     | <b>36</b> |
| 13.1      | Würth Elektronik eiSos in-house production tests . . . . . | 36        |
| 13.2      | EMS production tests . . . . .                             | 36        |
| <b>14</b> | <b>Physical specifications</b>                             | <b>38</b> |
| 14.1      | Dimensions . . . . .                                       | 38        |
| 14.2      | Weight . . . . .                                           | 38        |
| 14.3      | Module drawing . . . . .                                   | 39        |
| 14.4      | Footprint . . . . .                                        | 40        |
| 14.5      | Antenna free area . . . . .                                | 40        |
| <b>15</b> | <b>Marking</b>                                             | <b>41</b> |
| 15.1      | Lot number . . . . .                                       | 41        |
| <b>16</b> | <b>Information for explosion protection</b>                | <b>42</b> |
| <b>17</b> | <b>Important notes</b>                                     | <b>43</b> |
| <b>18</b> | <b>Legal notice</b>                                        | <b>43</b> |
| <b>19</b> | <b>License terms</b>                                       | <b>44</b> |

## Overview of helpful application notes

### **Application note ANR008 - Wireless Connectivity Software Development Kit**

<http://www.we-online.com/ANR008>

To ease the integration of the Würth Elektronik eiSos radio modules into an application, Würth Elektronik eiSos offers the corresponding Software Development Kit (SDK) for most commonly used host processors. This SDK contains drivers and examples in C-code to communicate with the corresponding radio module. This application note shows which SDKs are available and describes how to download and use them.

### **Application note ANR010 - Range estimation**

<http://www.we-online.com/ANR010>

This application note presents the two most used mathematical range estimation models, Friis and two ray ground reflection, and its implementation in the range estimation tool of the RED-EXPERT.

### **Application note ANR027 - Bluetooth qualification guide**

<http://www.we-online.com/ANR027>

Every product containing Bluetooth® technology needs to be qualified at the Bluetooth® SIG (special interest group). This application note explains the steps to be done to gain a Bluetooth® qualification for the end product using a Würth Elektronik eiSos Bluetooth® LE radio module.

### **Application note ANR030 - nRF Connect**

<http://www.we-online.com/ANR030>

This application note gives a short overview about the options to create a custom firmware for Würth Elektronik eiSos radio modules by using the hardware platform and the embedded nRF5x system on chip. It presents options on firmware development environments and accessories (like SDKs) for the use within the nRF5 ecosystem. The reader is informed on how to access to a multitude of radio standards (like Bluetooth® LE, Bluetooth® MESH, Bluetooth® LE Audio, Matter, Zigbee, Thread, Wirepas) for custom firmware developments whilst the hardware platform can stay the same.

### **Application note ANR031 - Certification of custom modules**

<http://www.we-online.com/ANR031>

This application note explains how certifications of a standard product can be used to gain the certification of a customized product. This is done for firmware, which has been adapted by Würth Elektronik eiSos, as well as for firmware written by customer.

### **Ground plane effects on radio module antennas**

<http://www.we-online.com/ANR033>

The ground plane plays a critical role in the performance of radio module antennas, affecting parameters such as radiation pattern, gain, and efficiency. This application note provides practical insights into how ground plane size, shape, and placement influence antenna behavior, offering guidance for optimal integration in real-world designs. Simulation results and measurement data are included to illustrate key effects and support design decisions.

**Application note ANR036 - Build your own firmware - getting started with Zephyr®**

*<http://www.we-online.com/ANR036>*

This application note describes how to use the Zephyr® to develop firmware for the supported Würth Elektronik eiSos BYOF (build your own firmware) radio modules. This includes the installation of the Zephyr® build system, as well as the selection of an appropriate example for the underlying radio module hardware.

# 1 Revision history

| Manual version | HW version | Notes                                                                                                                                                                                                            | Date         |
|----------------|------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|
| 1.0            | 1.4        | <ul style="list-style-type: none"><li>Initial release</li></ul>                                                                                                                                                  | March 2024   |
| 1.1            | 1.4        | <ul style="list-style-type: none"><li>Added chapters Hardware history and Development</li><li>Removed chapter "custom firmware" and "firmware update"</li><li>Added information for "UKCA" declaration</li></ul> | October 2024 |
| 1.2            | 1.5        | <ul style="list-style-type: none"><li>Added chapter Certification of the end device</li></ul>                                                                                                                    | October 2025 |

## 2 Abbreviations

| Abbreviation | Name                                        | Description                                                                                                   |
|--------------|---------------------------------------------|---------------------------------------------------------------------------------------------------------------|
| BTMAC        |                                             | Bluetooth® conform MAC address of the module used on the RF-interface                                         |
| CS           | Checksum                                    | Byte wise XOR combination of the preceding fields                                                             |
| DSSS         | Direct sequence spread spectrum             | Technique to spread a message on the radio                                                                    |
| DTM          | Direct test mode                            | Mode to test Bluetooth® specific RF settings                                                                  |
| EV (Board)   | Evaluation (Board)                          | Ophelia-III populated on motherboard with USB interface for test and evaluation purpose                       |
| FEC          | Forward error correction                    | Technique to correct received erroneous radio messages                                                        |
| I/O          | Input/Output                                | Pinout description                                                                                            |
| LPM          | Low power mode                              | Mode for efficient power consumption                                                                          |
| LRM          | Long range mode                             | Radio mode with higher range and lower throughput                                                             |
| MAC          |                                             | MAC address of the module                                                                                     |
| MTU          | Maximum transmission unit                   | Maximum packet size of the Bluetooth® connection                                                              |
| Payload      |                                             | The intended message in a frame / package                                                                     |
| RF           | Radio frequency                             | Describes wireless transmission                                                                               |
| RSSI         | Receive Signal Strength Indicator           | The RSSI indicates the strength of the RF signal. Its value is always printed in two's complement notation    |
| SPI          | Serial Peripheral Interface                 | Allows the serial communication with the module                                                               |
| UART         | Universal Asynchronous Receiver Transmitter | Allows the serial communication with the module                                                               |
| [HEX] 0xhh   | Hexadecimal                                 | All numbers beginning with 0x are hexadecimal numbers. All other numbers are decimal, unless stated otherwise |

## 3 Introduction

### 3.1 Operational description

The Ophelia-III module is a radio module/device for wireless communication between devices such as control systems, remote controls, sensors etcetera.



Be aware that the Ophelia-III module does not contain any firmware.

The user has the complete freedom to use it with proprietary firmware, Wirepas firmware or develop his own application based on the Nordic nRF Connect SDK (e.g. Matter, IEEE 802.11.4, Thread, Zigbee). To fulfill the needs and specifications of such applications, a tailored firmware can be developed, based on the Ophelia-III hardware. This includes the connection and communication to custom sensors, custom Bluetooth® LE profiles, timing configurations, security configurations as well as power consumption optimizations.

Even with its small dimensions of 8 x 12 mm, Ophelia-III provides a strongly miniaturized integrated PCB antenna. Besides, it is possible to connect an external antenna, if high radio ranges are of interest.

The main functionality is accessible through pads with edge castellation. This offers easy prototype building, as it is suitable for hand soldering. More optional GPIOs without enlarging the size are accessible through land grid pads that can only be connected through reflow process.



The Ophelia-III shares the same hardware platform as the Proteus-III module. For this reason, Proteus-III is often referred to in this user manual.



Figure 1: Ophelia-III

### 3.1.1 Key features

The Ophelia-III offers the following key features that are described in this manual in more detail:

**nRF52 series microprocessor generation provided by Nordic Semiconductor:** the heart of Ophelia-III is the Bluetooth® LE nRF52840 chip, offering high performance values combined with low power consumption. It is a 32 Bit ARM Cortex-M4F CPU with 1024 kB flash + 256 kB RAM and up to 8 dBm output power.

**Flexible wired interfacing:** Ophelia-III is equipped with extra pins suited for custom device/sensor connection. With help of these, a tailored firmware can be developed, which is optimized to the customer's needs. The pins can be configured to various functions such as UART, SPI, I<sup>2</sup>C, ADC, PWM, NFC and GPIO.

