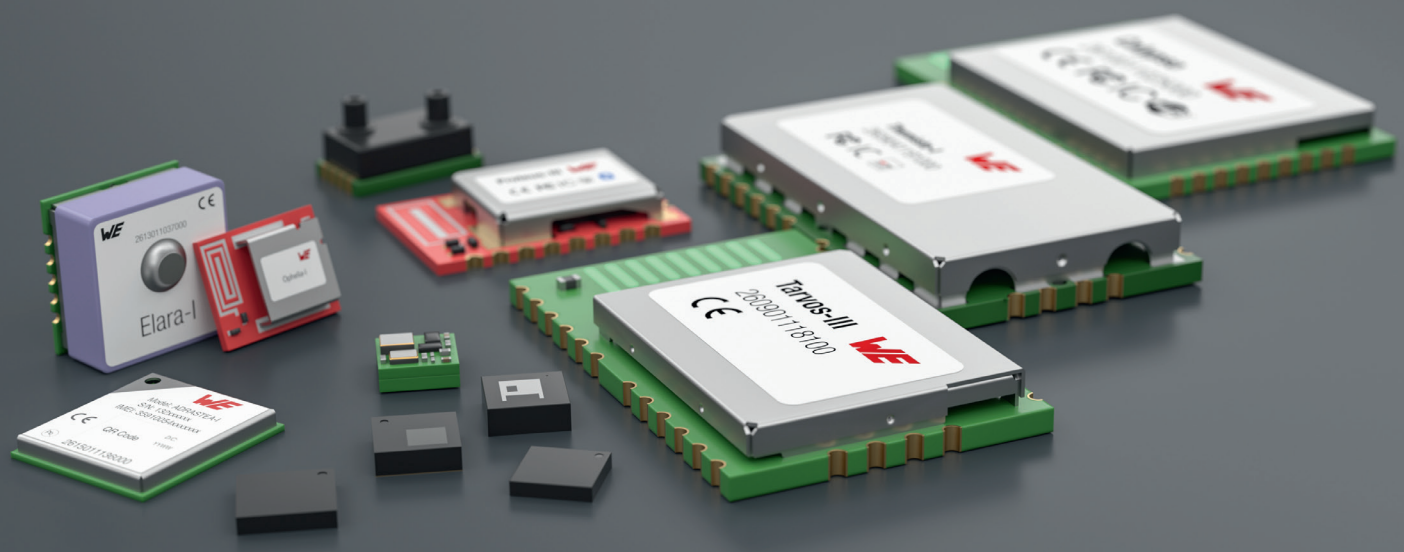


USER MANUAL

STEPHANO-I

2617011025000

VERSION 1.0

MARCH 20, 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	FW version	HW version	Notes	Date
1.0	3.2.0.0	4.0	• Initial version	March 2024

Abbreviations

Abbreviation	Name	Description
ACK	ACKnowledgment	Acknowledgment pattern confirming the reception of the transmitted data packet.
ASCII	American Standard Code for Information Interchange	Set of characters for computers and electronic devices.
AWS	Amazon Web Services	Cloud from Amazon.
BDM	Business Development Manager	Support and sales contact person responsible for limited sales area.
CCCD	Client Characteristic Configuration Descriptor	Descriptor of the Bluetooth® LE characteristic.
DC	Duty Cycle	Transmission time in relation of one hour. 1% means, channel is occupied for 36 seconds per hour.
FOTA	Firmware Over The Air	Update mechanism that is run via radio.
GUI	Graphic User Interface	Screen interface consisting of menus and icons that can be controlled by a mouse.
0xhh [HEX]	HEXadecimal	All numbers beginning with 0x are stated as hexadecimal numbers. All other numbers are decimal.
HIGH	High signal level	Signal level of the VDD.
HTTP	HyperText Transfer Protocol	Data transfer protocol used on the world wide web (WWW).
IoT	Internet of Things	Technology facilitating the communication between devices and the cloud, as well as between the devices themselves.
LOW	Low signal level	Signal level of the ground.
LPM	Low Power Mode	Operation mode for reduced power consumption.
LSB	Least Significant Bit	
MCU	MicroController Unit	
MSB	Most Significant Bit	

MQTT	Message Queuing Telemetry Transport	Messaging protocol especially used in cases where clients are connected to unreliable networks or networks with limited bandwidth resources.
PL	PayLoad	The real, non-redundant information in a frame/packet.
RF	Radio Frequency	Describes everything relating to the wireless transmission.
SDK	Software Development Kit	Set of tools for third-party developers to use in producing applications using a particular framework or platform.
SNTP	Simple Network Time Protocol	Protocol used to synchronize the clocks of computers or devices.
SSID	Service Set IDentifier	Sequence of characters that uniquely identifies a WiFi network.
SSL	Secure Sockets Layer	Protocol that uses encryption to ensure the secure transfer of data over the internet.
TCP/IP	Transmission Control Protocol/Internet Protocol	Set of standardized rules that allow computers to communicate to a network.
UART	Universal Asynchronous Receiver Transmitter	Protocol for the exchange of data in series between two devices.
UDP	User Datagram Protocol	Communication protocol for time-sensitive applications, such as DNS lookups.
VDD	Supply voltage	
WLAN	Wireless Local Area Network	Wireless network that connects two or more devices using wireless communication.
WPA-PSK	WiFi Protected Access-Pre-Shared Key	Security mechanism in wireless communications to establish a secure connection between a wireless client and a WiFi access point.

Contents

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 listing guide

http://www.we-online.com/ANR027
Every product containing Bluetooth® technology needs to be listed at the Bluetooth® SIG (special interest group). This application note explains the steps to be done to gain a Bluetooth® listing for the end product using a Würth Elektronik eiSos Bluetooth® LE radio module.

1 Introduction

The Stephano-I is a compact radio module which comes with a complete WiFi stack based on IEEE 802.11 b/g/n (2.4 GHz). Besides, the Stephano-I further brings Bluetooth® LE 5 functions in peripheral and central role enabling low power connectivity to smart devices.
This combination of widely used radio standards and an easy-to-use AT-style command interface, makes the Stephano-I an ideal product for any embedded wireless IoT application.

1.1 Operational description

The Stephano-I radio module is intended to be used as a radio sub-system in order to provide WLAN and Bluetooth® LE communication capabilities to the system.
The UART acts as the primary interface between the module and a host MCU. The module can be fully configured and operated using a set of AT-commands over UART. Once configured, the module independently manages radio connectivity, allowing the host MCU to utilize its resources elsewhere.
Therefore, a host MCU is required in the end product to control and access the radio module.

Figure 1: Stephano-I

1.2 Block diagram

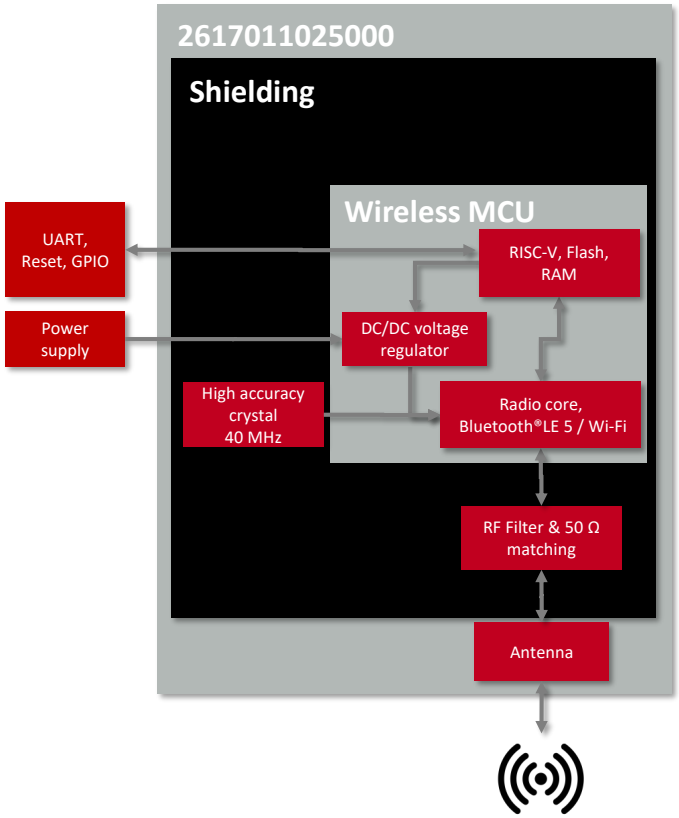


Figure 2: Block diagram

1.3 Ordering information

WE order code	Description
2617011025000	Stephano-I WiFi & Bluetooth® LE module with integrated PCB antenna, Tape & Reel
2617029025000	Evaluation board with Stephano-I module mounted

Table 1: Ordering information

2 Electrical specifications

If not otherwise stated, measured on the Stephano-I evaluation board with T = 25 °C, VDD = 3.3 V.

2.1 Recommended operating conditions

Description	Min.	Typ.	Max.	Unit
VDD	3.0	3.3	3.6	V
Temperature range	-40		85	°C

Table 2: Recommended operating conditions

2.2 Absolute maximum ratings

Description	Min.	Typ.	Max.	Unit
VDD	-0.3		3.6	V

Table 3: Absolute maximum ratings

2.3 Power consumption

2.3.1 Static

Description	Test condition	Min.	Typ.	Max.	Unit
WiFi TX current consumption at max output power	Mode: WiFi 11b, Data rate: 1 Mbps, Power index: 80		167		mA
WiFi RX current consumption			82		mA
Bluetooth® LE TX current consumption at max output power	Mode: Bluetooth® LE, Data rate: 1 Mbps, Power index: 12		161		mA
Bluetooth® LE RX current consumption			81		mA
Deep-sleep mode		5			µA
System-off mode (*/RESET* set to *GND*)		1			µA

Table 4: Power consumption

2.4 Radio characteristics

Description	Test condition	Min.	Typ.	Max.	Unit
Max output power[1]	Data rate: 1 Mbps, Power index: 80		13.4		dBm
Input sensitivity	Data rate: 1 Mbps		-87		dBm
Frequencies		2412		2484	MHz

Table 5: WiFi radio characteristics (radiated)

Description	Test condition	Min	Typ.	Max	Unit
Max output power[1]	Data rate: 1 Mbps, Power index: 12		4.5		dBm
Input sensitivity	Data rate: 1 Mbps		-89		dBm
Frequencies		2402		2480	MHz

Table 6: Bluetooth® LE radio characteristics (radiated)

2.5 Pin characteristics

Property	Min.	Typ.	Max.	Unit
Pin input low voltage	-0.3		0.25×VDD	V
Pin input high voltage	0.75×VDD		VDD+0.3	V
Pin output low voltage			0.1×VDD	V
Pin output high voltage	0.8×VDD			V
Pin output current sunk by any I/O and control pin		40		mA
Pin output current sourced by any I/O and control pin		28		mA
Internal pull-up/pull-down resistor		45		kΩ

Table 7: Pin characteristics

[1] Refer to the Table 14 for the certified power settings. For the certification of the end device, the power index can be adjusted to achieve the maximum certifiable output power.

3 Pinout

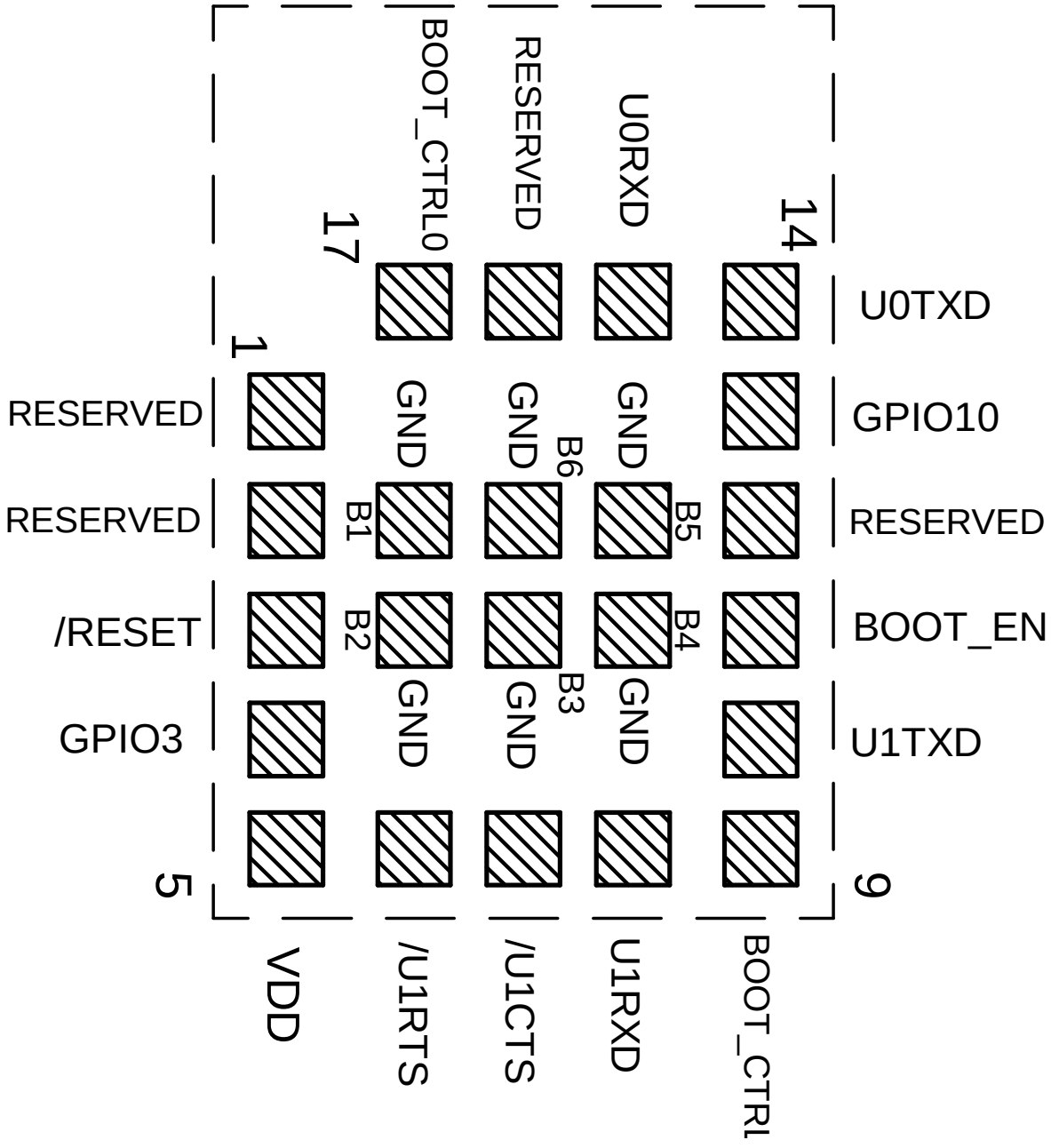


Figure 3: Pinout (top view)

No	µC Pin	Designation	I/O	Description
1	*GPIO0 / XTAL_P* [2]	*RESERVED*	I/O	Reserved pin. Do not connect.
2	*GPIO1 / XTAL_N* [2]	*RESERVED*	I/O	Reserved pin. Do not connect.
3	*CHIP_EN*	*/RESET*	Input	Reset pin. A low signal resets the module.
4	*GPIO3*	*GPIO3*	Input	Reserved pin. Can be used as wake-up source or ADC channel. Do not connect if not needed.
5		*VDD*	Supply	Supply voltage
6	*GPIO4*	*/U1RTS*	Output	/RTS signal of the application UART, if flow control is enabled. Do not connect if not needed.
7	*GPIO5*	*/U1CTS*	Input	/CTS signal of the application UART, if flow control is enabled. Uses internal pull-up [1]. Do not connect if not needed.
8	*GPIO6*	*U1RXD*	Input	Application UART (Reception). Uses internal pull-up resistor[1].
9	*GPIO8*	*BOOT_CTRL1*	Input	Boot control pin. External 1.5 kΩ pull-up resistor needed.
10	*GPIO7*	*U1TXD*	Output	Application UART (Transmission)
11	*GPIO9*	*BOOT_EN*	Input	Boot control pin. Low level: Boot Mode. High level: Application mode. Uses internal pull-up [1]
12	*GPIO18 / USB D-* [3]	*RESERVED*	I/O	Reserved pin. Do not connect.
13	*GPIO10*	*GPIO10*	Input	Reserved pin. Can be used as wake-up source. Do not connect if not needed.
14	*GPIO21*	*U0TXD*	Output	Debug UART (Transmission). Do not connect if not needed.
15	*GPIO20*	*U0RXD*	Input	Debug UART (Reception). Uses internal pull-up resistor[1]. Do not connect if not needed.
16	*GPIO19 / USB D+* [3]	*RESERVED*	I/O	Reserved pin. Do not connect.
17	*GPIO2*	*BOOT_CTRL0*	Input	Boot control pin. External 1.5 kΩ pull-up resistor needed.
B1 -B6	*GND*	*GND*	Supply	Ground

Table 8: Pinout

[1] Internal pull-ups or pull-downs (45 kΩ) are configured at start-up by the firmware installed in the SoC.
[2] Pins available to connect an external crystal in custom firmware only.
[3] Pins available to connect a USB in custom firmware only.

4 Quickstart

4.1 Minimal pin configuration

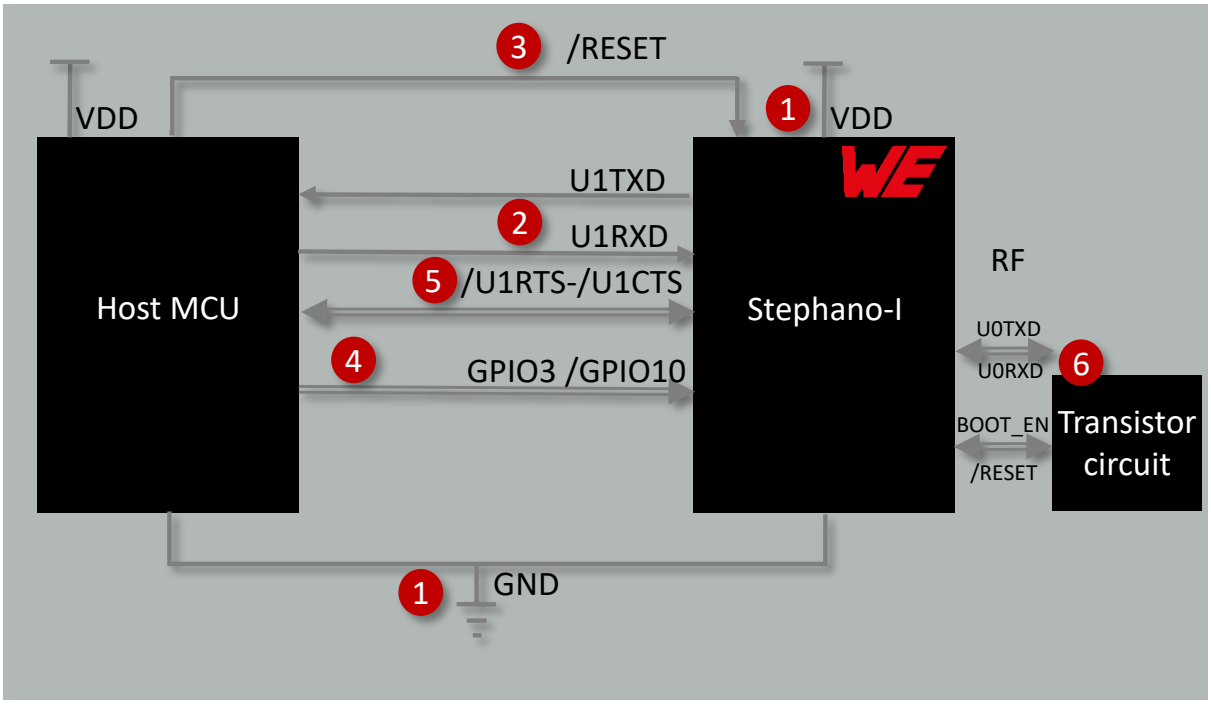


Figure 4: Minimal pin connections

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

1. Supply voltage and ground
   Firstly, connect the *VDD* and *GND* pins to supply the radio module with power.

2. UART serial interface to the host MCU
   Connect the application UART pins *U1TXD* and *U1RXD* to the host MCU to control the module via host MCU.

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

4. (Optional) Wakeup from sleep
   Connect the *GPIO3* or *GPIO10* pin to use it as trigger to wake-up from sleep mode.

5. (Optional) UART flow control
   Connect the */U1RTS* and */U1CTS* pins to the host MCU, in case the UART flow control shall be used.

6. (Optional) Debug UART and flash control for end device certification
   To run the certification process of the end device which integrates the Stephano-I radio module, it may be necessary that the pins *U0RXD* and *U0TXD* are accessible. Furthermore a special transistor circuit is needed to control the */RESET* and *BOOT_EN* pins to flash special test firmware. For more details of the hardware layout see chapter 20.10.

4.2 Power up

After a stable power supply has been applied to the module, the */RESET* pin can be released to high state to boot-up the Stephano-I. As soon as the radio module has booted, a start-up message "ready" is sent via UART to the connected host MCU. From this point on, the Stephano-I is ready to be controlled via AT-commands by the host MCU.

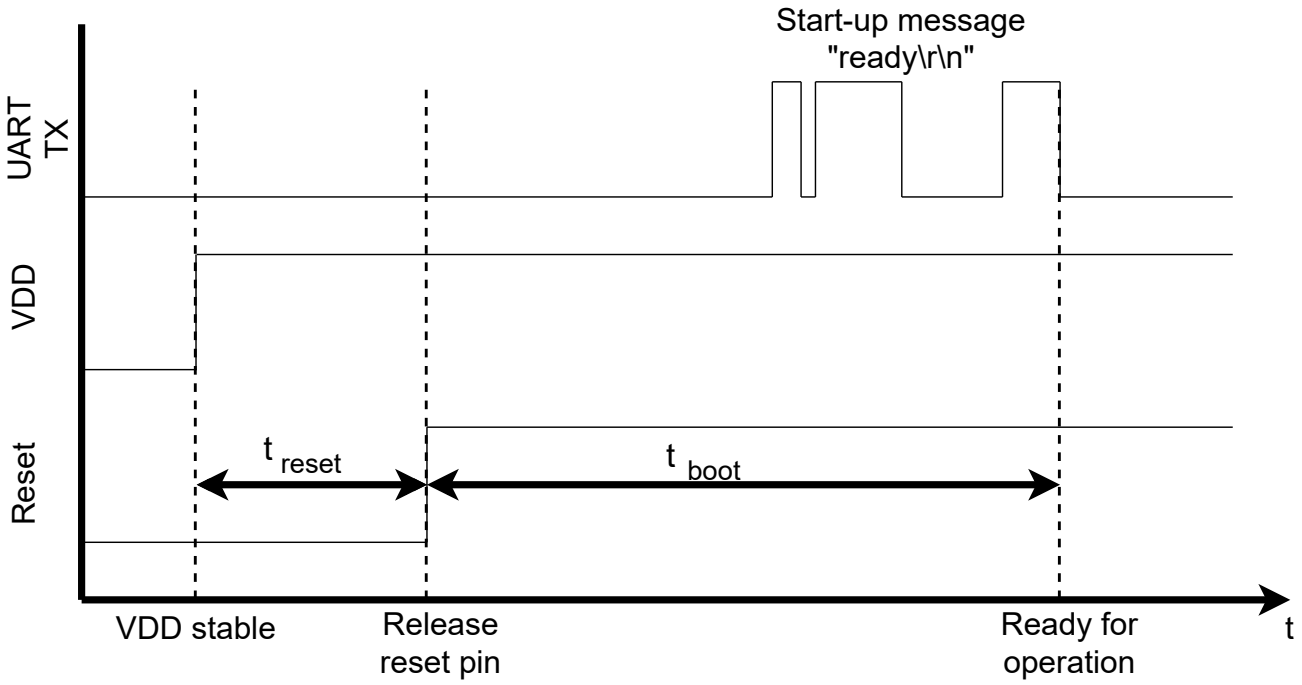


Figure 5: Power up

4.3 Quickstart example

This section describes how to quick start the Stephano-I. In this example, the goal is to connect to a router as WiFi station, set up a TCP connection and transmit data.

The arrow in the left column describes whether it's a message from host MCU to radio module or vice versa. A request command is always sent from host MCU to module (⇒). A response or event message is always sent from module to host MCU (⇐).

1. First of all, reset the device by applying a high-low-high sequence to the */RESET* pin. This can be done on the Stephano-I evaluation board by pressing the reset button. The module will reply with a start-up message "READY":

Info	Message
⇐ Module is ready for operation	READY\r\n

2. Set the module to "WiFi station" mode and connect to your local WiFi:

Info	Message
⇒ Read the WiFi's country code	AT+CWCOUNTRY?\r\n
⇐ Country code is "DE"	+CWCOUNTRY:1,"DE",1,13\r\n OK\r\n
⇒ Configure the Stephano-I as WiFi station	AT+CWMODE=1\r\n
⇐ Configuration done successfully	OK\r\n
⇒ Request a connection setup to an access point with SSID "mySSID" and password "myPWD"	AT+CWJAP="mySSID","myPWD"\r\n
⇐ WiFi has been connected and IP has been received	WIFI CONNECTED\r\n WIFI GOT IP\r\n OK\r\n
⇒ Request the assigned IP	AT+CIPSTA?\r\n
⇐ The router has assigned "191.178.168.228"	+CIPSTA:ip:"191.178.168.228"\r\n +CIPSTA:gateway:"191.178.168.1"\r\n +CIPSTA:netmask:"255.255.255.0"\r\n OK\r\n

3. Now a TCP server is needed, which is also connected to the same network. We assume that the server's IP address is 191.178.168.229, and the port is 8080.

4. Setup a TCP connection from the Stephano-I to that server:

Info	Message
⇒ Request a connection to that server	AT+CIPSTART="TCP","191.178.168.229",8080\r\n
⇐ Connection set up successfully	CONNECT\r\n OK\r\n

5. Transmit "hello server" (12 bytes):

Info	Message
⇒ Request data transmission of 12 bytes	AT+CIPSEND=12\r\n
⇐ Stephano-I is ready for data reception	OK\r\n >\r\n
⇒ Now send the data	hello server\r\n
⇐ Data transmitted successfully to the connected TCP server	Recv 12 bytes\r\n SEND OK\r\n

6. Now assume that the server replies with "hello client":

Info	Message
⇐ Server send data to the client	+IPD,12:hello client\r\n

The Espressif web page [1] contains numerous examples for WiFi and Bluetooth® LE connectivity, as well as for low power operation. Refer to the chapter `Use cases and examples` for more examples.

4.3.1 WE Smart Commander

The WE Smart Commander [2] is an easy-to-use PC software for Windows that enables complete control of the WÃ¼rth Elektronik eiSos wireless modules through an intuitive GUI. It implements the UART command interface of the Stephano-I. Since all device functions are abstracted to buttons and drop-down menus, the WE Smart Commander significantly simplifies prototyping and product evaluation.

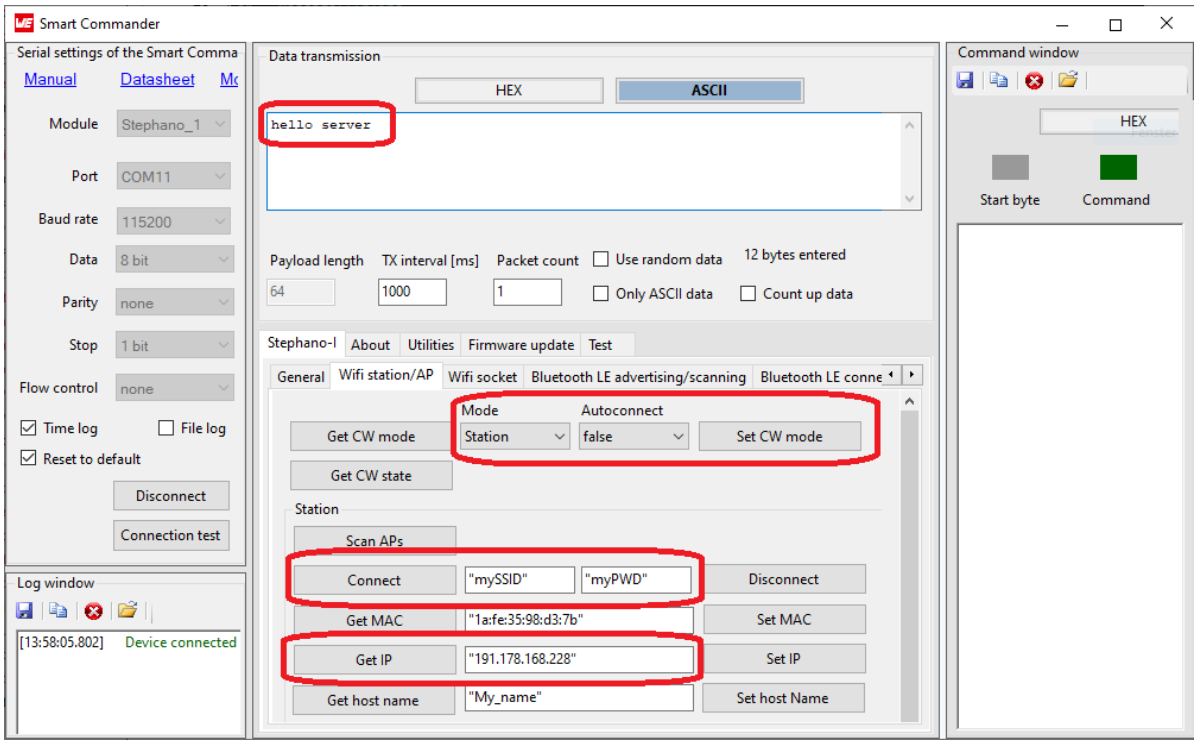


Figure 6: WE Smart Commander PC tool for prototyping

5 Functional description

The Stephano-I radio module is intended to be used as a radio sub-system, in order to provide WLAN and Bluetooth® LE communication capabilities to the system.

5.1 Key features

The Stephano-I offers the following key features:

- General features:

  Fast serial interface: The Stephano-I offers a UART interface to communicate with a host MCU using a simple AT-command interface. A baud rate of up to 5 MBaud, the flow control, the parity as well as the number of start and stop bits can be configured to match the applications needs.

  Latest microprocessor generation provided by Espressif: The heart of the Stephano-I is the ESP32-C3 radio chip, offering high performance values combined with low power consumption. It is a 32-bit RISC-V single-core processor with up to 160 MHz.

  Low power capabilities: The Stephano-I provides several sleep modes, which allow to shut down different parts of the radio module. This enables the option to reduce the power consumption depending on the application's state.

- Bluetooth® LE features:

  Bluetooth® LE 5 stack: The Bluetooth® LE 5 stack enables fast and energy efficient data transmission using state-of-the-art radio technology.

  All Bluetooth® LE roles supported: The integrated Bluetooth® LE stack supports all Bluetooth® LE roles.

    Peripheral: Provides a simple custom profile "WE SPP-like" for transmission of generic data (see chapter 5.2).

    Central: The use of generic GATT functions allows to communicate to any other Bluetooth® LE device, independent of the provided services.

    Broadcaster: Allows to transmit beacons.

    Observer: Allows to receive beacons.

  Multiconnect: Setup up to 3 congruent Bluetooth® LE connections at the same time.

  Additional Bluetooth® LE 5 radio modes: Besides the legacy Bluetooth® LE data rate of 1 Mbit, the Stephano-I provides the advanced data rate of 2 Mbit mode for faster data transmission and LE-Coded mode for higher range.

  Pre-configured Bluetooth® LE profiles: Besides the profile for generic data transmission "WE SPP-like", the Stephano-I provides the HID (human interface device) profile.

- WiFi features:

  Radio standards and modes: The Stephano-I is equipped with IEEE 802.11b/g/n protocol. It can act as station as well as soft access point.

Security: Provides WPAPSK, WPA2PSK and WPA/WPA2PSK encryption method when configured as soft access point.

Full TCP/IP stack on board: A complete TCP/IP stack is included which provides TCP, SSL connections and UDP transmission. Up to 5 connections possible to TCP/SSL servers.

Advanced protocols: The Stephano-I can act as MQTT as well as HTTP client for easy connectivity and data transmission.

Provisioning: The credentials of the local WiFi network can be entered via web page or UART command.

FOTA: The Stephano-I provides the opportunity to update the device firmware via WiFi interface.

5.2 Bluetooth® LE: WE SPP-like profile

The "WE SPP-like" profile is a custom Bluetooth® LE profile used in the Würth Elektronik eiSos Bluetooth® LE module series Proteus, as well as in Stephano-I, when acting as peripheral (server).
The profile consists of a primary service containing two characteristics:

Service	Full UUID	Short explanation
Primary service	6E400001-C352-11E5-953D-0002A5D5C51B	
`RX_CHARACTERISTIC`	6E400002-C352-11E5-953D-0002A5D5C51B	Used to send data from the central to the peripheral
`TX_CHARACTERISTIC`	6E400003-C352-11E5-953D-0002A5D5C51B	Used to send data from the peripheral to the central

Table 13: WE SPP-like UUIDs

- The first characteristic of the Stephano-I primary service is `RX_CHARACTERISTIC`:
  - The data is sent from central/client to peripheral/server using a write command.
  - Server:
    - Has to allow a write command as well as a write without response command.
  - Client:
    - Use write command to send data to the server.
- The second characteristic of the Stephano-I primary service is `TX_CHARACTERISTIC`:
  - The data is sent from peripheral/server to central/client using a notification.
  - Server:
    - Has to allow/enable notifications. Notify client/central when sending data.
  - Client:

- Has to enable notifications. To do this the central must write the notification enable bit in the CCCD of this characteristic.

When communicating with a radio module from Würth Elektronik eiSos Proteus series (Proteus-I,-II,-III,-III-SPI,-e as well as Setebos-I) via Bluetooth® LE, a header byte 0x01 must be prepended to the payload. Otherwise the Proteus module will reject the data message.

5.3 Frequently asked questions (FAQ)

Is it possible to change the web page shown when entering provisioning or update mode?
Yes, it is. The Stephano-I file system contains an "index.html" file that defines the function and appearance of the integrated web page. This file can be accessed and replaced with the file system command `AT+FS` [3].