**High design flexibility:** Ophelia-III offers the user a high grade of freedom when developing an application.

## 3.2 Block diagram

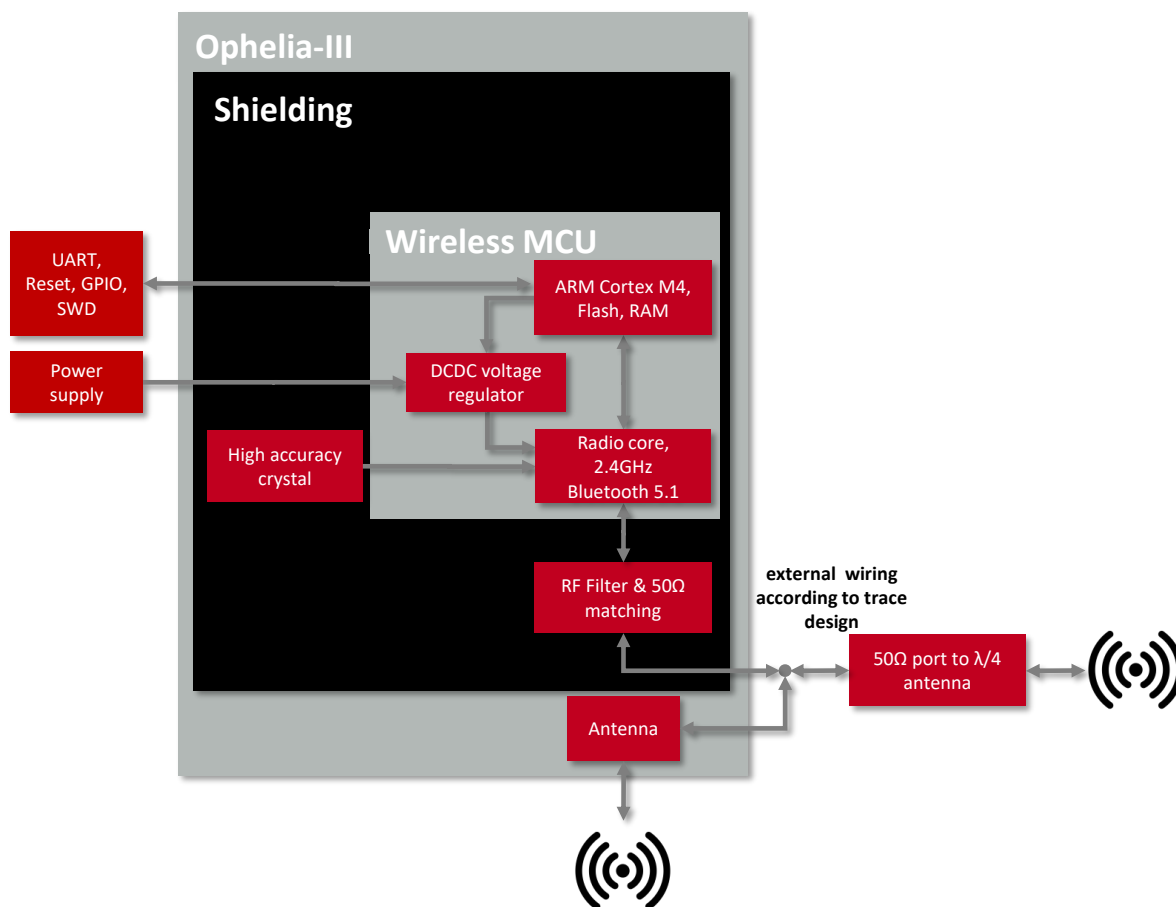


Figure 2: Block diagram of the module

## 3.3 Ordering information

| WE order code | Description                     |
|---------------|---------------------------------|
| 2611011022000 | Ophelia-III Module, Tape & Reel |

Table 3: Ordering information

## 4 Electrical specifications

If not otherwise stated, the following values have been measured on an EV-Board Proteus-III EV with  $T = 25\text{ °C}$ ,  $V_{DD5} = 3\text{ V}$ ,  $f = 2.44\text{ GHz}$ , internal DC-DC converter in use.



The Ophelia-III shares the same hardware platform as the Proteus-III module. For this reason, the following values have been measured on a Proteus-III-EV and the electrical specifications are based on the Proteus-III module.

### 4.1 Operating conditions

| Description                                  | Min.             | Typ. | Max. | Unit |
|----------------------------------------------|------------------|------|------|------|
| Ambient temperature                          | -40              | 25   | 85   | °C   |
| Supply voltage ( $V_{DD5}$ )                 | 1.8 <sup>1</sup> | 3    | 3.6  | V    |
| Supply rise time (0V to $\geq 1.7\text{V}$ ) |                  |      | 60   | ms   |

Table 4: Operating conditions



The on-chip power-on reset circuitry may not function properly for rise times longer than the specified maximum.



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

<sup>1</sup>Power fail comparator can be activated and configured. Since Ophelia-III does not have any firmware, this function is not automatically active. To avoid flash fail due to voltage drop, the comparator can be set to 1.8 V.

## 4.2 Absolute maximum ratings

| Description                                         | Min.   | Typ. | Max.        | Unit               |
|-----------------------------------------------------|--------|------|-------------|--------------------|
| Supply voltage (VDD)                                | -0.3   |      | +3.9        | V                  |
| Voltage on any digital pin, $VDD < 3.6\text{ V}$    | -0.3   |      | $VDD + 0.3$ | V                  |
| Voltage on any digital pin, $VDD \geq 3.6\text{ V}$ | -0.3   |      | 3.9         | V                  |
| Input RF level                                      |        |      | 10          | dBm                |
| Flash endurance                                     | 10 000 |      |             | Write/erase cycles |

Table 5: Absolute maximum ratings

## 4.3 Power consumption

### 4.3.1 Static

| Parameter              | Power                | Test conditions                                                                                                                              | Value | Unit |
|------------------------|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------|-------|------|
| TX current consumption | Maximum output power | Transmitter only,<br>DC/DC converter enabled,<br>1 Mbps Bluetooth® LE,<br>CPU current not included,<br>nRF52840 <i>product specification</i> | 16.4  | mA   |
|                        |                      | Full module current consumption<br>DC/DC converter enabled,<br>(Bluetooth® LE firmware)                                                      | 18.9  | mA   |

Table 6: Current consumption - transmitting

| Parameter              | Test conditions                                                                                                   | Value | Unit |
|------------------------|-------------------------------------------------------------------------------------------------------------------|-------|------|
| RX current consumption | Receiver only,<br>DC/DC converter enabled,<br>1 Mbps Bluetooth® LE,<br>CPU current not included, nRF52 data sheet | 6.25  | mA   |
|                        | Full module current consumption<br>DC/DC converter enabled,<br>(Bluetooth® LE firmware)                           | 7.7   | mA   |

Table 7: Current consumption - receiving

| Parameter           | Test conditions         | Value | Unit |
|---------------------|-------------------------|-------|------|
| Current consumption | Sleep (system off mode) | 0.4   | µA   |

Table 8: Current consumption - low power

<sup>1</sup>For ease of use, our current measurements include all active components and options of the SoC that are active in an operation state in the stated value (e.g. CPU, radio, UART, timers, flash, RAM...).

## 4.4 Radio characteristics

| Parameter | Min. | Max. | Unit |
|-----------|------|------|------|
| Frequency | 2360 | 2500 | MHz  |

Table 9: Frequency range

| Parameter                               | Min. | Max. | Unit |
|-----------------------------------------|------|------|------|
| RSSI accuracy valid range ( $\pm 2$ dB) | -90  | -20  | dBm  |

Table 10: RSSI accuracy

| Parameter         | Test conditions                              | Value | Unit |
|-------------------|----------------------------------------------|-------|------|
| Output power      | Conducted                                    | +6    | dBm  |
|                   | Radiated                                     | +4    | dBm  |
| Input sensitivity | Conducted, BER = 1E-3, 1 Mbps, Bluetooth® LE | -92   | dBm  |
|                   | Radiated, BER = 1E-3, 1 Mbps, Bluetooth® LE  | -90   | dBm  |

Table 11: Transmit and receive power

All transmit and receive power levels are measured on the EV-Board. The values already include losses of transitions from module to motherboard to SMA or modules PCB antenna. They are realistic values for the end application.