How can I update the integrated certificates used for secure communication?
This can be done via the command `AT+SYSMFG`, as shown in chapter `10.3.1`. Updating these files via radio is not supported.

Is it possible to change the integrated default Bluetooth® LE profile?
No, the profile described in chapter `5.2` can not be changed at run time. In case a special Bluetooth® LE profile is needed, address your BDM or send an inquiry to WCS@we-online.com for further information on custom firmware creation.

Is the Stephano-I compatible to other Würth Elektronik eiSos Bluetooth® LE modules like Proteus?
Yes, the same Bluetooth® LE profile is used in Proteus modules as well as in Stephano-I. The only difference is that Proteus modules use a header byte 0x01 for data transmission. This must be added when sending to the Proteus modules and must be removed when receiving data from a Proteus device. Refer to chapter `5.2` for more information as well as to chapter `10.1` that demonstrate how to setup a communication between Stephano-I and Proteus devices.

Is there a mobile application that I can use to connect to the Stephano-I via Bluetooth® LE?

Yes, the Proteus Connect App [4, 5, 6] also supports Stephano-I.

Figure 7: QR codes for application download

6 Host connection

6.1 Serial interface: UART

The configuration in factory state of the UART is 115200 baud with data format of 8 data bits, no parity, 1 stop bit ("8n1") and flow control disabled. The configuration such as baud rate of the UART can be updated by means of the command `AT+UART_DEF` [3].

7 The command interface

The Stephano-I provides a simple AT-command interface for configuration and control of the WiFi and Bluetooth® LE functions. For command interface documentation, refer to the Espressif command documentation [3].

Note the Windows PC tool WE Smart Commander (see chapter `WE Smart Commander`), which implements all commands for rapid prototyping.

7.1 Wireless connectivity SDK

Besides the WE Smart Commander PC tool, there is also the so called "Wireless connectivity SDK" [7], which is a implementation of all AT-commands into C code. This implementation can be used to quickly integrate the UART connectivity to the connected host MCU:

```
...
/**
* @brief Bluetooth LE init type
*/
typedef enum ATBluetoothLE_InitType_t
{
    ATBluetoothLE_InitType_None = 0,
    ATBluetoothLE_InitType_Client = 1,
    ATBluetoothLE_InitType_Server = 2,
} ATBluetoothLE_InitType_t;

extern bool ATBluetoothLE_Init(ATBluetoothLE_InitType_t type);
extern bool ATBluetoothLE_SetDeviceID(ATBluetoothLE_Address_t type,
    ATBluetoothLE_DeviceID_t ID);
extern bool ATBluetoothLE_GetDeviceID(ATBluetoothLE_DeviceID_t *ID);
extern bool ATBluetoothLE_SetDeviceName(ATBluetoothLE_DeviceName_t dev_name);
extern bool ATBluetoothLE_GetDeviceName(ATBluetoothLE_DeviceName_t *dev_name);
...
```

Code 1: Stephano-I/ATCommands/ATBluetoothLE.h

8 Radio power settings

The radio output power of the Stephano-I can be adjusted by the `AT+RFPOWER` command. Depending on the country of operation, the power index can be modified accordingly.

Country	Maximum Bluetooth® LE power index	Maximum WiFi power index
Factory default	12 (9 dBm)	80 (20 dBm)
TELEC/Japan	12 (9 dBm)	74 (18.5 dBm)[1]
RED/EU	13 (12 dBm)	80 (20 dBm)
FCC/US	13 (12 dBm)	80 (20 dBm)
IC/Canada	13 (12 dBm)	80 (20 dBm)

Table 14: Maximum allowed power setting

Note that the power index only defines the conducted output power of the radio chip. The actual output power radiated by the module's integrated antenna is lower due to the antenna loss. Refer to chapter `Electrical specifications` for more details about the radiated output power.

8.1 Supported power indices

[1] For country code "Japan", the power index is internally limited to 74 (18.5 dBm).

Power index	Conducted power value [dBm]
0	-27
1	-24
2	-21
3	-18
4	-15
5	-12
6	-9
7	-6
8	-3
9	0
10	3
11	6
12	9
13	12

Table 15: Bluetooth® LE power table

Power index	Conducted power value [dBm]
40-80	Index × 0.25
40	10
⋮	⋮
80	20

Table 16: WiFi power table

9 Timing parameters

9.1 Throughput - WiFi

9.1.1 Test procedure

The test procedure is as follows:

1. Set the WiFi mode to station using the command `AT+CWMODE`.
2. Connect to the router using the command `AT+CWJAP`.
3. Use a network tool on the PC to create a TCP server.
4. Connect the module to the TCP server as a client over TCP using the command `AT+CIPSTART`.
5. Iterate over:
   a) Send data from the module to the PC by making use of the command `AT+CIPSEND`. If the data length exceeds 8192 bytes, use the `AT+CIPSENDL` command instead.
   b) Wait for the transmission success message (`OK`) which is returned on the UART as result of the previous transmission request.
6. Follow the same procedure for UDP throughput test.

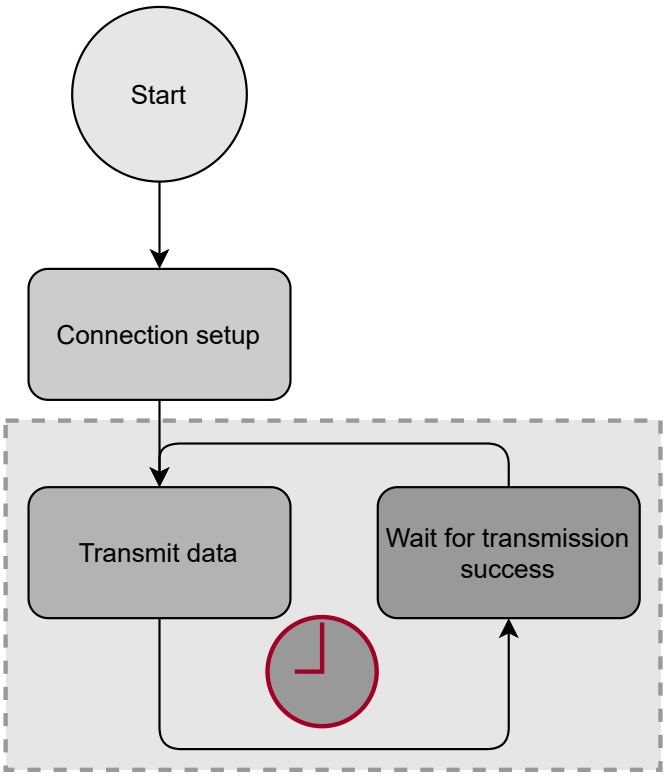


Figure 8: Flow diagram throughput measurement

9.1.2 Test setup and test results

The Stephano-I module is connected via UART1 to an STM32F4 MCU, which triggers the repeated data transmission.

Device	Baud rate [Baud]	Packet size [Bytes]	Throughput [kBytes/s]
Stephano-I TCP Client	3000000	8192	168.213
Stephano-I TCP Client	3000000	16384	226.611
Stephano-I UDP Client	3000000	8192	168.559
Stephano-I UDP Client	3000000	16384	227.239

Table 17: Test results via STM32

9.2 Throughput - Bluetooth® LE

9.2.1 Test procedure

The test procedure is as follows:

1. Turn WiFi off using the command `AT+CWMODE`.
2. Setup a Bluetooth® LE connection between the two Bluetooth® LE enabled devices. We call the transmitting device "Device A" and the receiving device "Device B".
3. Set the MTU Φ_{ST} of the connection to 512 Bytes using the command `AT+BLECFGMTU`.
4. Switch the PHY to 2 Mbit using the `AT+BLESETPHY` command.
5. Iterate over:
   a) Transmit a data packet of maximum size Φ_{ST} Bytes using a `BLEGATTWRT` (central transmission) or `BLEGATTSNTFY` (peripheral transmission) command.
   b) Wait for the transmission success message (`OK`), which is returned on the UART as result of the previous transmission request.

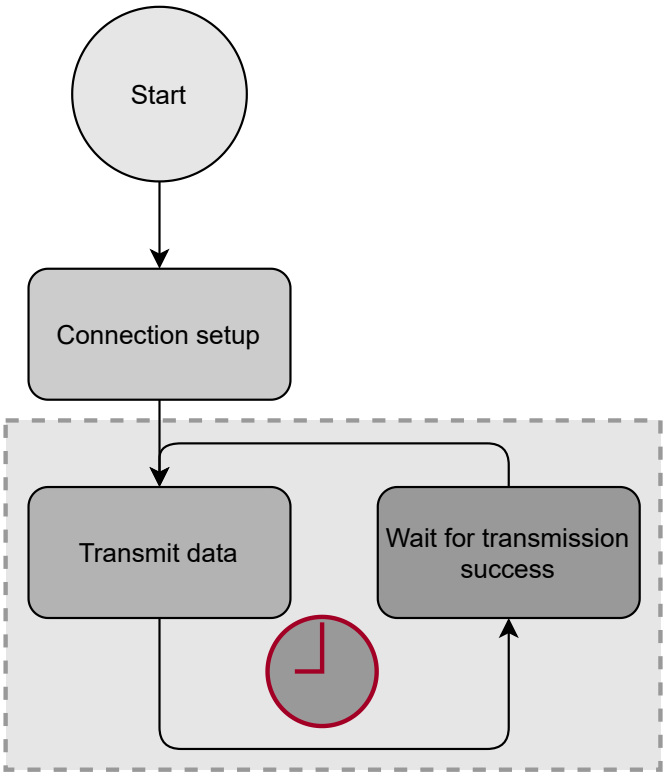


Figure 9: Flow diagram throughput measurement

9.2.2 Test setup and test results

The Stephano-I module is connected via UART1 to an STM32F4 MCU, which triggers the repeated data transmission.

Device A	Device B	Baud rate [Baud]	Connection interval [ms]	Throughput [kBytes/s]
Stephano-I Central	Stephano-I Peripheral	3000000	7.5	40.2

Table 18: Test results via STM32

10 Use cases and examples

The Espressif documentation [1] contains numerous examples for WiFi and Bluetooth® LE connectivity as well as for low power operation. Most of these examples are valid for the Stephano-I too. Exceptions are the examples using Bluetooth® LE profiles, as the Stephano-I implements special profiles invented by Würth Elektronik eiSos.
Examples for special applications, such as the Würth Elektronik eiSos Bluetooth® LE profile "WE SPP-like", can be found below.

Note that when using Bluetooth® LE and WiFi interface simultaneously, the radio performance of each radio standard will be slowed down due to the shared transmission medium.

10.1 Bluetooth® LE examples

10.1.1 Central: connect to Proteus radio module using WE SPP-like profile

In this chapter, the goal is to configure the Stephano-I as Bluetooth® LE central. Then connect to a Proteus radio module acting as peripheral for bidirectional data transmission. Proteus-e [8], Proteus-I [9], Proteus-II [10], Proteus-III [11] and Proteus-III-SPI [12] support this function.
To do this, the services, characteristics and the corresponding UUIDs of the "WE SPP-like" profile must be known. Refer to chapter 5.2 for further information.
In this example, the peripheral is the Proteus device and the central, the Stephano-I.

Note that payload data which is written to the `TX_CHARACTERISTIC` or `RX_CHARACTERISTIC` must be prefixed by the WE SPP-like header 0x01. Otherwise, the payload data will be rejected by the Proteus.
In the following example, only the header byte is written in HEX notation. All other data is ASCII notation.
Due to simplicity, the \r\n which is attached to each command, will be neglected.

1. First of all reset the device by applying a high-low-high sequence to the */RESET* pin. This can be done on the Stephano-I evaluation board by pressing the reset button. The module will reply with a start-up message "ready":

Info	Message
⇐ Module is ready for operation	ready

2. Then enable the Bluetooth® LE central function of the Stephano-I:

Info	Message
⇒ Enable the central function	AT+BLEINIT=1
⇐ Module is ready for operation	OK

3. The next step is to scan the radio to find available Proteus radio modules:

Info	Message
⇒ Scan for 2 s to find available devices	AT+BLESCAN=1,2
⇐ Found Bluetooth® LE device with MAC "00:18:da:00:00:05" and UUID 1bc5d5a502003d95e51152c30100406e and device name "Prot3"	OK +BLESCAN:"00:18:da:00:00:05", -50, 020106 020a08 11071bc5d5a502003d95e51152c30100406e 060950726f7433„0

4. Now setup the physical connection:

Info	Message
⇒ Connect to BLE device with MAC 00:18:da:00:00:05 on connection index 0	AT+BLECONN=0,"00:18:da:00:00:05"
⇐ Connection has been setup with MTU of 247 bytes	+BLECFGMTU:0,247 +BLECONN:0,"00:18:da:00:00:05" OK

5. The next step is to discover the services of the Proteus device to see what services it provides:

Info	Message
⇒ Discover services	AT+BLEGATTCPRIMSRV=0
⇐ Found service "Generic Access" and "Generic Attribute"	+BLEGATTCPRIMSRV:0,1,0x1800,1 +BLEGATTCPRIMSRV:0,2,0x1801,1
⇐ Found WE SPP-like primaary service with service index 3	+BLEGATTCPRIMSRV:0,3, 0x6E400001C35211E5953D0002A5D5C51B,1 OK

6. Now discover the characteristic of the WE SPP-like primary services to see what characteristics it provides:

Info	Message
⇒ Discover characteristics of service index 3	AT+BLEGATTCCHAR=0,3

⇐ Found WE SPP-like RX_CHARACTERISTIC characteristic with characteristics index 1	+BLEGATTCCHAR:"char",0,3,1, 0x6E400002C35211E5953D0002 A5D5C51B,0x0c
⇐ Found WE SPP-like TX_CHARACTERISTIC characteristic with characteristics index 2	+BLEGATTCCHAR:"char",0,3,2, 0x6E400003C35211E5953D0002 A5D5C51B,0x10
⇐ Found descriptor with descriptor index 1 for characteristic index 2	+BLEGATTCCHAR:"desc",0,3,2,1,0x2902 OK

7. To be able to receive data from the Proteus device, the notification of the TX_CHARACTERISTIC must be enabled:

Info	Message
⇒ Enable notification by writing 0x0001 (2 bytes) to the descriptor of TX_CHARACTERISTIC (char. index 2)	AT+BLEGATTCWR=0,3,2,1,2
⇐ Stephano-I is ready to receive data via UART	>
⇒Now send the data	0x01 0x00 (HEX, no ASCII)
⇐	OK

8. On the Proteus device, send "Hello Stephano-I" to receive it on the Stephano-I side. See CMD_DATA_REQ commands in Proteus user manual [8, 9, 10, 11, 12]:

Info	Message
⇐ Received a notification on the TX_CHARACTERISTIC with payload "0x01 Hello Stephano-I"	+NOTIFY:0,3,2,17,0x01 Hello Stephano-I

9. Then transmit "Hello Proteus" to the Proteus device by writing the data to the RX_CHARACTERISTIC (char. index 1). Here the header byte 0x01 must be prefixed:

Info	Message
⇒ Write to the RX_CHARACTERISTIC	AT+BLEGATTCWR=0,3,1„14
⇐ Stephano-I is ready to receive data via UART	>
⇒ Transmit "Hello Proteus" with a prefixed 0x01 (WE SPP Header)	0x01 Hello Proteus
⇐	OK

10. (Optional) Use the passthrough mode. The passthrough mode allows to bind certain characteristics to the UART interface. When the passthrough mode has been enabled,

data sent via UART to the Stephano-I is forwarded to the bound outgoing characteristic. Furthermore, data sent via Bluetooth® LE to the bound incoming characteristics is forwarded to the UART. Thus, the passthrough mode acts like a transparent bridge between UART and Bluetooth® LE interface.

Data sent in passthrough mode does not need to be attached by a "\r\n".

a) Configure and start the passthrough mode. Configuration is done by binding the `TX_CHARACTERISTIC` (srv. index 3, char. index 1) and `RX_CHARACTERISTIC` (srv. index 3, char. index 2) with the UART interface:

Info	Message
⇒ Configure the passthrough mode	AT+BLESPPCFG=1,3,1,3,2,0
⇐	OK
⇒ Start the passthrough mode	AT+BLESPP
⇐	OK >

b) Now transparent data can be sent to the Stephano-I for Bluetooth® LE transmission. Here we choose "Hey Proteus":

Info	Message
⇒ Transmit "Hey Proteus" with a prefixed 0x01 (WE SPP Header)	0x01 Hey Proteus

c) Data is received on the Proteus. It replies with "Hey Stephano-I":

Info	Message
⇐ "Hey Stephano-I" with a prefixed 0x01 (WE SPP Header) is received by the Stephano-I	0x01 Hey Stephano-I

d) Stop passthrough mode:

Info	Message
⇒ Stop the passthrough mode by sending "+++"	+++

The "+++" must be sent without "\r\n". The "+++" is not confirmed by an "OK".