## 4.5 Pin characteristics

The following specifications are from the nRF52 datasheet.

| Description                                                            | Min.             | Typ. | Max.             | Unit       |
|------------------------------------------------------------------------|------------------|------|------------------|------------|
| Input high voltage                                                     | $0.7 \times VCC$ |      | VCC              | V          |
| Input low voltage                                                      | VSS              |      | $0.3 \times VCC$ | V          |
| Current at VSS+0.4 V, output set low, standard drive, $VDD \geq 1.7V$  | 1                | 2    | 4                | mA         |
| Current at VSS+0.4 V, output set low, high drive, $VDD \geq 2.7 V$     | 6                | 10   | 15               | mA         |
| Current at VSS+0.4 V, output set low, high drive, $VDD \geq 1.7 V$     | 3                |      |                  | mA         |
| Current at VDD-0.4 V, output set high, standard drive, $VCC \geq 1.7V$ | 1                | 2    | 4                | mA         |
| Current at VDD-0.4 V, output set high, high drive, $VDD \geq 2.7 V$    | 6                | 9    | 14               | mA         |
| Current at VDD-0.4 V, output set high, high drive, $VDD \geq 1.7 V$    | 3                |      |                  | mA         |
| Internal pull-up resistance                                            | 11               | 13   | 16               | k $\Omega$ |
| Internal pull-down resistance                                          | 11               | 13   | 16               | k $\Omega$ |

Table 12: Pin characteristics

## 5 Pinout

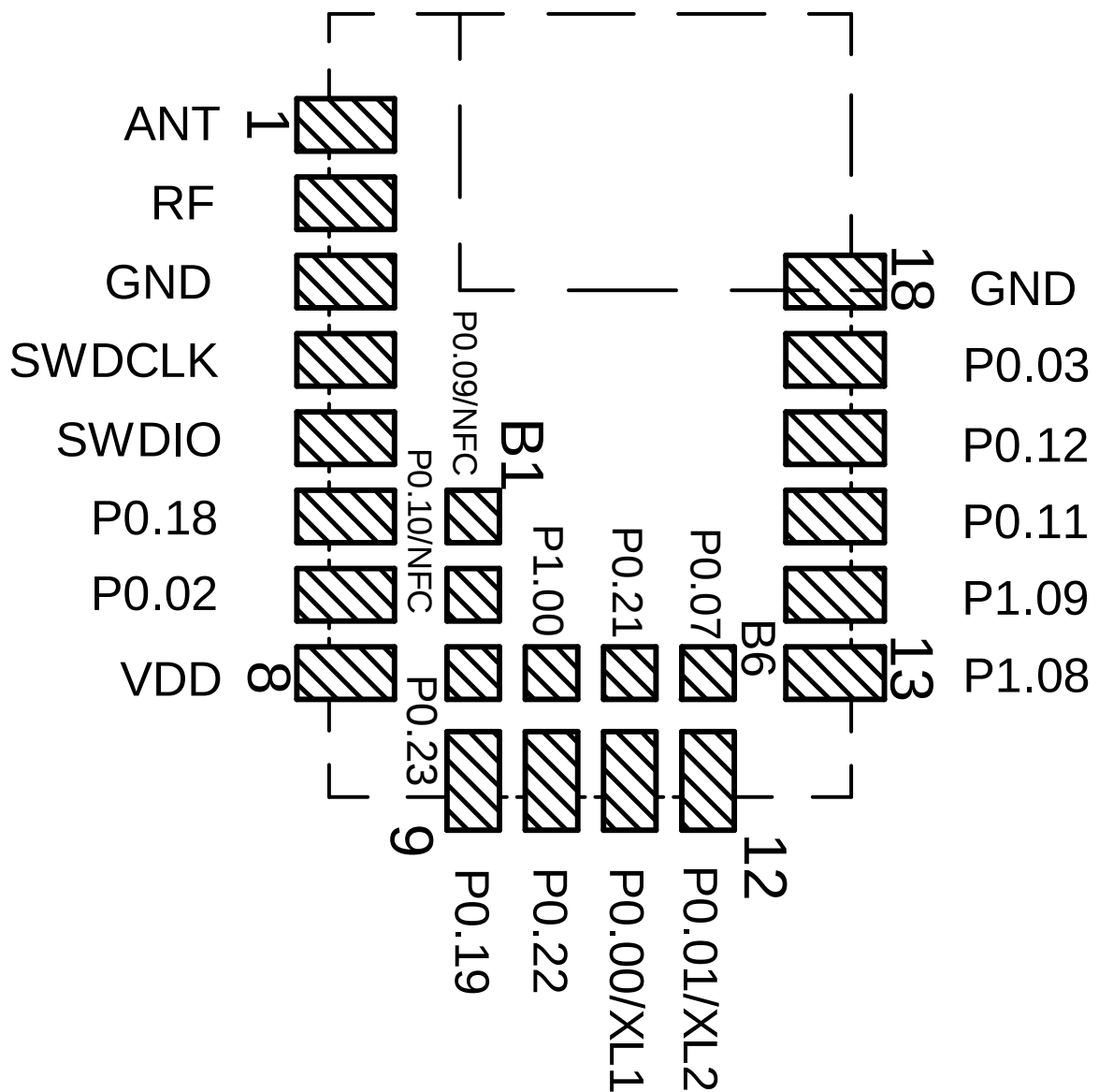


Figure 3: Pinout (top view)

| No | μC Pin     | I/O    | Description                                                                                |
|----|------------|--------|--------------------------------------------------------------------------------------------|
| 1  | <i>ANT</i> | I/O    | RF connection to PCB antenna. (see section 8)                                              |
| 2  | <i>RF</i>  | I/O    | 50 Ω RF connection through radio front end to transceiver part of chipset. (see section 8) |
| 3  | <i>GND</i> | Supply | Ground                                                                                     |

|    |                         |        |                                                                                                         |
|----|-------------------------|--------|---------------------------------------------------------------------------------------------------------|
| 4  | <i>SWDCLK</i>           | I/O    | Serial wire clock (SWD Interface). Uses internal pull down resistor. Do not connect if not needed.      |
| 5  | <i>SWDIO</i>            | I/O    | Serial wire input/output (SWD Interface). Uses internal pull up resistor. Do not connect if not needed. |
| 6  | P0.18                   | I/O    | General purpose I/O                                                                                     |
| 7  | P0.02                   | I/O    | General purpose I/O                                                                                     |
| 8  | <i>VDD</i>              | Supply | Supply voltage                                                                                          |
| 9  | P0.19                   | I/O    | General purpose I/O                                                                                     |
| 10 | P0.22                   | I/O    | General purpose I/O                                                                                     |
| 11 | P0.00/XL1 <sup>1</sup>  | I/O    | General purpose I/O                                                                                     |
| 12 | P0.01/XL2 <sup>1</sup>  | I/O    | General purpose I/O                                                                                     |
| 13 | P1.08                   | I/O    | General purpose I/O                                                                                     |
| 14 | P1.09                   | I/O    | General purpose I/O                                                                                     |
| 15 | P0.11                   | I/O    | General purpose I/O                                                                                     |
| 16 | P0.12                   | I/O    | General purpose I/O                                                                                     |
| 17 | P0.03                   | I/O    | General purpose I/O                                                                                     |
| 18 | <i>GND</i>              | Supply | Ground                                                                                                  |
| B1 | P0.09/NFC1 <sup>2</sup> | I/O    | General purpose I/O                                                                                     |
| B2 | P0.10/NFC2 <sup>2</sup> | I/O    | General purpose I/O                                                                                     |
| B3 | P0.23                   | I/O    | General purpose I/O                                                                                     |
| B4 | P1.00                   | I/O    | General purpose I/O                                                                                     |
| B5 | P0.21                   | I/O    | General purpose I/O                                                                                     |
| B6 | P0.07                   | I/O    | General purpose I/O                                                                                     |

Table 13: Pinout



The main functionality is accessible through pad 1 - 18 with edge castellation. This offers easy prototype building as it is suitable for hand soldering. More optional GPIOs without enlarging the size are accessible through the land grid pads B1 - B6 that can only be connected through reflow process.

<sup>1</sup>Pins available to connect an external crystal in custom firmware. The standard firmware of Ophelia-III does not implement this function.

<sup>2</sup>NFC pins available for NFC function in custom firmware. The standard firmware of Ophelia-III does not implement this function.

## 6 Development

The Ophelia-III is a product without firmware. For the development of custom firmware, Nordic Semiconductor offers the nRFConnect SDK. It contains the hardware description of the Ophelia-III, chip related drivers and various examples codes to demonstrate the use of these drivers. Refer to application note *ANR030* for a more detailed description.

Besides the nRFConnect SDK and an Ophelia-III EV kit, a Segger J-Link Flasher is recommended for debugging and flashing operations. The Ophelia-III offers a serial wire debug and programming interface (SWD) for module flash access. This interface can be used by customers to install their own firmware.

To benefit from the certifications of Würth Elektronik eiSos products and transfer them to the new product, refer to application note *ANR027* and application note *ANR031*.

After the firmware has been developed, Würth Elektronik eiSos offers the service to flash the firmware at our production site. Please contact your local contact person or [WCS@we-online.com](mailto:WCS@we-online.com) for quotes regarding these topics.

## 7 Certification of the end device

For the certification of the end device, which integrates the Ophelia-III, it is necessary to run the Bluetooth® direct test modes (DTM) on the Ophelia-III and check its radio behavior.

The Bluetooth® tester<sup>1</sup> used by the test house wants to communicate with the radio module via 2-wire DTM protocol on the UART. Thus it is necessary to flash the radio module with a 2-wire DTM firmware using the production flash interface.



It is required to expose the UART and the SWD pins to be able to flash and control the Ophelia-III for certification tests.

The 2-wire DTM firmware is provided on request, as well as the DTM GUI PC tool. This tool is used to send the DTM test commands to the radio module.