11. The data has been received on the Proteus device. Now the connection can be closed, if no further data is supposed to be transmitted:

Info	Message
⇒ Disconnect on connection index 0	AT+BLEDISCONN=0
⇐	OK

10.1.2 Peripheral: receive connection from Proteus radio module using WE SPP-like profile

In this chapter, the goal is to configure the Stephano-I as Bluetooth® LE peripheral and use the integrated WE SPP-like Bluetooth® LE profile, which is also part of the Proteus Bluetooth® LE module series. Then connect from a Proteus radio module acting as central to the Stephano-I for bidirectional data transmission. Proteus-I [9], Proteus-II [10], Proteus-III [11] and Proteus-III-SPI [12] support this function.
For this, the services, characteristics and the corresponding UUIDs of the "WE SPP-like" profile must be known. Refer to chapter 5.2 for further information.
In this example, the central is the Proteus device and the peripheral is the Stephano-I.

Note that payload data which is written to the `TX_CHARACTERISTIC` or `RX_CHARACTERISTIC` must be prefixed by the WE SPP-like header 0x01. Otherwise, the payload data will be rejected by the Proteus.
In the following example, only the header byte is written in HEX notation. All other data is ASCII notation. Due to simplicity, the \r\n which is attached to each command, will be neglected.

1. First of all reset the device by applying a high-low-high sequence to the */RESET* pin. This can be done on the Stephano-I evaluation board by pressing the reset button. The module will reply with a start-up message "ready":

Info	Message
⇐ Module is ready for operation	ready

2. Then enable the Bluetooth® LE peripheral function of the Stephano-I:

Info	Message
⇒ Enable the peripheral function	AT+BLEINIT=2
⇐	OK

3. Start service and check what is available on the Stephano-I:

Info	Message
⇒ Create the local services	AT+BLEGATTSSRVCRE
⇐	OK
⇒ Start the local services	AT+BLEGATTSSRVSTART
⇐	OK
⇒ Request which services are available	AT+BLEGATTSSRV?
⇐ WE SPP-like primary service is available on service index 1	+BLEGATTSSRV:1,1, 0x6E400001C35211E5953D0002A5D5C51B,1 OK

⇒ Request which characteristics are available	AT+BLEGATTSCHAR?
⇐ WE SPP-like RX_CHARACTERISTIC is available on characteristic index 1	+BLEGATTSCHAR:"char",1,1, 0x6E400002C35211E5953D0002A5D5C51B, 0x0c
⇐ WE SPP-like TX_CHARACTERISTIC is available on characteristic index 2	+BLEGATTSCHAR:"char",1,2, 0x6E400003C35211E5953D0002A5D5C51B, 0x10
⇐ Descriptor with index 1 is available for characteristic index 2	+BLEGATTSCHAR:"desc",1,2,1,0x2902 OK

4. The next step is to set the right advertising data such that the Proteus device is able to detect the Stephano-I. Therefore, at least the advertising flags and the UUID of the WE SPP-like primary service 1BC5D5A502003D95E51152C30100406E must be placed into the advertising packet:

Info	Message
⇒ Set the advertising data	AT+BLEADVDATA="020106 11071BC5D5A502003D95E51152C30100406E"
⇐	OK
⇒ Start advertising	AT+BLEADVSTART
⇐	OK

5. On the Proteus side scan for the advertising Stephano-I and connect to this. See CMD_SCANSTART_REQ and CMD_CONNECT_REQ commands in Proteus user manual [9, 10, 12, 11]:

Info	Message
⇐ Connection has been established on connection index 0 with MTU 247	+BLECONN:0,"00:18:da:00:00:05" +BLECFGMTU:0,247
⇐ 0x0100 has been written to the descriptor of the TX_CHARACTERISTIC to enable notifications	+WRITE:0,1,2,1,2, 0x0100

6. On the Proteus device send "Hello Stephano-I" to receive it on the Stephano-I side. See CMD_DATA_REQ command in Proteus user manual [9, 10, 11, 12]:

Info	Message
⇐ Received write on the RX_CHARACTERISTIC with payload 0x01 Hello Stephano-I	+WRITE:0,1,1„17,0x01 Hello Stephano-I

7. Then transmit "Hello Proteus" to the Proteus device by writing the data to the RX_CHARACTERISTIC (char. index 2). Here the header byte 0x01 must be prefixed:

Info	Message
⇒ Notify to the RX_CHARACTERISTIC	AT+BLEGATTSNTFY=0,1,2,14
⇐ Stephano-I is ready to receive data via UART	>
⇒ Transmit "Hello Proteus" with a prefixed 0x01 (WE SPP Header)	0x01 Hello Proteus
⇐	OK

8. (Optional) Use the passthrough mode. The passthrough mode allows to bind certain characteristics to the UART interface. When the passthrough mode has been enabled, data sent via UART to the Stephano-I is forwarded to the bound outgoing characteristic. Furthermore, data sent via Bluetooth® LE to the bound incoming characteristics is forwarded to the UART. Thus, the passthrough mode acts like a transparent bridge between UART and Bluetooth® LE interface.

Data sent in passthrough mode does not need to be attached by a "\r\n".

a) Configure and start the passthrough mode. Configuration is done by binding the TX_CHARACTERISTIC (srv. index 1, char. index 1) and RX_CHARACTERISTIC (srv. index 1, char. index 2) with the UART interface:

Info	Message
⇒ Configure the passthrough mode	AT+BLESPPCFG=1,1,2,1,1,0
⇐	OK
⇒ Start the passthrough mode	AT+BLESPP
⇐	OK >

b) Now transparent data can be sent to the Stephano-I for Bluetooth® LE transmission. Here we choose "Hey Proteus":

Info	Message
⇒ Transmit "Hey Proteus" with a prefixed 0x01 (WE SPP Header)	0x01 Hey Proteus

c) Data is received on the Proteus. It replies with "Hey Stephano-I":

Info	Message
⇐ "Hey Stephano-I" with a prefixed 0x01 (WE SPP Header) is received by the Stephano-I	0x01 Hey Stephano-I

d) Stop passthrough mode:

Info	Message
⇒ Stop the passthrough mode by sending "+++"	+++

The "+++" must be sent without "\r\n". The "+++" is not confirmed by an "OK".

9. The data has been received on the Proteus device. Now the connection can be closed, if no further data is supposed to be transmitted:

Info	Message
⇒ Disconnect on connection index 0	AT+BLEDISCONN=0
⇐	OK

10.1.3 Peripheral: receive connection from smart phone using WE SPP-like profile

In this chapter, the goal is to configure the Stephano-I as Bluetooth® LE peripheral and use the integrated WE SPP-like Bluetooth® LE profile. Then connect from a smartphone acting as central to the Stephano-I for bidirectional data transmission. On the smartphone, the **nRF Connect** App [13, 14] is used, which provides all Bluetooth® LE related functions.
For this, the services, characteristics and the corresponding UUIDs of the "WE SPPlike" profile must be known. Refer to chapter 5.2 for further information.
In this example, the central is the smartphone and the peripheral is the Stephano-I.

In the following example, only the header byte is written in HEX notation. All other data is in ASCII notation.
Due to simplicity, the \r\n which is attached to each command, will be neglected.

1. First of all reset the device by applying a high-low-high sequence to the */RESET* pin. This can be done on the Stephano-I evaluation board by pressing the reset button. The module will reply with a start-up message "ready":

Info	Message
⇐ Module is ready for operation	ready

2. Then enable the Bluetooth® LE peripheral function of the Stephano-I:

Info	Message
⇒ Enable the peripheral function	AT+BLEINIT=2
⇐	OK

3. Start the service and check what is available on the Stephano-I:

Info	Message
⇒ Create the local services	AT+BLEGATTSSRVCRE
⇐	OK
⇒ Start the local services	AT+BLEGATTSSRVSTART
⇐	OK
⇒ Request which services are available	AT+BLEGATTSSRV?
⇐ WE SPP-like primary service is available on service index 1	+BLEGATTSSRV:1,1, 0x6E400001C35211E5953D0002A5D5C51B,1 OK
⇒ Request which characteristics are available	AT+BLEGATTSCHAR?

⇐ WE SPP-like RX_CHARACTERISTIC is available on characteristic index 1	+BLEGATTSCHAR:"char",1,1, 0x6E400002C35211E5953D0002A5D5C51B, 0x0c
⇐ WE SPP-like TX_CHARACTERISTIC is available on characteristic index 2	+BLEGATTSCHAR:"char",1,2, 0x6E400003C35211E5953D0002A5D5C51B, 0x10
⇐ Descriptor with index 1 is available for characteristic index 2	+BLEGATTSCHAR:"desc",1,2,1,0x2902 OK

4. The next step is to set the advertising data such that the Stephano-I can be detected by the smartphone. Therefore, at least the advertising flags and the name (here we choose "Stephano-I") should be placed into the advertising packet:

Info	Message
⇒ Set the advertising data	AT+BLEADVDATA="020106 0B09537465706861E6F2D49"
⇐	OK
⇒ Start advertising	AT+BLEADVSTART
⇐	OK

5. On the smartphone side, scan for the advertising Stephano-I and connect to this. Due to that, the Stephano-I outputs the following:

Info	Message
⇐ Connection has been established on connection index 0 with connection interval of 45 ms	+BLECONN:0,"00:18:da:00:00:05" +BLECONNPARAM:0,0,0,36,0,500

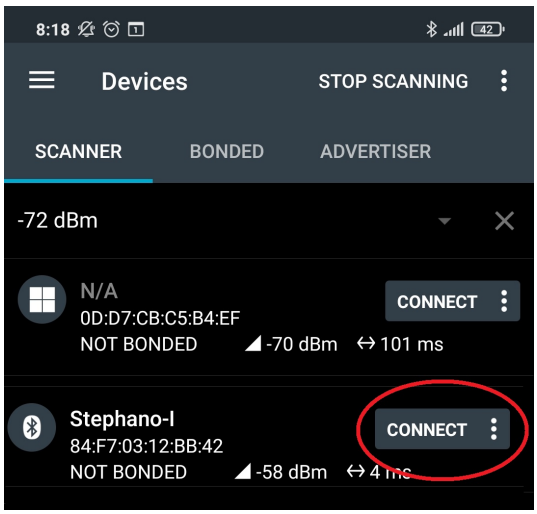


Figure 10: Screenshot of the nRF Connect App

6. On the smartphone side, enable the notifications of the `TX_CHARACTERISTIC`. Due to that, the Stephano-I outputs the following:

Info	Message
⇐ 0x0100 has been written to the descriptor of the `TX_CHARACTERISTIC` to enable notifications	+WRITE:0,1,2,1,2, 0x0100

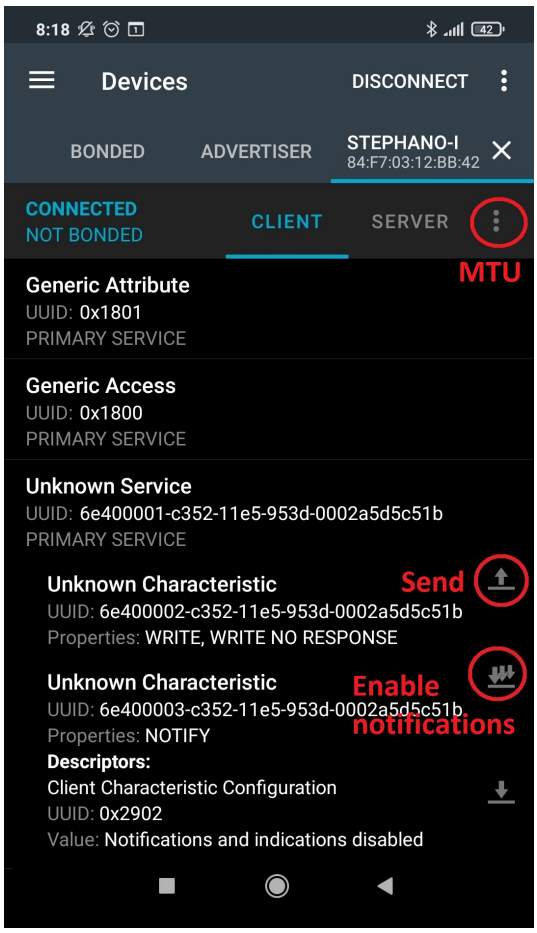


Figure 11: Screenshot of the nRF Connect App

7. On the smart phone side, set the MTU to 255. Due to that the Stephano-I outputs the following:

Info	Message
⇐ MTU has been set to 255	+BLECFGMTU:0,255

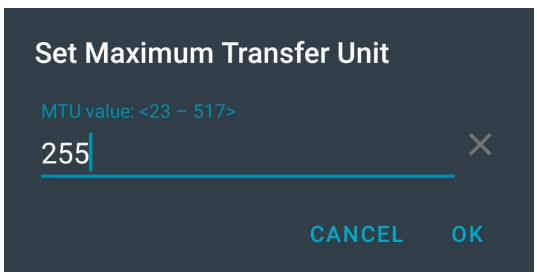


Figure 12: Screenshot of the nRF Connect App

8. On the smartphone side, send "Hello Stephano-I" to receive it on the Stephano-I side.

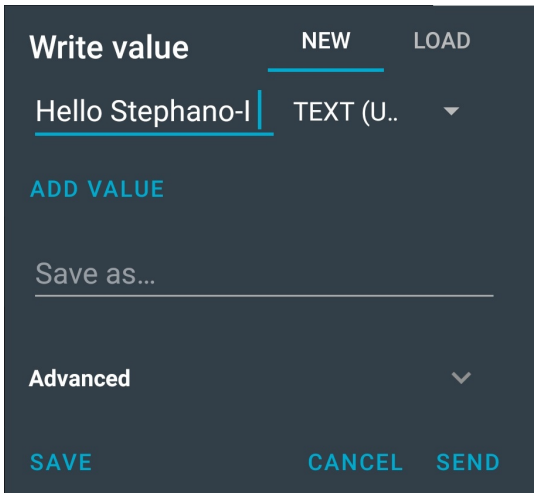


Figure 13: Screenshot of the nRF Connect App

Due to that, the Stephano-I outputs the following:

Info	Message
⇐ Received write on the RX_CHARACTERISTIC with payload "Hello Stephano-I"	+WRITE:0,1,1„16,Hello Stephano-I

9. Then transmit "Hello mobile" to the smartphone by writing the data to the RX_CHARACTERISTIC (char. index 2):

Info	Message
⇒ Notify to the RX_CHARACTERISTIC	AT+BLEGATTSNTFY=0,1,2,12
⇐ Stephano-I is ready to receive data via UART	>
⇒ Transmit "Hello mobile"	Hello mobile
⇐	OK

10. The data has been received on the smartphone device:

11. (Optional) Use the passthrough mode. The passthrough mode allows to bind certain characteristics to the UART interface. When the passthrough mode has been enabled, data sent via UART to the Stephano-I is forwarded to the bound outgoing characteristic. Furthermore, data sent via Bluetooth® LE to the bound incoming characteristics is forwarded to the UART. Thus, the passthrough mode acts like a transparent bridge between UART and Bluetooth® LE interface.

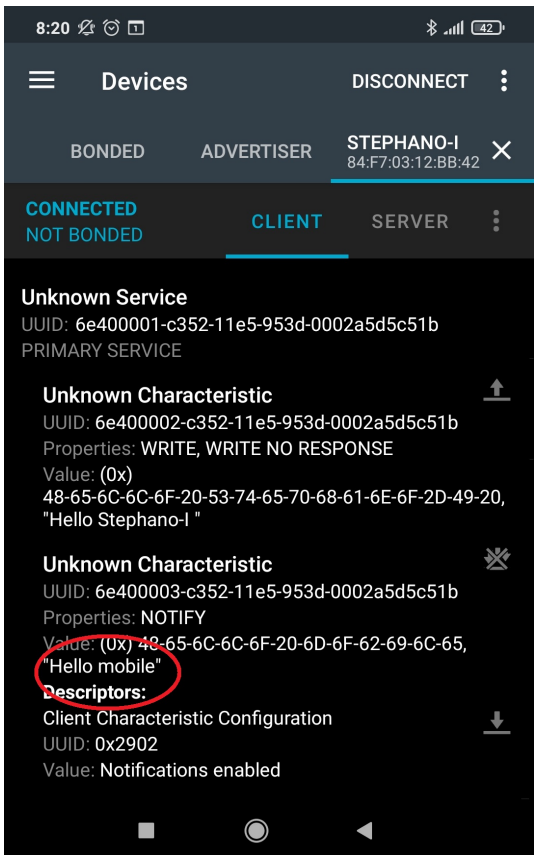


Figure 14: Screenshot of the nRF Connect App

Data sent in passthrough mode does not need to be attached by a "\r\n".

a) Configure and start the passthrough mode. Configuration is done by binding the `TX_CHARACTERISTIC` (srv. index 1, char. index 1) and `RX_CHARACTERISTIC` (srv. index 1, char. index 2) with the UART interface:

Info	Message
⇒ Configure the passthrough mode	AT+BLESPPCFG=1,1,2,1,1,0
⇐	OK
⇒ Start the passthrough mode	AT+BLESPP
⇐	OK >

b) Now transparent data can be sent to the Stephano-I for Bluetooth® LE transmission. Here we choose "Hey mobile":

Info	Message
⇒ Transmit "Hey mobile"	Hey mobile

c) Data is received on the smartphone. Smart phone replies with "Hey Stephano-I":

Info	Message
⇐ "Hey Stephano-I" is received by the Stephano-I	Hey Stephano-I

10.1.4 Central and peripheral: establish connection between two Stephano-I using WE SPP-like profile

In this chapter, the goal is to configure one Stephano-I as Bluetooth® LE peripheral and a second Stephano-I as central device. Then setup a connection between both for bidirectional data transmission.
For this, the services, characteristics and the corresponding UUIDs of the "WE SPPlike" profile must be known. Refer to chapter 5.2 for further information.

For simplicity reasons, in this chapter the Stephano-I acting as central is called CENTRAL and the Stephano-I acting as peripheral is called PERIPHERAL. The below commands are in ASCII notation. Due to simplicity, the \r\n which is attached to each command, will be neglected.

Setup the PERIPHERAL

1. First of all reset the PERIPHERAL by applying a high-low-high sequence to the */RESET* pin. This can be done on the Stephano-I evaluation board by pressing the reset button. The module will reply with a start-up message "ready":

Info - PERIPHERAL	Message
⇐ Module is ready for operation	ready

2. Then enable the Bluetooth® LE peripheral function of the PERIPHERAL:

Info - PERIPHERAL	Message
⇒ Enable the peripheral function	AT+BLEINIT=2
⇐	OK

3. Start the service and check what is available on the PERIPHERAL:

Info - PERIPHERAL	Message
⇒ Create the local services	AT+BLEGATTSSRVCRE
⇐	OK
⇒ Start the local services	AT+BLEGATTSSRVSTART
⇐	OK
⇒ Request which services are available	AT+BLEGATTSSRV?
⇐ WE SPP-like primary service is available on service index 1	+BLEGATTSSRV:1,1, 0x6E400001C35211E5953D0002A5D5C51B,1 OK
⇒ Request which characteristic are available	AT+BLEGATTSCHAR?

⇐ WE SPP-like RX_CHARACTERISTIC is available on characteristic index 1	+BLEGATTSCHAR:"char",1,1, 0x6E400002C35211E5953D0002A5D5C51B, 0x0c
⇐ WE SPP-like TX_CHARACTERISTIC is available on characteristic index 2	+BLEGATTSCHAR:"char",1,2, 0x6E400003C35211E5953D0002A5D5C51B, 0x10
⇐ Descriptor with index 1 is available for characteristic index 2	+BLEGATTSCHAR:"desc",1,2,1,0x2902 OK

4. The next step is to set the advertising data such that the Stephano-I can be detected on the radio by the CENTRAL. Therefore, at least the advertising flags and the name (here we choose "Stephano-I") should be placed into the advertising packet:

Info - PERIPHERAL	Message
⇒ Set the advertising data	AT+BLEADVDATA="020106 0B09537465706861E6F2D49"
⇐	OK
⇒ Start advertising	AT+BLEADVSTART
⇐	OK

5. (Optional) Configure the input output capabilities to enable radio security (pairing/bonding):

Info - PERIPHERAL	Message
⇒ Set security level to SC_MITM_BOND, the IO capabilities to "display only" and keylength of 16 bytes	AT+BLESECPARAM=13,0,16,3,3,0
⇐	OK

Setup the CENTRAL

1. Reset the CENTRAL by applying a high-low-high sequence to the */RESET* pin. This can be done on the Stephano-I evaluation board by pressing the reset button. The module will reply with a start-up message "ready":

Info - CENTRAL	Message
⇐ Module is ready for operation	ready

2. (Optional) Configure the input output capabilities to enable radio security (pairing/bonding):

Info - CENTRAL	Message
⇒ Set security level to SC_MITM_BOND, the IO capabilities to "keyboard only" and keylength of 16 bytes	AT+BLESECPARAM=13,2,16,3,3,0
⇐	OK

3. Then enable the Bluetooth® LE central function of the CENTRAL:

Info - CENTRAL	Message
⇒ Enable the central function	AT+BLEINIT=1
⇐ Module is ready for operation	OK

4. The next step is to scan the radio to find available radio modules:

Info - CENTRAL	Message
⇒ Scan for 2 s to find available devices	AT+BLESCAN=1,2
⇐ Found Bluetooth® LE device with MAC "00:18:da:00:00:05" and device name "Stephano-I"	OK +BLESCAN:"00:18:da:00:00:05", -50, 020106 0B095374657068616E6F2D49„0

Connect the CENTRAL to the PERIPHERAL

1. Now setup the physical connection:

Info - CENTRAL	Message
⇒ Connect to Bluetooth® LE device with MAC 00:18:da:00:00:05 on connection index 0	AT+BLECONN=0,"00:18:da:00:00:05"
⇐ Connection has been setup	+BLECONN:0,"00:18:da:00:00:05" OK

Info - PERIPHERAL	Message
⇐ Connection has been established on connection index 0	+BLECONN:0,"00:18:da:00:00:06"

2. (Only if security has been enabled before) Now start the pairing and bonding:

Info - CENTRAL	Message
⇒ Start the pairing/bonding	AT+BLEENC=0,1
⇐	OK

Info - PERIPHERAL	Message
⇐ Pairing has been requested	+BLESECREQ:0"
⇒ Accept request	AT+BLEENCRSP=0,1
⇐ Shows pairing key	OK +BLEENCNTFYKEY=0,172512

Info - CENTRAL	Message
⇐ Request to enter the key	+BLESECKEYREQ:0
⇒ Enter the key	AT+BLEKEYREPLY=0,172512
⇐Pairing has been completed	OK +BLESECKEYTYPE:0,32 +BLEAUTHCMPL:0,0

Info - PERIPHERAL	Message
⇐Pairing has been completed	+BLESECKEYTYPE:0,32 +BLEAUTHCMPL:0,0

3. Now the CENTRAL must discover the services of the PERIPHERAL:

Info - CENTRAL	Message
⇒ Discover services	AT+BLEGATTCPRIMSRV=0
⇐ Found service "Generic Access" and "Generic Attribute"	+BLEGATTCPRIMSRV:0,1,0x1800,1 +BLEGATTCPRIMSRV:0,2,0x1801,1
⇐ Found WE SPP-like primaary service with service index 3	+BLEGATTCPRIMSRV:0,3, 0x6E400001C35211E5953D0002A5D5C51B,1 OK

4. Now discover the characteristics of the WE SPP-like primary services to see what characteristics it provides:

Info - CENTRAL	Message
⇒ Discover characteristics of service index 3	AT+BLEGATTCCHAR=0,3
⇐ Found WE SPP-like `RX_CHARACTERISTIC` characteristic with characteristics index 1	+BLEGATTCCHAR:"char",0,3,1, 0x6E400002C35211E5953D0002 A5D5C51B,0x0c

⇐ Found WE SPP-like TX_CHARACTERISTIC characteristic with characteristics index 2	+BLEGATTCCHAR:"char",0,3,2, 0x6E400003C35211E5953D0002 A5D5C51B,0x10
⇐ Found descriptor with descriptor index 1 for characteristic index 2	+BLEGATTCCHAR:"desc",0,3,2,1,0x2902 OK

5. To be able to receive data from the PERIPHERAL, the notification of the TX_CHARACTERISTIC must be enabled:

Info - CENTRAL	Message
⇒ Enable notification by writing 0x0001 (2 bytes) to the descriptor of TX_CHARACTERISTIC (char. index 2)	AT+BLEGATTCWR=0,3,2,1,2
⇐ Stephano-I is ready to receive data via UART	>
⇒Now send the data	0x01 0x00 (HEX, no ASCII)
⇐	OK

Info - PERIPHERAL	Message
⇐ 0x0100 has been written to the descriptor of the TX_CHARACTERISTIC to enable notifications	+WRITE:0,1,2,1,2, 0x0100

Transmit data

1. On the CENTRAL side, send "Hello" by writing the data to the RX_CHARACTERISTIC (char. index 1):

Info - CENTRAL	Message
⇒ Write to the RX_CHARACTERISTIC	AT+BLEGATTCWR=0,3,1„5
⇐ Stephano-I is ready to receive data via UART	>
⇒ Transmit "Hello"	Hello
⇐	OK

Due to that the PERIPHERAL outputs the following:

Info - PERIPHERAL	Message
⇐ Received write on the RX_CHARACTERISTIC with payload "Hello"	+WRITE:0,1,1,5,Hello

2. Then transmit "Hello too" from the PERIPHERAL to the CENTRAL by writing the data to the RX_CHARACTERISTIC (char. index 2):

Info - PERIPHERAL	Message
⇒ Notify to the RX_CHARACTERISTIC	AT+BLEGATTSNTFY=0,1,2,9
⇐ Stephano-I is ready to receive data via UART	>
⇒ Transmit "Hello too"	Hello too
⇐	OK

Info - CENTRAL	Message
⇐ Received a notification on the TX_CHARACTERISTIC with payload "Hello too"	+NOTIFY:0,3,2,9,Hello too

(Optional) Use the passthrough mode

Use the passthrough mode. The passthrough mode allows to bind certain characteristics to the UART interface. When the passthrough mode has been enabled, data sent via UART to the Stephano-I is forwarded to the bound outgoing characteristic. Furthermore, data sent via Bluetooth® LE to the bound incoming characteristics is forwarded to the UART. Thus, the passthrough mode acts like a transparent bridge between UART and Bluetooth® LE interface.

Data sent in passthrough mode does not need to be attached by a "\r\n".

1. Configure and start the passthrough mode for the CENTRAL. Configuration is done by binding the TX_CHARACTERISTIC (srv. index 3, char. index 1) and RX_CHARACTERISTIC (srv. index 3, char. index 2) with the UART interface:

Info - CENTRAL	Message
⇒ Configure the passthrough mode	AT+BLESPPCFG=1,3,1,3,2,0
⇐	OK
⇒ Start the passthrough mode	AT+BLESPP
⇐	OK >

2. Configure and start the passthrough mode for the CENTRAL. Configuration is done by binding the `TX_CHARACTERISTIC` (srv. index 1, char. index 1) and `RX_CHARACTERISTIC` (srv. index 1, char. index 2) with the UART interface:

Info - PERIPHERAL	Message
⇒ Configure the passthrough mode	AT+BLESPPCFG=1,1,2,1,1,0
⇐	OK
⇒ Start the passthrough mode	AT+BLESPP
⇐	OK >

3. Now transparent data can be sent to the CENTRAL for Bluetooth® LE transmission. Here we choose "Hey there":

Info - CENTRAL	Message
⇒ Transmit "Hey there"	Hey there

4. Data is received on the PERIPHERAL, and it replies with "Hey!":

Info - PERIPHERAL	Message
⇐ "Hey there" is received by the PERIPHERAL	Hey there
⇒ "Hey!" is transmitted to the CENTRAL	Hey!

Info - CENTRAL	Message
⇐ "Hey!" is received	Hey!

5. Stop passthrough mode on the CENTRAL and PERIPHERAL:

Info - CENTRAL	Message
⇒ Stop the passthrough mode by sending "+++"	+++

Info - PERIPHERAL	Message
⇒ Stop the passthrough mode by sending "+++"	+++

The "+++" must be sent without "\r\n". The "+++" is not confirmed by an "OK".

Close the connection

1. Now the connection can be closed, if no further data is supposed to be transmitted:

Info - CENTRAL	Message
⇒ Disconnect on connection index 0	AT+BLEDISCONN=0
⇐	OK

Info - PERIPHERAL	Message
⇐ Connected has been closed	+BLEDISCONN:0,"00:18:da:00:00:06"

10.2 WiFi examples

10.2.1 Create a TCP socket: establish connection between two Stephano-I as TCP Server and Client

In this chapter, the goal is to configure a TCP server in one Stephano-I and create a connection to the server with another Stephano-I as a client.

For simplicity reasons, in this chapter the Stephano-I acting as server is called SERVER and the Stephano-I acting as client is called CLIENT.
The below commands are in ASCII notation. Due to simplicity, the \r\n which is attached to each command, will be neglected in the below example.

Setup the TCP Server

1. First of all reset the SERVER by applying a high-low-high sequence to the */RESET* pin. This can be done on the Stephano-I evaluation board by pressing the reset button. The module will reply with a start-up message "ready":

Info - SERVER	Message
⇐ Module is ready for operation	ready

2. Configure the SERVER as softAP

Info - SERVER	Message
⇒ Set the WiFi mode to softAP	AT+CWMODE=2
⇐	OK
⇒ Enable multiple connections	AT+CIPMUX=1
⇐	OK
⇒ Set the configuration of the SoftAP	AT+CWSAP="Stephano1_softAP","1234567890",5,3
⇐	OK

3. Setup the TCP Server in the SERVER Module:

Info - SERVER	Message
⇒ Create the TCP Server on port 8089	AT+CIPSERVER=1,8089
⇐	OK

Setup the CLIENT

1. Reset the CLIENT by applying a high-low-high sequence to the */RESET* pin. This can be done on the Stephano-I evaluation board by pressing the reset button. CLIENT will reply

with a start-up message "ready":

Info - CLIENT	Message
⇐ Module is ready for operation	ready

2. Configure the CLIENT as station and connect it to the softAP of the SERVER module:

Info - CLIENT	Message
⇒ Set the WiFi mode to station	AT+CWMODE=1
⇐	OK
⇒ Connect to the softAP	AT+CWJAP="Stephano1_softAP","1234567890"
⇐	WIFI CONNECTED WIFI GOT IP OK

3. The next step is to connect the CLIENT to the SERVER as a client over TCP:

Info - CLIENT	Message
⇒ Establish the TCP Socket by connecting to the SERVER	AT+CIPSTART="TCP","192.168.3.102",8089
⇐	CONNECT OK

Transmit data

1. Send data from the SERVER to the CLIENT:

Info - SERVER	Message
⇒ Send 4 bytes of data	AT+CIPSEND=0,4
⇐ SERVER is ready to send data	>
⇒ Transmit "Hello"	Hello
⇐	Recv 4 bytes SEND OK

Info - CLIENT	Message
⇐	+IPD,4:Hello

2. Send data from the CLIENT to the SERVER:

Info - CLIENT	Message
⇒ Send 4 bytes of data	AT+CIPSEND=4

⇐ CLIENT is ready to send data	>
⇒ Transmit "Hello"	Hello
⇐	Recv 4 bytes SEND OK

Info - SERVER	Message
⇐	+IPD,4:Hello

Close the connection

1. Now the socket can be closed, if no further data is supposed to be transmitted:

Info - CLIENT	Message
⇒ Disconnect from the server	AT+CIPCLOSE
⇐	CLOSED OK

2. TCP Server can be deleted on the SERVER side:

Info - SERVER	Message
⇒ Delete the server	AT+CIPSERVER=0,1
⇐	OK

10.2.2 MQTT example: establish connection from Stephano-I to AWS IoT with MQTT AT commands

In this chapter, the goal is to connect the Stephano-I to AWS IoT.

Gaining and uploading the certificates

You need to obtain the device.pem.crt (device certificate), private.pem.key (private key) and Amazon-root-CA-1.pem (root CA certificate) from AWS as a prerequisite as the first step. They must be saved in the module using AT commands:

- Amazon-root-CA-1.pem as mqtt_ca.cert
- device.pem.crt as mqtt_client.crt
- private.pem.key as mqtt_client.key

Refer to chapter 10.3.1 for further information.

The below commands are in ASCII notation. Due to simplicity, the \r\n which is attached to each command, will be neglected in the below example.

MQTT Configuration

1. Use MQTT AT-commands to connect to AWS IoT:

Info	Message
⇒ Set the WiFi mode to station	AT+CWMODE=1
⇐	OK
⇒ Connect to the access point	AT+CWJAP=<ssid>,<password>
⇐	OK
⇒ Set the SNTP server	AT+CIPSNTPCFG=1,2,"0.de.pool.ntp.org"
⇐	OK
⇒ Set the MQTT user configuration	AT+MQTTUSERCFG=0,5,"stephano1", "stephano1_aws","1234567890",0,0,""
⇐	OK
⇒ Setup connection to AWS IoT	AT+MQTTCONN=0,"<endpoint>",8883,1
⇐	+MQTTCONNECTED:0,5,<endpoint>,"8883","",1 OK
⇒ Subscribe to MQTT topic	AT+MQTTSUB=0,"topic/stephano1",1
⇐	OK
⇒ Publish message to an MQTT topic	AT+MQTTPUB=0,"topic/stephano1","hello aws!",1,0

⇐	+MQTTSUBRECV:0,"topic/stephano1",10,hello aws! OK

Close the MQTT connection

1. Now the MQTT connection can be closed, if no further data is supposed to be transmitted:

Info	Message
⇒ Unsubscribe from the defined topic	AT+MQTTUNSUB=0,"topic/stephano1"
⇐	OK
⇒ Disconnect on connection index 0	AT+MQTTCLEAN=0
⇐	OK

10.2.3 SSL example: establish connection from a test PC as client to Stephano-I as server using mutual authentication

In this chapter, the goal is to configure an SSL server in one Stephano-I and create a connection from a PC as a client. The certificates used in this example are from Espressif. You can flash your own server certificates as explained in chapter 10.3.1.

For simplicity reasons, in this chapter the Stephano-I acting a server is called SERVER and the test computer is mentioned as PC.
The below commands are in ASCII notation. Due to simplicity, the \r\n which is attached to each command, will be neglected in the below example.