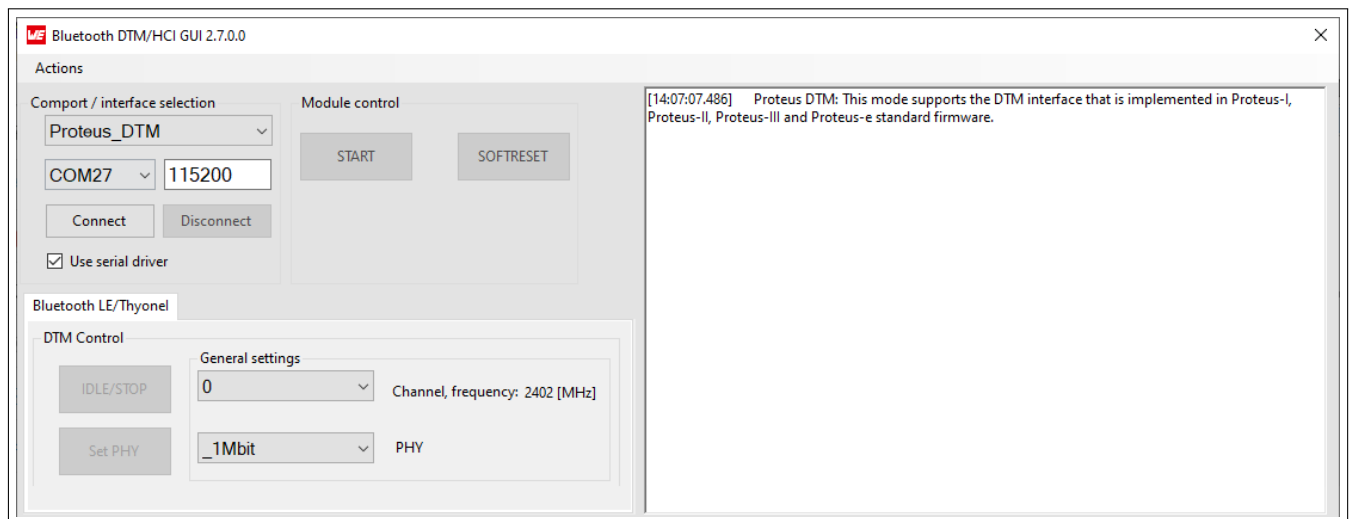


Figure 4: Bluetooth® DTM GUI PC tool

<sup>1</sup> A Bluetooth® tester is a certified device running automated tests on a connected Bluetooth® enabled device.

## 8 Antenna connection

Ophelia-III's smart antenna configuration enables the user to choose between two antenna options:

### 8.1 On-board PCB antenna

The Ophelia-III has an on-board PCB antenna optimized for strong miniaturization operating in the 2.4 GHz frequency band. A simple short between the pins *RF* and *ANT* feeds the RF output of the module to the on-board antenna of the Ophelia-III. In this configuration, the module does not require any additional RF circuitry.

### 8.2 External antenna

For applications that use an external antenna, the Ophelia-III provides a 50  $\Omega$  RF signal on pin *RF* of the module. In this configuration, pin *ANT* of the module has to be connected to ground and pin *RF* to the external antenna via 50  $\Omega$  feed line. Refer to chapter 11 for further information.



The use cases for the integrated antenna are miniaturization and re-use of module certifications for the end-application. The use cases for the external antenna are optimization of radio range spending more space for the antenna and differentiated antenna for example when metal housings are used.

## 9 Hardware history

### **Version 1.4 "Release"**

- First production release
- nRF52840, WLCSP, revision 2

### **Version 1.5 "Release"**

- nRF52840, WLCSP, revision 3

## 10 Design in guide

### 10.1 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.
- 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.
- 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.
- 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.

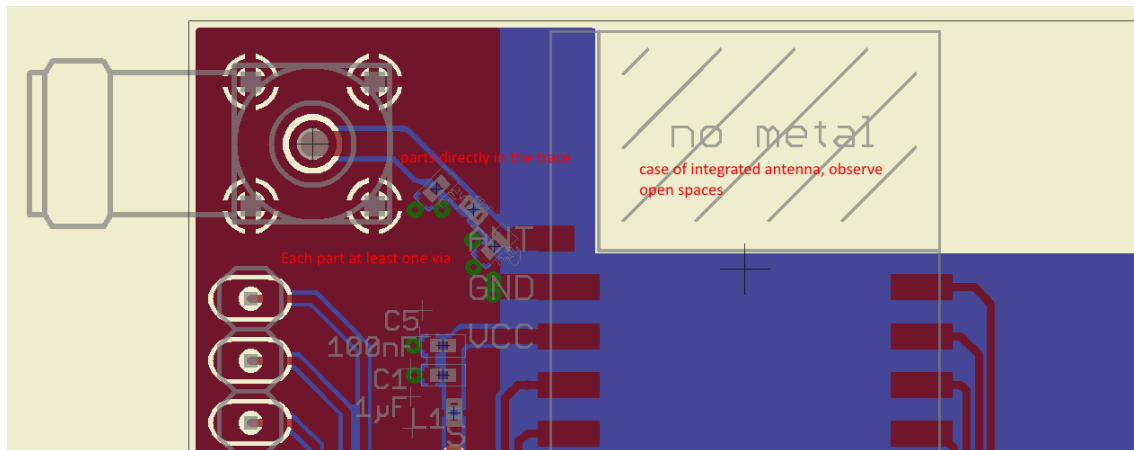


Figure 5: Layout

- 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.



Fixed values can not be recommended, as these depend on the circumstances of the application (main power source, interferences etc.).

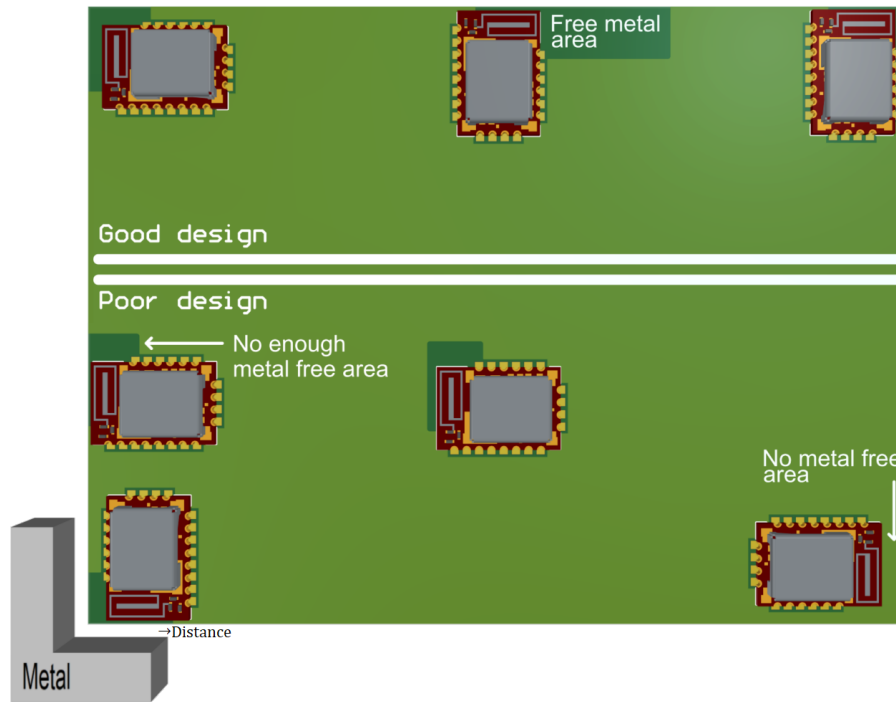


Figure 6: Placement of the module with integrated antenna

## 10.2 Designing the antenna connection

The antenna should be connected with a  $50\ \Omega$  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  $50\ \Omega$  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.

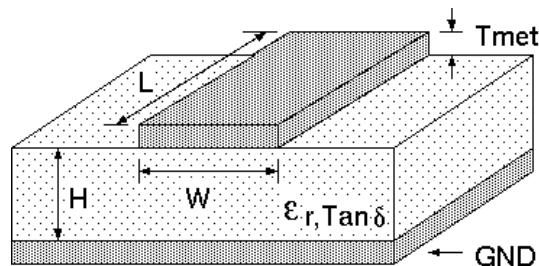


Figure 7: Dimensioning the antenna connection as micro strip

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

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

Example:

A FR4 material with  $\epsilon_r = 4.3$ , a height  $H = 1000\ \mu\text{m}$  and a copper thickness of  $T_{met} = 18\ \mu\text{m}$  will lead to a trace width of  $W \sim 1.9\ \text{mm}$ . 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  $3 \times W$  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.

### 10.3 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  $\lambda / 10$  (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.

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

#### 10.3.1 Wire antenna

An effective antenna is a  $\lambda / 4$  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  $\lambda / 4$  radiator has approximately  $40 \Omega$  input impedance. Therefore, matching is not required.