Setup the SSL Server

1. First of all reset the SERVER by applying a high-low-high sequence to the */RESET* pin. This can be done on the Stephano-I evaluation board by pressing the reset button. The module will reply with a start-up message "ready":

Info - SERVER	Message
⇐ Module is ready for operation	ready

2. Configure the SERVER as a station:

Info - SERVER	Message
⇒ Set the WiFi mode to station	AT+CWMODE=1
⇐	OK
⇒ Enable multiple connections	AT+CIPMUX=1
⇐	OK
⇒ Connect to the router	AT+CWJAP="<ssid>","<pwd>"
⇐	"WIFI CONNECTED WIFI GOT IP OK"

3. Setup the SSL server in the SERVER module:

Info - SERVER	Message
⇒ Create the SSL server on port 8070	AT+CIPSERVER=1,8070,"SSL",1
⇐	OK

Configure the PC to start a client request

1. Tools like OpenSSL can be used on a PC to create an SSL client request to the server that the SERVER module has created before. The CA, certificate and key files used here are obtained from *Espressive's site* on Github. You can use your own client certificates files if you have already flashed the server certificates using `SYSMFG` command. Add the IP address of the SERVER as assigned by the router in the below command to make an SSL connection request to the SERVER.

```
openssl s_client -CAfile client_ca_00.crt -cert client_cert_00.crt -key
    client_key_00.key -host <ip address> -port 8070
```

Info - SERVER	Message
⇐ SERVER response when a connection is established	0,CONNECT

Transmit data

1. Send data from the SERVER to the CLIENT:

Info - SERVER	Message
⇒ Send 4 bytes of data	AT+CIPSEND=0,4
⇐ SERVER is ready to send data	>
⇒ Transmit "Hello"	Hello
⇐	Recv 4 bytes SEND OK

2. Send 4 bytes of data "Hello" from the PC to the SERVER:

Info - SERVER	Message
⇐	+IPD,4:Hello

Close the connection and delete the server

1. Now the socket can be closed from the PC, if no further data is supposed to be transmitted:

Info - SERVER	Message
⇐	0,CLOSED OK
⇒ Delete the server	AT+CIPSERVER=0,1
⇐	OK

Eventhough we made only one SSL connection in this example, multiple connections are pos-

sible, as we have enabled multiple connections in the SERVER.

10.2.4 WiFi provisioning: configure the WiFi network by remote access

When running the Stephano-I in a new environment for the first time, it must know the credentials such as SSID and password of the local WiFi network first.
To do this via remote access, the so called provisioning feature is used. In this case, the Stephano-I is configured as access point with web server first. Then another device, like a smartphone, connects to it and opens the provided web page in its browser. Then the user can enter the credentials of the local WiFi network. In case the Stephano-I can connect to the local WiFi using the entered data, the provisioning is finished.
In this chapter we will describe this feature.

The below commands are in ASCII notation. Due to simplicity, the \r\n which is attached to each command, will be neglected in the below example.

Setup the access point and web server

1. First of all reset the Stephano-I by applying a high-low-high sequence to the */RESET* pin. This can be done on the Stephano-I evaluation board by pressing the reset button. The module will reply with a start-up message "ready":

Info	Message
⇐ Module is ready for operation	ready

2. Configure the Stephano-I as softAP + station:

Info	Message
⇒ Set the WiFi mode to softAP and station	AT+CWMODE=3
⇐	OK
⇒ Enable multiple connections	AT+CIPMUX=1
⇐	OK
⇒ Set the configuration of the softAP	AT+CWSAP="pos_softap","",11,0,3
⇐	OK

3. Now start the included web server:

Info	Message
⇒ Start the web server on port 80	AT+WEBSERVER=1,80,25
⇐	OK

Use a browser to enter the credentials of the local WiFi network

1. The Stephano-I now acts as an access point. A smartphone or PC can use the configured credentials (SSID = "pos_softap", empty pass word) to connect to it.

Figure 15: Connect to access point

2. Now open a browser in the remote device and enter the IP of the Stephano-I. The default IP is 192.168.4.1, or you can query the current softAP IP address by command `AT+CIPAP?`.

The provisioning has been tested with a Chrome browser. In case of failure, set the developer settings to "http only". Other browsers may or may not support accepting self signed certificates. For further information, refer to the documentation of the browser.

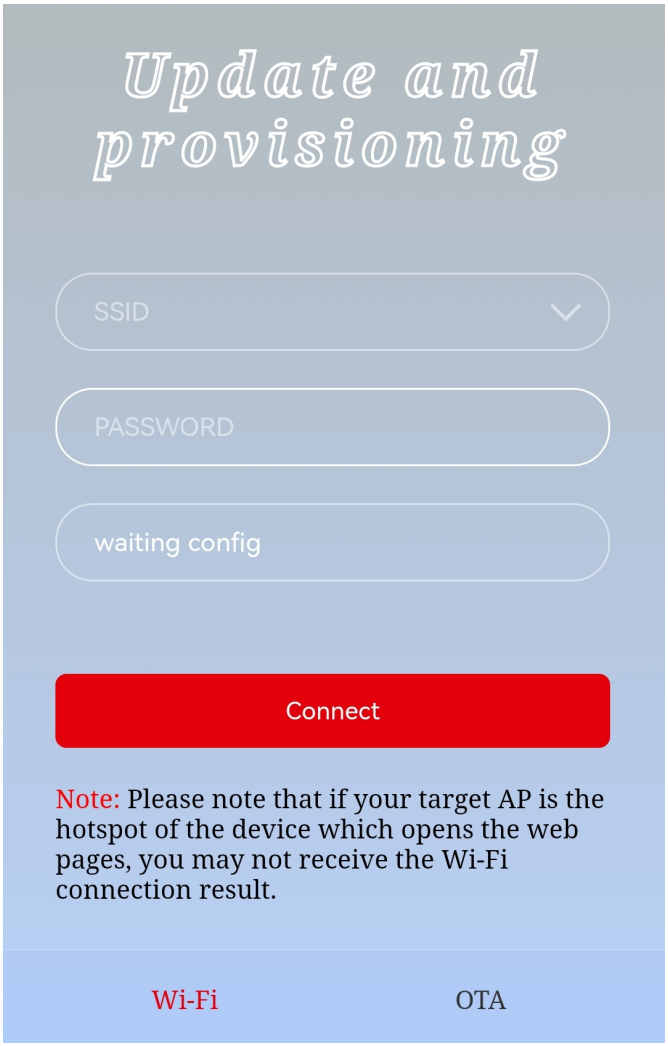


Figure 16: Open web page for provisioning

A web page opens with WiFi tab selected as default, where the credentials of the local WiFi network can be entered. For simplicity reasons, the Stephano-I can scan for all available WiFi networks by pressing the arrow in the drop-down menu.

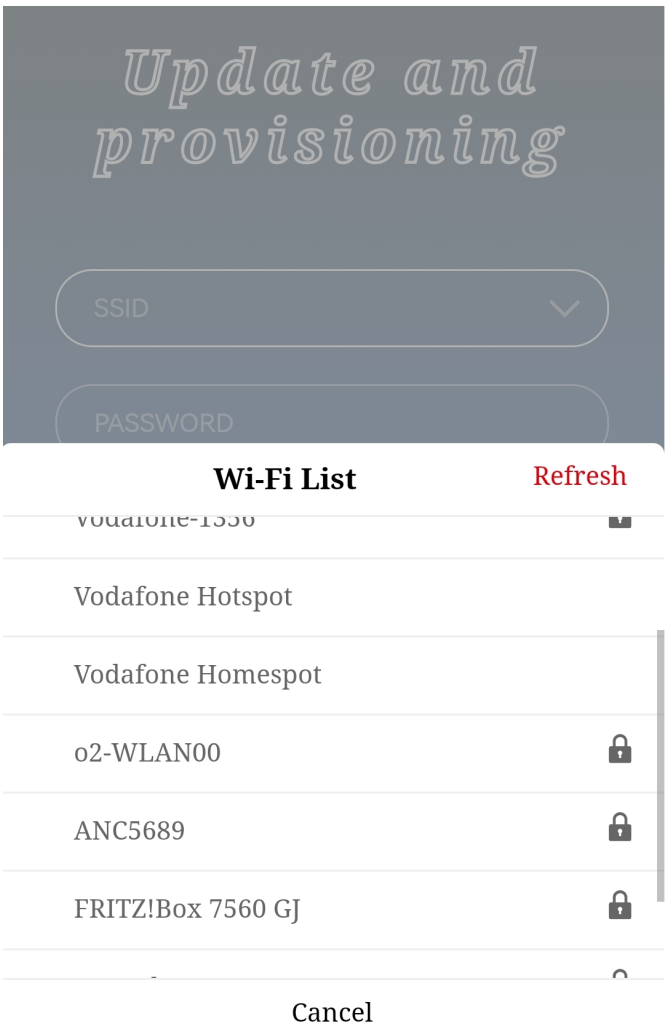


Figure 17: Scan for local networks

3. After entering the credentials (SSID and password) of the local network, the Stephano-I tries to connect. In case of success, the web page closes.

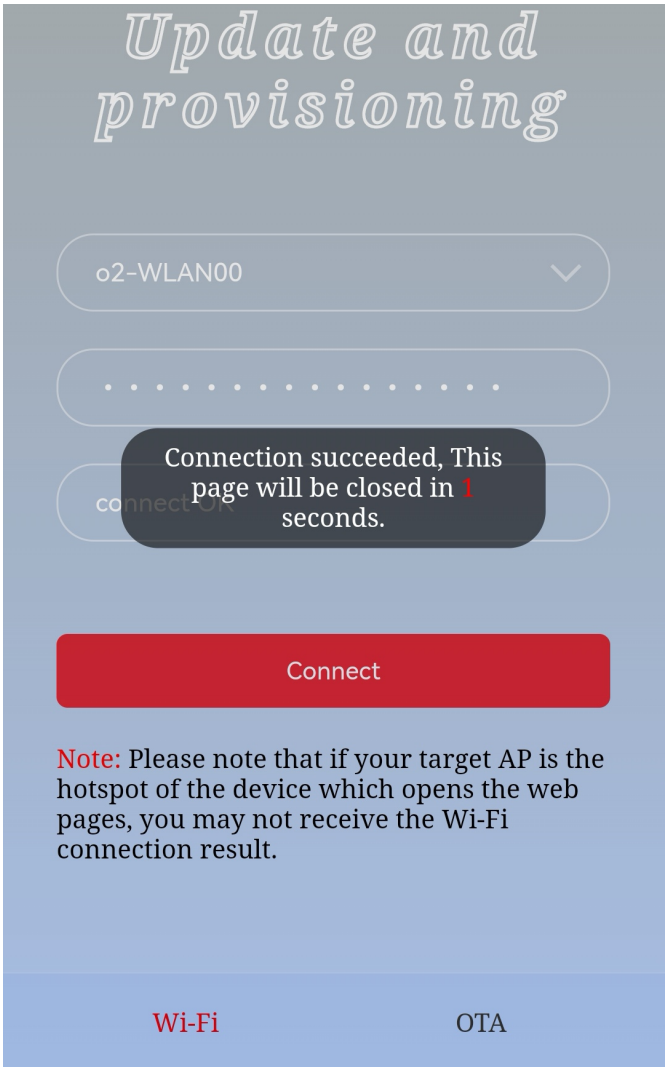


Figure 18: Successfully connected to the local WiFi

At the same time, the Stephano-I sends the following messages to the connected host via UART:

Info	Message
⇐ The module has received WiFi connection information	+WEBSERVERRSP:1
⇐ The module has connected to the new network	WIFI CONNECTED
⇐ The module has received an IP	WIFI GOT IP
⇐ The provisioning has finished with success	+WEBSERVERRSP:2

In case of wrong credentials, the `+WEBSERVERRSP:2` message is not printed.

10.2.5 OTA via WiFi: update of the module firmware or manufacturing user partition over the air

The Stephano-I allows a FOTA update. To achieve this, a remote device, such as a smartphone, has to connect to the Stephano-I and open a local web page in its browser. With help of this, the new firmware image can be transmitted and applied to the radio module.
This process is described in this chapter.

The steps to upload the manufacturing user partition via web server are the same. To update single certificates or keys, refer to chapter `10.3.1`.
The below commands are in ASCII notation. Due to simplicity, the \r\n which is attached to each command, will be neglected in the below example.

1. First of all, ensure that the Stephano-I and the device that runs the update, i.e. smartphone or PC, are in the same network:
   a) In case the Stephano-I acts as access point, connect to that.
   b) Or in case the Stephano-I is in station mode, connect to the same network, i.e. access point.

We recommend to use the method, where the Stephano-I does not act as access point to reduce the work load on the Stephano-I and increase update stability.

2. Then set the Stephano-I to update mode by starting the included web server:

Info	Message
⇒ Start the web server on port 80	AT+WEBSERVER=1,80,25
⇐	OK

3. Now open a browser on the smartphone or PC and enter the IP of the Stephano-I. The default IP is 192.168.4.1, or you can query the current softAP IP address by command `AT+CIPAP?`.

The FOTA has been tested with a Chrome browser. In case of failure, set the developer settings to "http only". Other browsers may or may not support accepting self signed certificates. Please check the documentation of the browser.

4. A web page opens. Click on the OTA tab and select the option "ota" from the "Partition" list. For uploading certificate files, the user can select the corresponding certificate name from the list. In this example we are trying to update the module firmware, hence "ota" is selected.

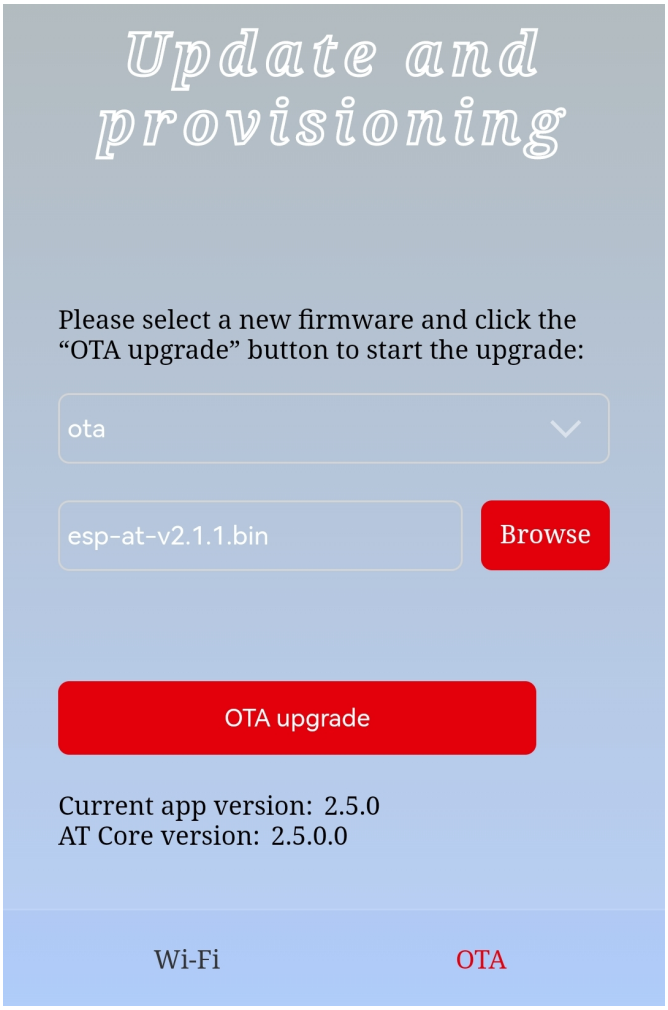


Figure 19: Choose the firmware image

5. Then press the "OTA upgrade" button and wait for the success message.

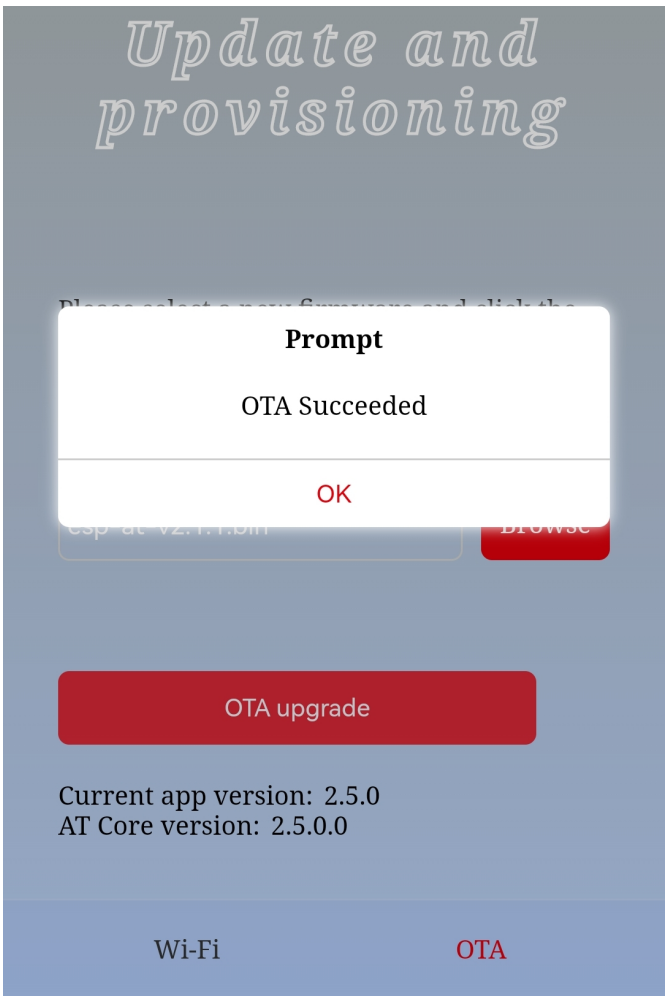


Figure 20: Successfully updated the radio module

At the same time, the Stephano-I sends the following messages to the connected host via UART:

Info	Message
⇐ The transmission of the new firmware image has started	+WEBSERVERRSP:3
⇐ The new firmware image has been received successfully	+WEBSERVERRSP:4

After a restart of the module, the new firmware image is applied. Therefore, a reset of the Stephano-I is required.