#### 10.3.2 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.

### 10.3.3 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.

### 10.3.4 Antennas provided by Würth Elektronik eiSos

Besides the radio modules Würth Elektronik eiSos provides various antennas tailored for the different frequency bands. The recommended single external antennas are shown in the subsequent chapters.



In case integrated multilayer chip antennas are needed because of space limitations, please refer to  
<https://www.we-online.com/en/components/products/WE-MCA>.

#### 10.3.4.1 2600130021 - Himaia dipole antenna



Figure 8: Himaia dipole antenna

Due to the fact that the antenna has dipole topology, there is no need for an additional ground plane. Nevertheless, the specification was measured edge mounted and 90 ° bent on a 100 x 100 mm ground plane.

| Specification                          | Value            |
|----------------------------------------|------------------|
| Frequency range [GHz]                  | 2.4 – 2.5        |
| Impedance [ $\Omega$ ]                 | 50               |
| VSWR                                   | $\leq 2:1$       |
| Polarization                           | Linear           |
| Radiation                              | Omni-Directional |
| Peak Gain [dBi]                        | 2.8              |
| Average Gain [dBi]                     | -0.6             |
| Efficiency                             | 85 %             |
| Dimensions (L x d) [mm]                | 83.1 x 10        |
| Weight [g]                             | 7.4              |
| Connector                              | SMA plug         |
| Operating temp. [ $^{\circ}\text{C}$ ] | -40 – +80        |

Special care must be taken for FCC certification when using this external antenna to fulfill the requirement of permanently attached antenna or unique coupling, for example by using the certified dipole antenna in a closed housing, so that it is possible to remove it only through professional installation.

## 11 Reference design

The Ophelia-III with a special firmware based on Proteus-III was tested and certified on the corresponding EV-Board. This serves as a proved reference design. For the European Conformity, the EV-Board serves as reference design; for the FCC, it is mandatory to follow at least the trace design.

Complete layout and schematic information can be found in the manual of the Ophelia-III EV-Board.

11.1 EV-Board

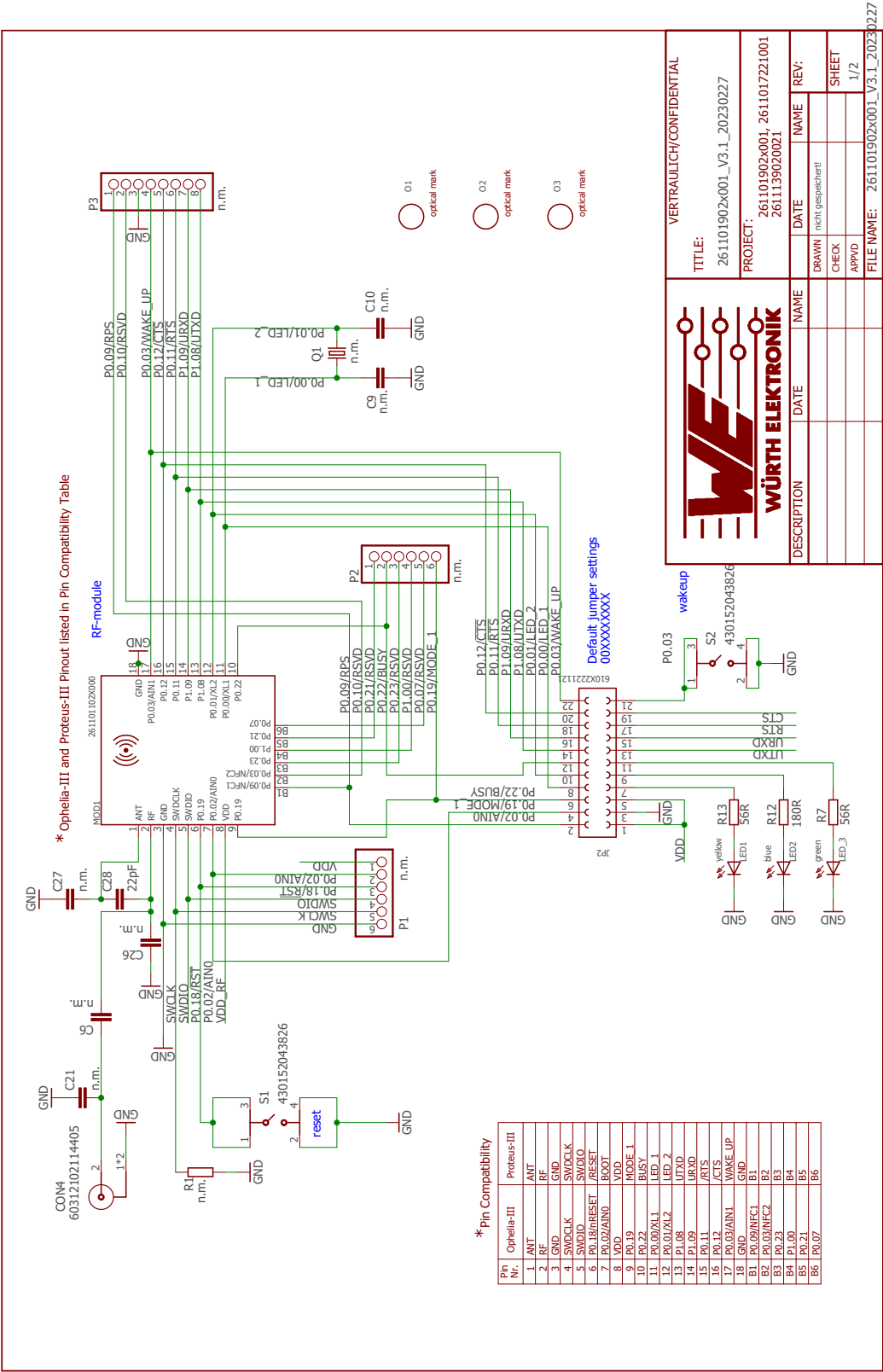
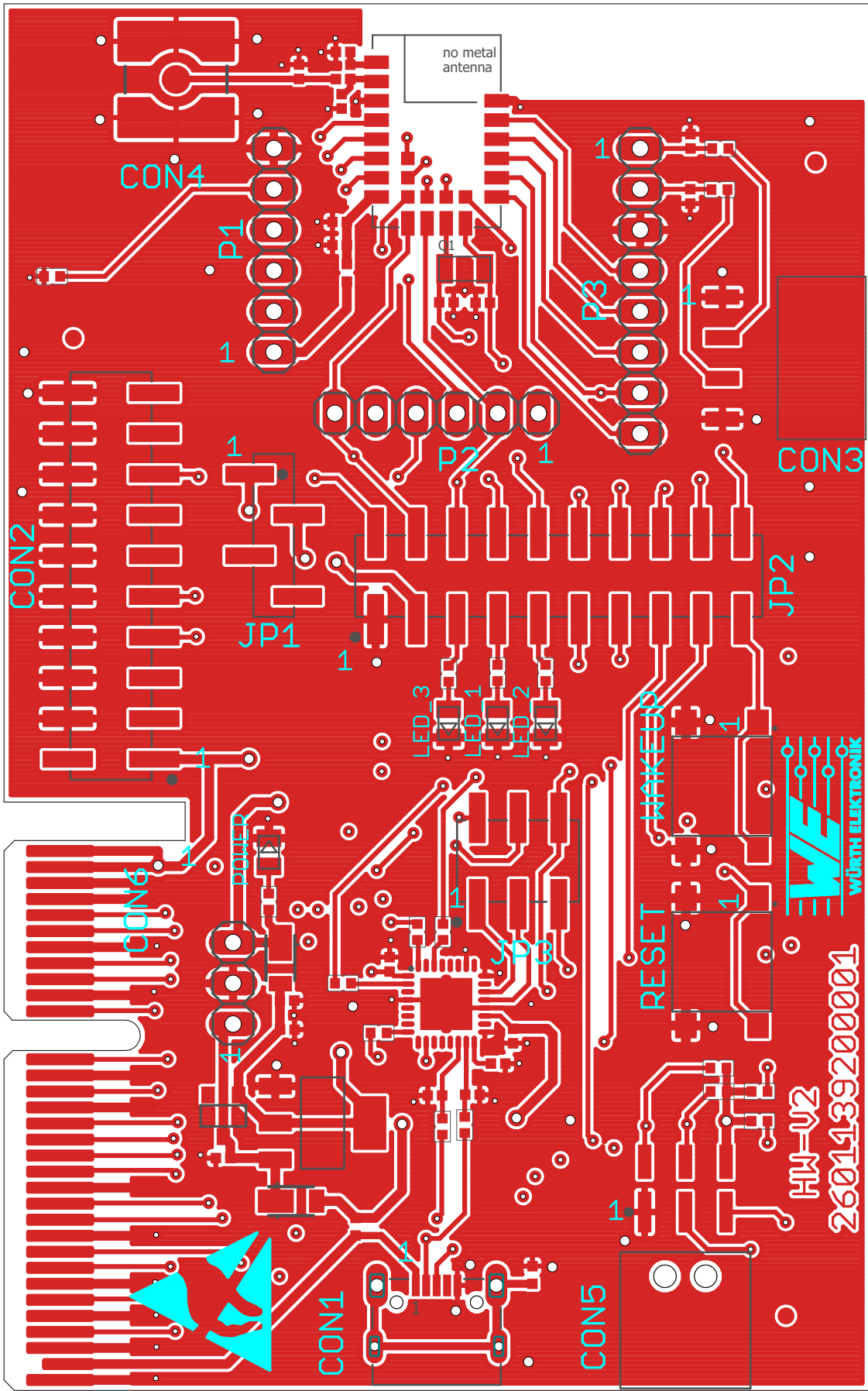