In case of error, a `+WEBSERVERRSP:5` message is printed.

10.3 General examples

10.3.1 Update the certificates and keys for secure communication

To setup a secure communication, the certificates and keys must be updated periodically. The command `AT+SYSMFG` allows to read and write the files in the manufacturing user partition (MFG), which also contains the certificates. This example shows how to update the "mqtt_cert".

The below commands are in ASCII notation. Due to simplicity, the \r\n which is attached to each command, will be neglected in the below example.

1. First of all we read which files are available in the MFG:

Info - SERVER	Message
⇒ Read the available files	AT+SYSMFG?
⇐	+SYSMFG:"server_key" +SYSMFG:"server_ca" +SYSMFG:"client_cert" +SYSMFG:"client_key" +SYSMFG:"client_ca" +SYSMFG:"mqtt_cert" +SYSMFG:"mqtt_key" +SYSMFG:"mqtt_ca" +SYSMFG:"factory_param" +SYSMFG:"ble_data" OK

2. Now we are interested in updating the "mqtt_cert". Thus, we read its key first:

Info - SERVER	Message
⇒ Read the key of the"mqtt_cert"	AT+SYSMFG=1,"mqtt_cert"
⇐ The key of the "mqtt_cert" is "mqtt_cert" and the format is binary (8)	+SYSMFG:"mqtt_cert","mqtt_cert",8 OK

3. Now the update can be run. The new certificate is a .crt-file in ASCII format:

Info - SERVER	Message
⇒ Delete the certificate on the module first	AT+SYSMFG=0,"mqtt_cert","mqtt_cert""
⇐	OK

⇒ Write the new file (data length is 1174, format is binary (8))	AT+SYSMFG=2,"mqtt_cert","mqtt_cert",8,1174
⇐	OK >
⇒ Now send the content (1174 bytes)	- - - - -BEGIN CERTIFICATE- - - - -\r\n MIIDQTCCAimgAwIBAgITBmyfz5m/jAo54vB4 ikPmljZbyjANBgkqhkiG9w0BAQsF\r\n . . . - - - - -END CERTIFICATE- - - - -\r\n
⇐ Received the new file	OK

Note that each line of the certificate must end with a "\r\n".

11 Firmware update

The Stephano-I supports FOTA update. To run an update of a single module, the Stephano-I must be set to update mode. In this case, a web page which is hosted on the module can be accessed by any web browser. Using this, a new firmware image is loaded to the radio module. An example demonstrating this process can be found in chapter 10.2.5.

New firmware images, if existent, are available on the Stephano-I web page [15].

12 Firmware history

Version 3.2.0.0 "Release"

- Initial version using Espressif AT-command firmware version 3.2.0.0, including Würth Elektronik eiSos bug fixes and performance improvements.

12.1 Known issues

Index	Details	Affected versions
KI-001	**Description:** The command `AT+SYSTEMP?` returns proper temperature values only once after reset. **Affected functions**: Espressif core implementation of command `AT+SYSTEMP?`. **Workaround:** Reset the device before reading the temperature.	3.2.0.0
KI-002	**Description:** Using the command `AT+BLEADVPARAM` to enable non-connectable advertising has no effect. Thus, non-connectable advertising (non-connectable beacons) is not supported. **Affected functions**: Espressif core implementation of command `AT+BLEADVPARAM`. **Workaround:** None	3.2.0.0
KI-003	**Description:** If Bluetooth® LE is disabled, the command `AT+RFPOWER` returns index 9 (0 dBm) as Bluetooth® LE rf power, independent of the configuration. **Affected functions**: Espressif core implementation of command `AT+RFPOWER`. **Workaround:** When reading the Bluetooth® power, enable the Bluetooth® LE interface before.	3.2.0.0

13 Design in guide

13.1 Advice for schematic and layout

For users with less RF experience it is advisable to closely copy the relating evaluation 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.).

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.).

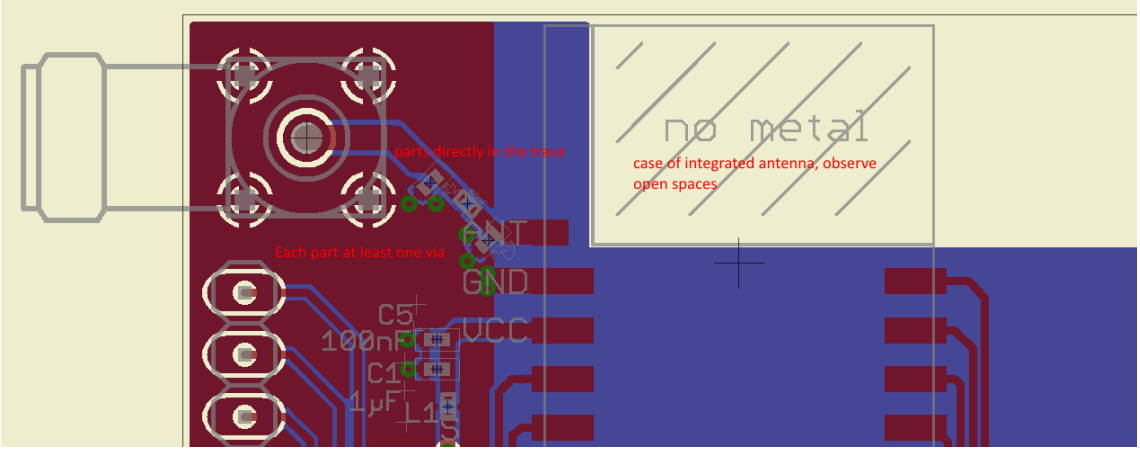


Figure 21: Layout

- 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 evaluation 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.

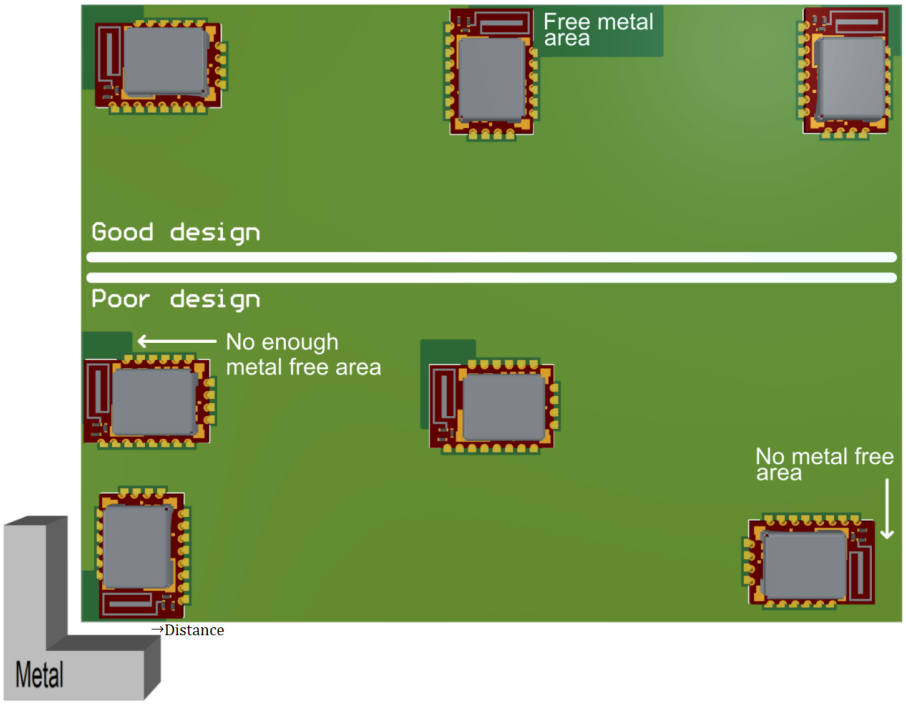


Figure 22: Placement of the module with integrated antenna

13.2 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.

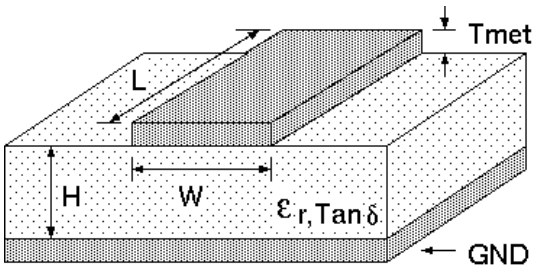


Figure 23: Dimensioning the antenna connection as micro strip

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.

13.3 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.

13.3.1 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.

13.3.2 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.

13.3.3 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 evaluation 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.

14 Reference design

Stephano-I was tested and certified on the corresponding Stephano-I evaluation board (order code 2617029025000). For the compliance with the EU directive 2014/53/EU Annex I, the evaluation board serves as reference design.
This is no discrepancy due to the fact that the evaluation board itself does not fall within the scope of the EU directive 2014/53/EU Annex I, as the module is tested on the evaluation board, which is also the recommended use.

Further information concerning the use of the evaluation board can be found in the manual of the Stephano-I evaluation board.