Figure 9: Reference design: Schematic page 1





## 11.2 Radiation characteristic of the module's internal antenna

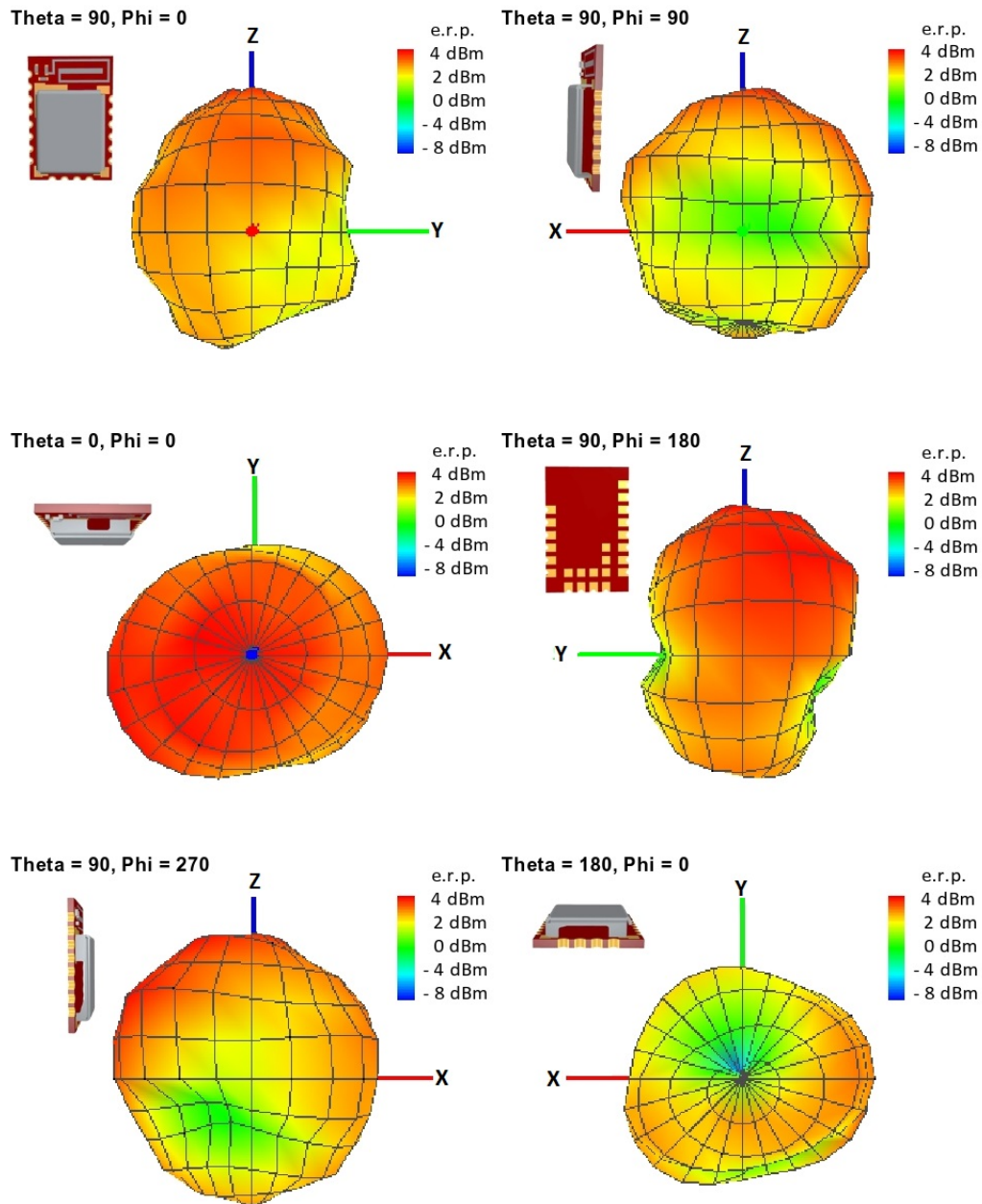


Figure 12: Antenna characteristic of the module with its integrated antenna measured on the official EV-Board



It is important to be aware that size and shape of the ground plane as well as the placement of module has influence on the radiation pattern.

## 12 Manufacturing information

### 12.1 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](http://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](http://www.jedec.org).

### 12.2 Soldering

#### 12.2.1 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                                     | $T_{S \text{ Min}}$ | 150 °C      |
| Preheat temperature, max                                     | $T_{S \text{ Max}}$ | 200 °C      |
| Preheat time from $T_{S \text{ Min}}$ to $T_{S \text{ Max}}$ | $t_S$               | 60 - 120 s  |
| Ramp-up rate ( $T_L$ to $T_P$ )                              |                     | 3 °C/s max. |
| Liquidous temperature                                        | $T_L$               | 217 °C      |
| Time $t_L$ maintained above $T_L$                            | $t_L$               | 60 - 150 s  |
| Peak package body temperature                                | $T_P$               | 260 °C      |
| Time within 5 °C of actual peak temperature                  | $t_P$               | 20 - 30 s   |
| Ramp-down rate ( $T_P$ to $T_L$ )                            |                     | 6 °C/s max. |
| Time 20 °C to $T_P$                                          |                     | 8 min max.  |

Table 14: 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.

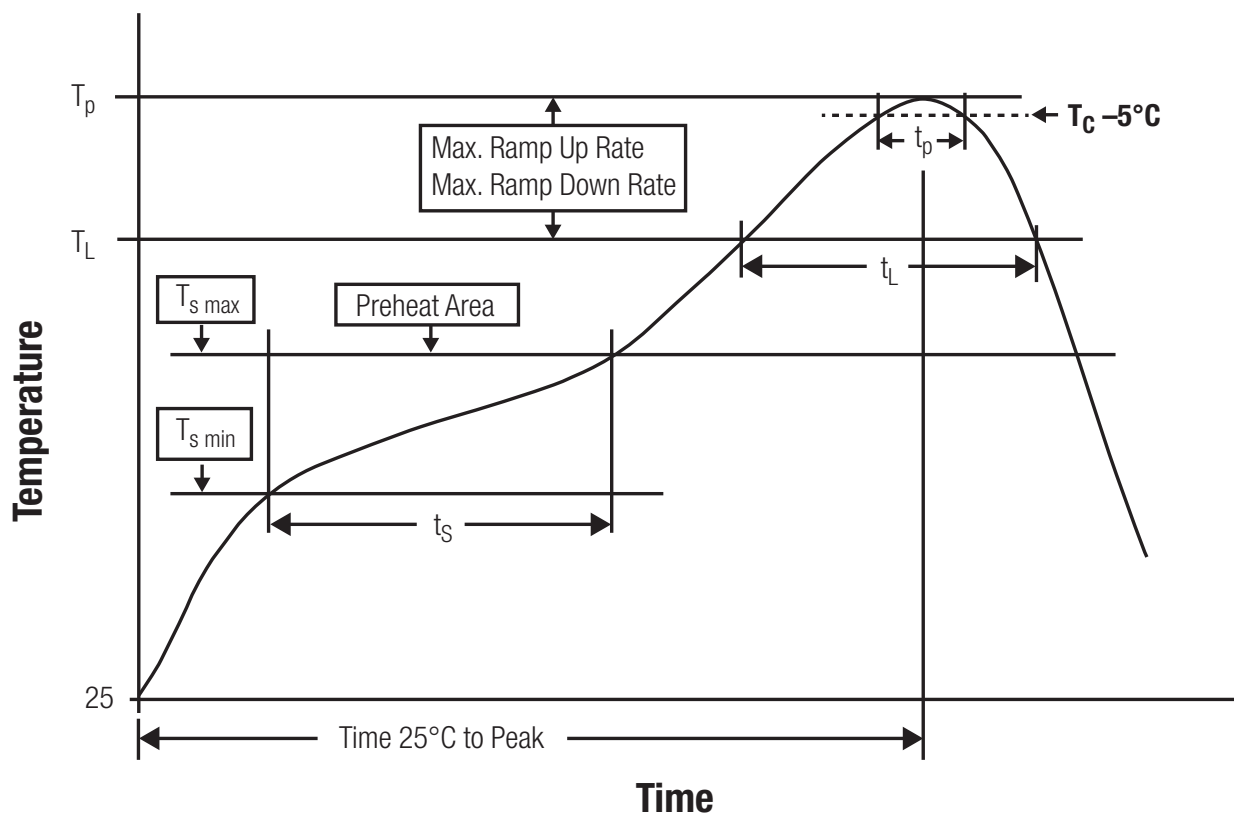


Figure 13: Reflow soldering profile

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

### 12.2.2 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.

### 12.2.3 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 behavior of the device. This might be critical for components with high power.

### 12.2.4 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.

## 12.3 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 4. 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.

## 12.4 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 generate a large amount of heat while transmitting. The manufacturer of the end device must take care of potentially necessary actions for his application.

## 13 Product testing

### 13.1 Würth Elektronik eiSos in-house production tests

To achieve a high quality standard, Würth Elektronik eiSos follows a philosophy of supplying fully tested radio modules. At the end of the production process, every unit undergoes an optical inspection. Here the quality of soldering, edge castellation and edge milling is monitored.

If this has been passed, the radio modules are handed over to the automatic test equipment for the electrical characterization. This includes:

- Voltage and current tests to ensure proper electrical performance
- RF characteristics (frequency, spectrum, TX power) measurement and calibration
- Radio communication tests
- Firmware and serial number programming
- Host interface communication tests

The automated testing process is logged for internal quality control. The gained measurement data of each unit is analysed to detect defective parts and investigate the corresponding root cause. Defective radio modules are discarded, in order to guarantee a 100% failure-free delivery to customers.

### 13.2 EMS production tests

The rigorous in-series production testing ensures that EMS don't need to duplicate firmware tests or measurements. This streamlines the process and eliminates the need for additional testing over analogue and digital interfaces during device production. When it comes to device testing, the ideal focus should be on module assembly quality:

- All module pins are soldered properly on the base PCB
- There are no short circuits
- The mounting process did not damage the module
- The communication between host and radio module is working
- The antenna is connected properly

Simple "Go/No go" tests, like checking the RSSI value, give already a hint if the power supply and antenna have been connected properly.

In addition to such standard testing procedures, radio module integrators have the flexibility to perform additional dedicated tests to thoroughly evaluate the device. Specific tests they can consider are:

- Measure module current consumption in a specified operating state. Deviations from expected results (compared to a "Golden Device") can signal potential issues.

- Perform functional tests, including communication checks with the host controller and verification of interfaces.
- Assess fundamental RF characteristics (modulation accuracy, power levels, spectrum). Verify that the device meets expected performance standards.

## 14 Physical specifications

### 14.1 Dimensions

| Dimensions    |
|---------------|
| 12 x 8 x 2 mm |

Table 15: Dimensions

### 14.2 Weight

| Weight |
|--------|
| < 1 g  |

Table 16: Weight

## 14.3 Module drawing

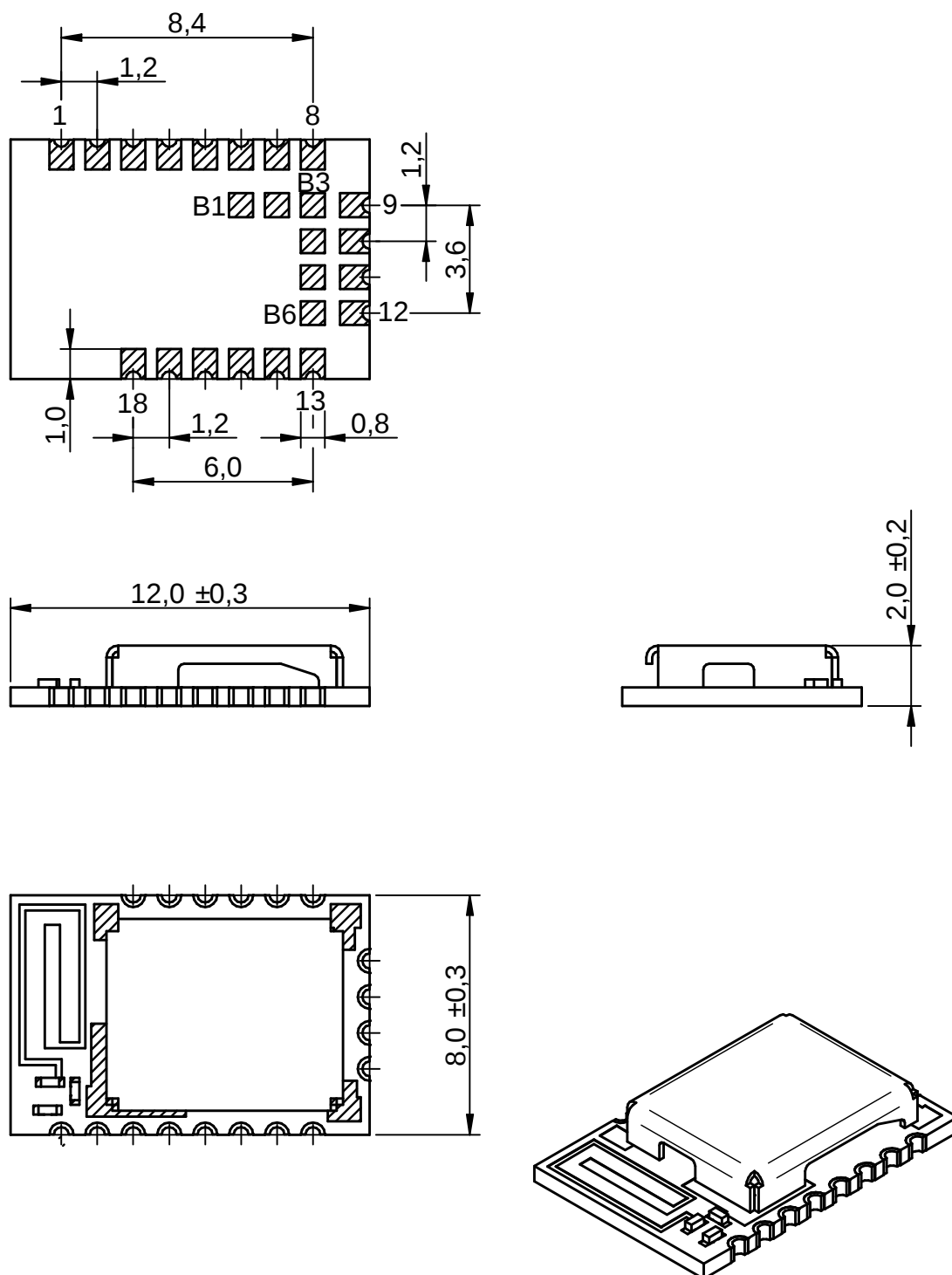


Figure 14: Module dimensions [mm]

## 14.4 Footprint

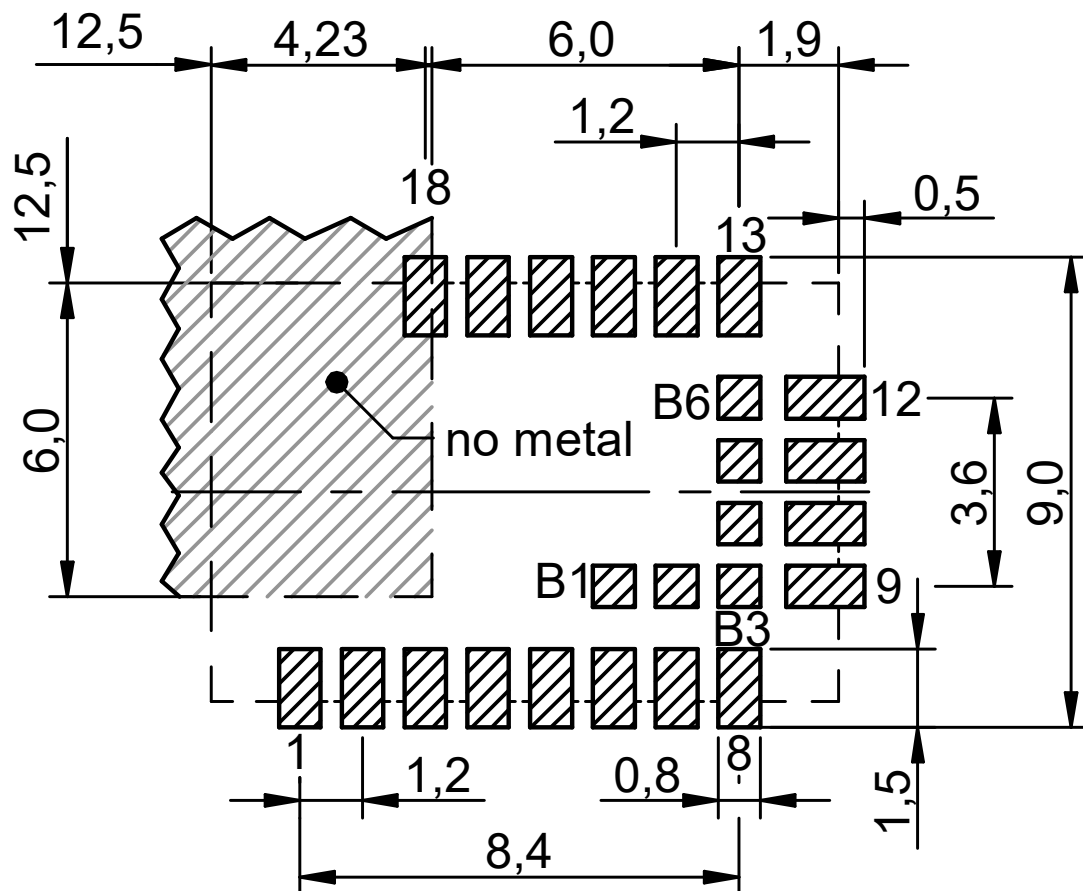


Figure 15: Footprint [mm]

## 14.5 Antenna free area

To avoid influence and mismatching of the antenna the recommended free area around the antenna should be maintained. As rule of thumb a minimum distance of metal parts to the antenna of  $\lambda/10$  should be kept (see figure 15). Even though metal parts would influence the characteristic of the antenna, but the direct influence and matching keep an acceptable level.

# 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.

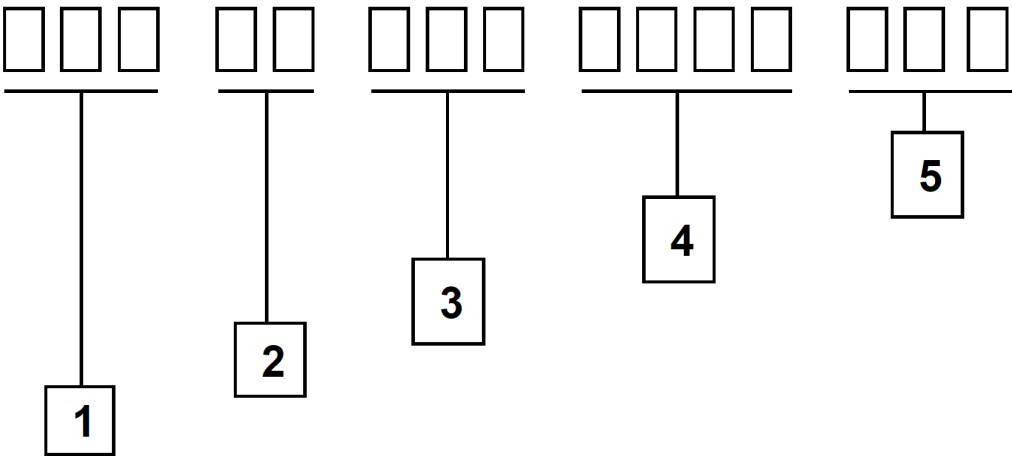


Figure 16: Lot number structure

| 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        | 2103 = week 03 in year 2021,<br>2216 = week 16 in year 2022 |
| 5     | Firmware version, 3 digits | V3.2 = 302, V5.13 = 513                                     |

Table 17: Lot number details

## 16 Information for explosion protection

In case the end product should be used in explosion protection areas the following information can be used:

- The module itself is unfused.
- The maximum output power of the module is 6 dBm for external antenna and 4 dBm for internal antenna.
- The total amount of capacitance of all capacitors is 7.2  $\mu\text{F}$ .
- The total amount of inductance of all inductors is 10.025  $\mu\text{H}$ .
- A DC/DC regulator is included in the chip set and used to obtain low power functionality.

## 17 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, PCNs, warnings and cautions must be strictly observed in the most recent versions and matching to the products revisions. These 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 Business Development Engineer (BDM) 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 Business Development Engineer (BDM), the internal sales person or the technical support team in charge should be contacted. The basic responsibility of the customer as per section 17 and 17 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 Business Development Engineer (BDM) 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.

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The responsibility for the applicability and use of the Würth Elektronik eiSos wireless connectivity product with the incorporated firmware in a particular customer design is always solely within the authority of the customer. Due to this fact, it is up to you to evaluate and investigate, where appropriate, and to decide whether the device with the specific product characteristics described in the product specification is valid and suitable for your respective application or not.

You are responsible for using the Würth Elektronik eiSos wireless connectivity product with the incorporated firmware in compliance with all applicable product liability and product safety laws. You acknowledge to minimize the risk of loss and harm to individuals and bear the risk for failure leading to personal injury or death due to your usage of the product.

Würth Elektronik eiSos' products with the incorporated firmware are not authorized for use in safety-critical applications, or where a failure of the product is reasonably expected to cause severe personal injury or death. Moreover, Würth Elektronik eiSos' products with the incorporated firmware are neither designed nor intended for use in areas such as military, aerospace, aviation, nuclear control, submarine, transportation (automotive control, train control, ship control), transportation signal, disaster prevention, medical, public information network etc. You shall inform Würth Elektronik eiSos about the intent of such usage before design-in stage. In certain customer applications requiring a very high level of safety and in which the malfunction or failure of an electronic component could endanger human life or health, you must ensure to have all necessary expertise in the safety and regulatory ramifications of your applications. You acknowledge and agree that you are solely responsible for all legal, regulatory and safety-related requirements concerning your products and any use of Würth Elektronik eiSos' products with the incorporated firmware in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by Würth Elektronik eiSos. **YOU SHALL INDEMNIFY WÜRTH ELEKTRONIK EISOS AGAINST ANY DAMAGES ARISING OUT OF THE USE OF WÜRTH ELEKTRONIK EISOS' PRODUCTS WITH THE INCORPORATED FIRMWARE IN SUCH SAFETY-CRITICAL APPLICATIONS.**

#### Ownership

## User manual Ophelia-III

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## List of Figures

|    |                                                                                                              |    |
|----|--------------------------------------------------------------------------------------------------------------|----|
| 1  | Ophelia-III . . . . .                                                                                        | 7  |
| 2  | Block diagram of the module . . . . .                                                                        | 9  |
| 3  | Pinout (top view) . . . . .                                                                                  | 15 |
| 4  | Bluetooth® DTM GUI PC tool . . . . .                                                                         | 18 |
| 5  | Layout . . . . .                                                                                             | 22 |
| 6  | Placement of the module with integrated antenna . . . . .                                                    | 23 |
| 7  | Dimensioning the antenna connection as micro strip . . . . .                                                 | 23 |
| 8  | Himalia dipole antenna . . . . .                                                                             | 26 |
| 9  | Reference design: Schematic page 1 . . . . .                                                                 | 28 |
| 10 | Reference design: Schematic page 2 . . . . .                                                                 | 29 |
| 11 | Reference design: Layout . . . . .                                                                           | 30 |
| 12 | Antenna characteristic of the module with its integrated antenna measured on the official EV-Board . . . . . | 31 |
| 13 | Reflow soldering profile . . . . .                                                                           | 33 |
| 14 | Module dimensions [mm] . . . . .                                                                             | 39 |
| 15 | Footprint [mm] . . . . .                                                                                     | 40 |
| 16 | Lot number structure . . . . .                                                                               | 41 |

## List of Tables

|    |                                                                                        |    |
|----|----------------------------------------------------------------------------------------|----|
| 3  | Ordering information . . . . .                                                         | 9  |
| 4  | Operating conditions . . . . .                                                         | 10 |
| 5  | Absolute maximum ratings . . . . .                                                     | 11 |
| 6  | Current consumption - transmitting . . . . .                                           | 12 |
| 7  | Current consumption - receiving . . . . .                                              | 12 |
| 8  | Current consumption - low power . . . . .                                              | 12 |
| 9  | Frequency range . . . . .                                                              | 13 |
| 10 | RSSI accuracy . . . . .                                                                | 13 |
| 11 | Transmit and receive power . . . . .                                                   | 13 |
| 12 | Pin characteristics . . . . .                                                          | 14 |
| 13 | Pinout . . . . .                                                                       | 16 |
| 14 | Classification reflow soldering profile, Note: refer to IPC/JEDEC J-STD-020E . . . . . | 32 |
| 15 | Dimensions . . . . .                                                                   | 38 |
| 16 | Weight . . . . .                                                                       | 38 |
| 17 | Lot number details . . . . .                                                           | 41 |