14.1 EV-Board

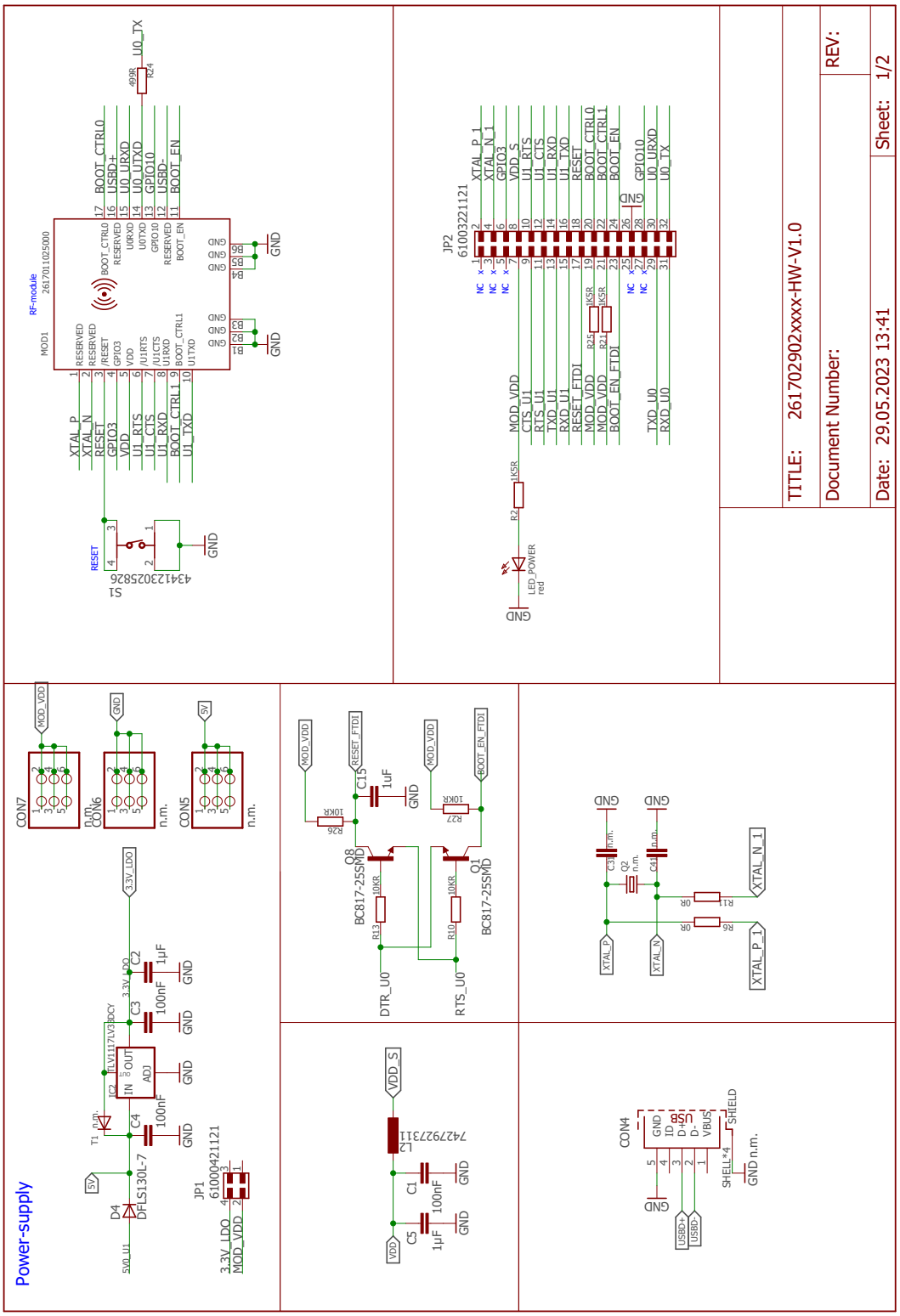


Figure 24: Reference design: schematic page 1

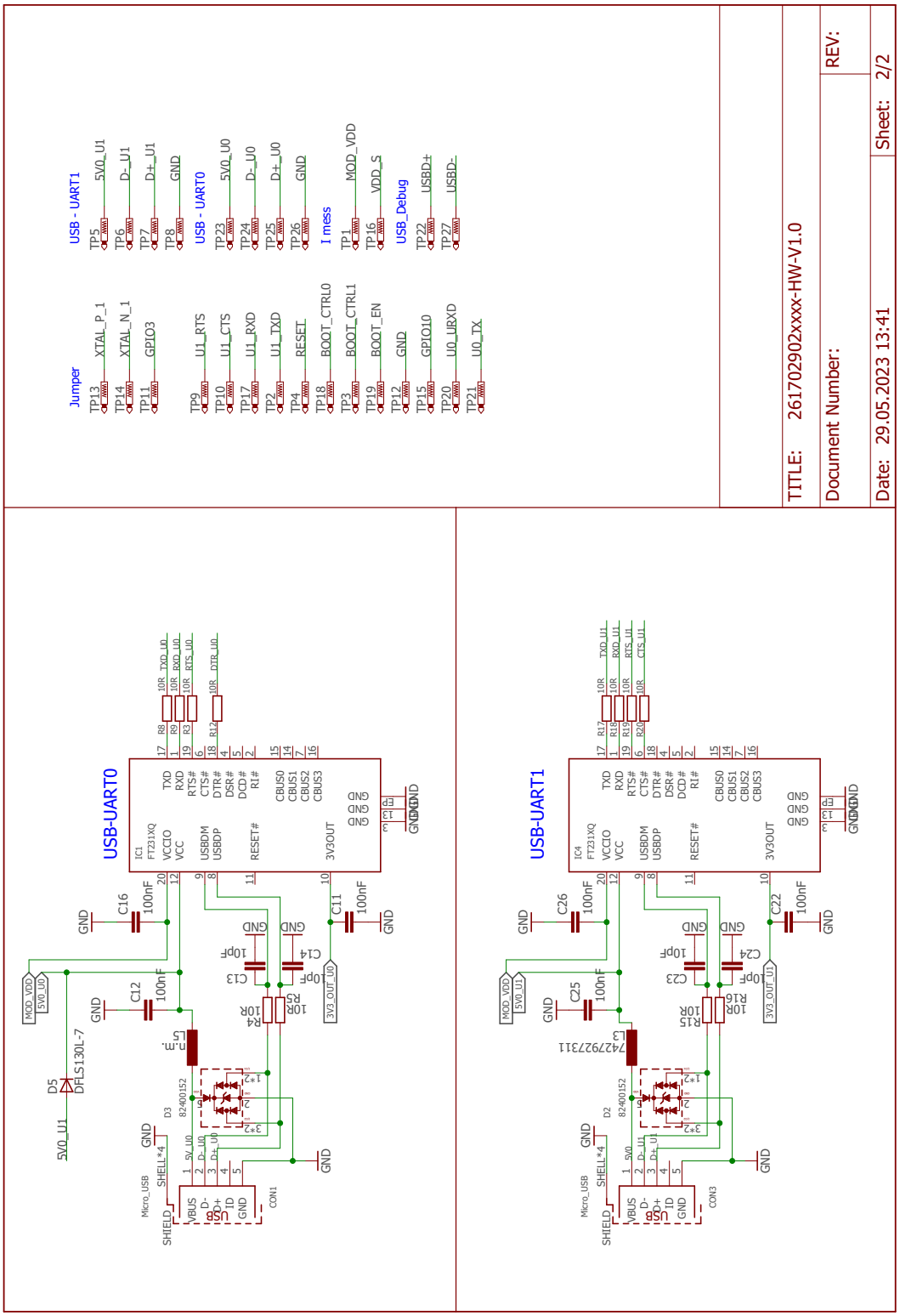


Figure 25: Reference design: schematic page 2

14.2 Layout

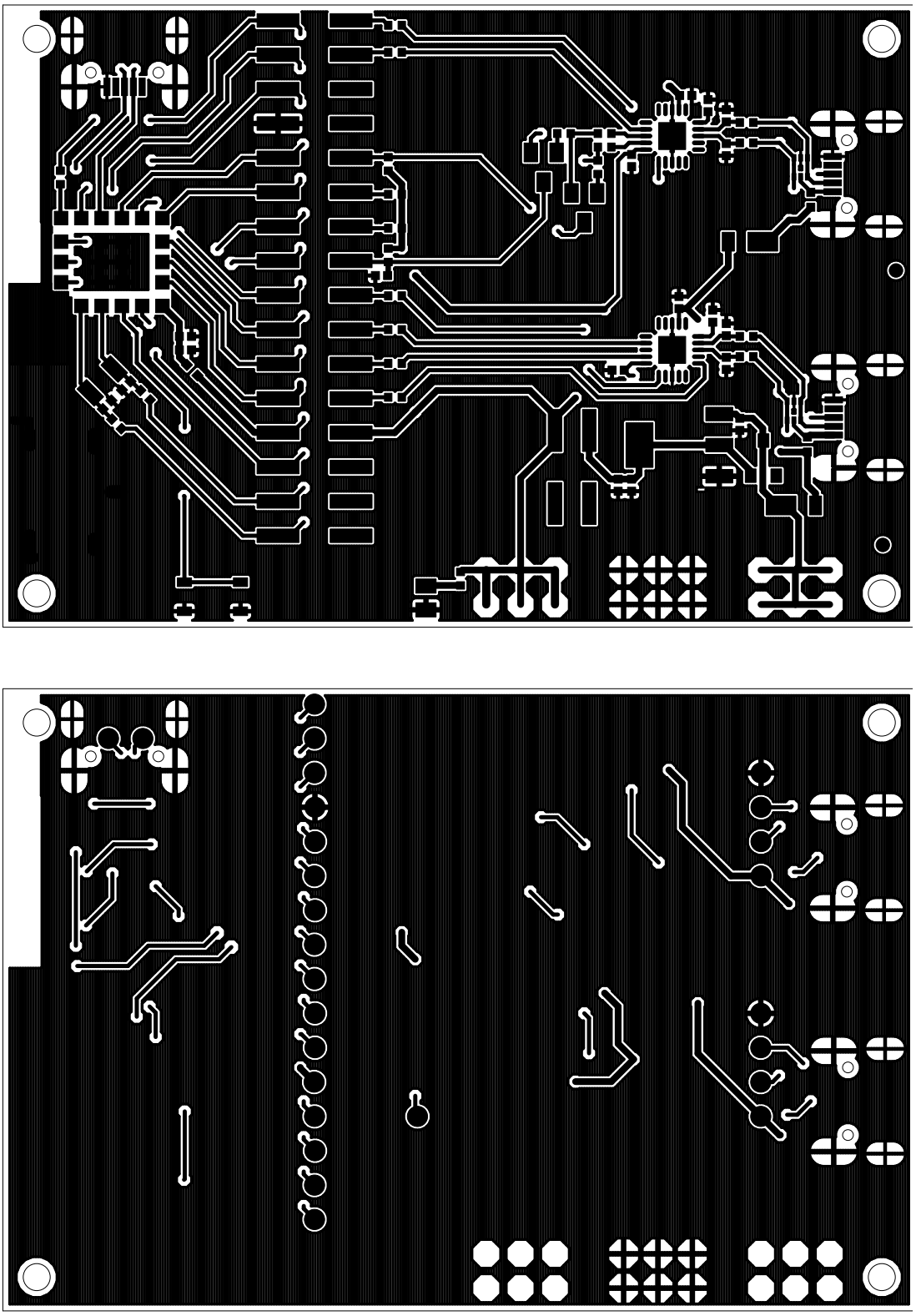


Figure 26: Top layer (top), bottom layer (bottom)

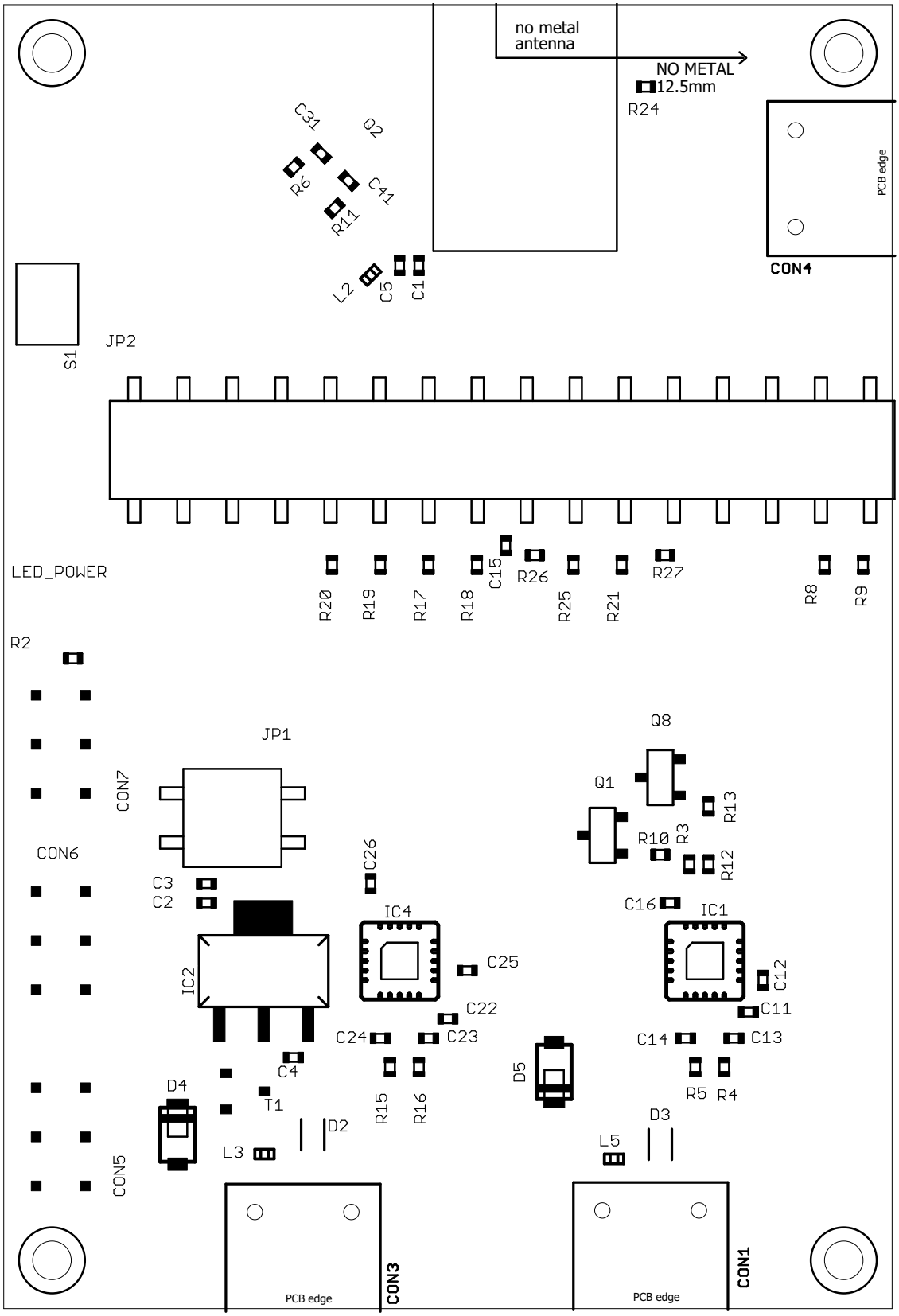


Figure 27: Reference design assembly plan

14.3 Flashing or erasing of the chipset

The debug UART (UART0) of the Stephano-I is used to bring the test firmware on the module and to control its test modes. Thus the debug UART (UART0) must be accessible and an electronic circuit must be added, which controls the */RESET* and *BOOT_EN* pin of the radio module (see figure 28).

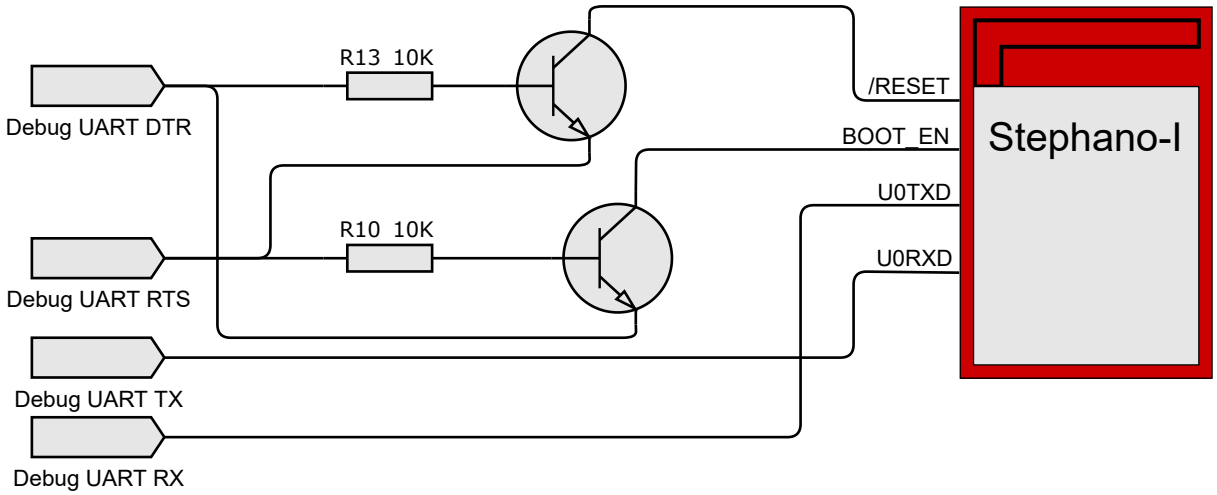


Figure 28: Flash circuit

Having the debug UART interface accessible allows to erase or flash any kind of firmware on the module using the so called "Espressif Flash Download Tool" [16].

Please note that any PC tool provided by Espressif requires the hardware setup as shown in figure 28.

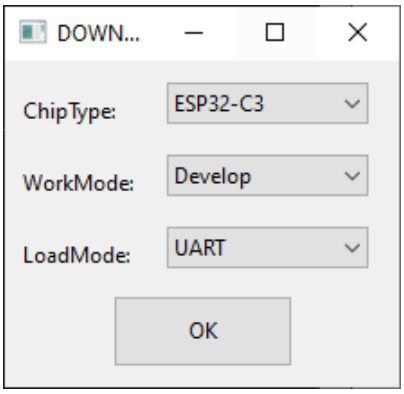


Figure 29: Flash download tool: Chip selection

After start-up of the tool, the selection of the ESP32-C3 chipset, firmware image, start address and the COM port of the debug UART, the radio module can be erased or flashed with a new firmware image.

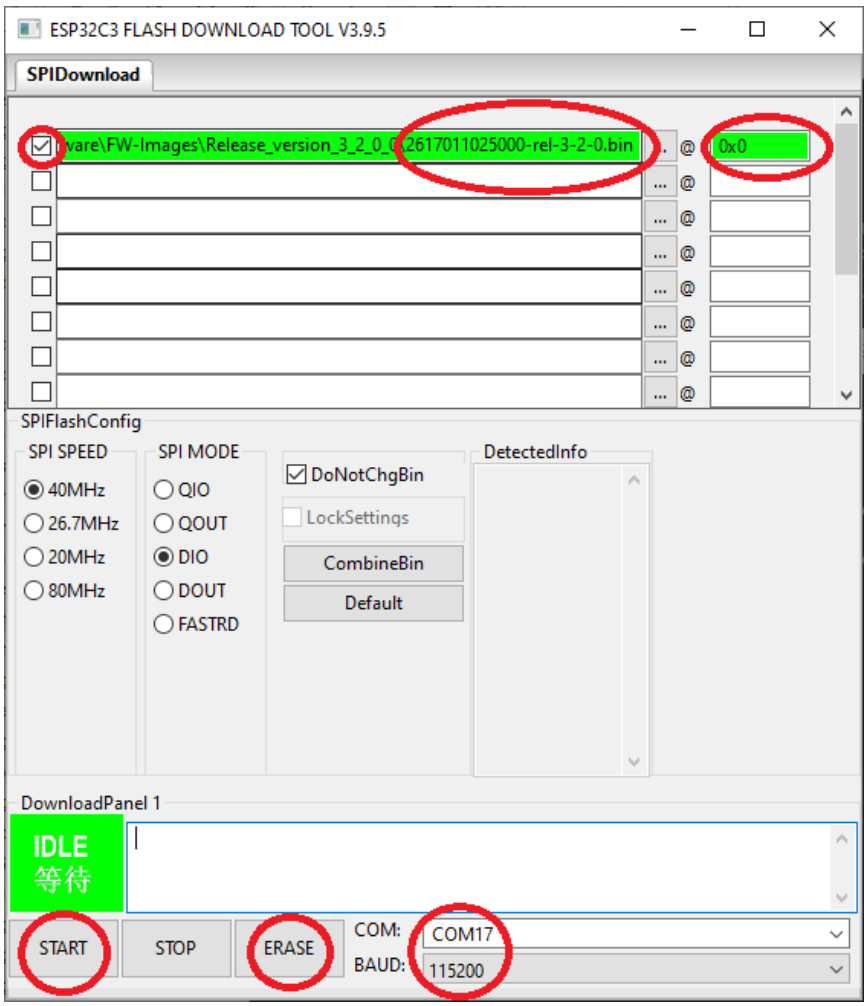


Figure 30: Flash download tool: Erase or flash chipset

15 Manufacturing information

15.1 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*.

15.2 Soldering

15.2.1 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.

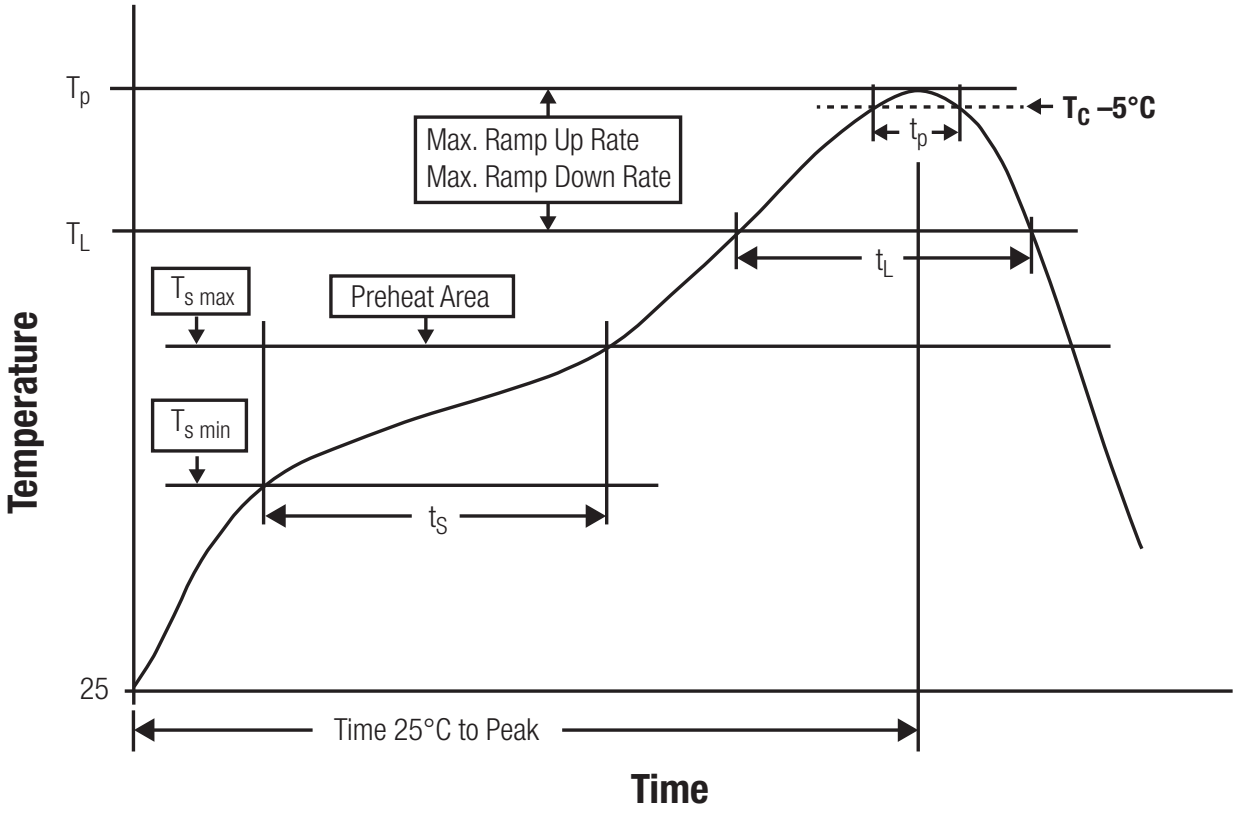


Figure 31: Reflow soldering profile

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

15.2.2 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.

15.2.3 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.

15.2.4 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.

15.3 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.

15.4 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.

16 Physical specifications

16.1 Dimensions

Dimensions
9.5 x 13 x 2 mm

Table 66: Dimensions

16.2 Weight

Weight
<1 g

Table 67: Weight

16.3 Module drawing

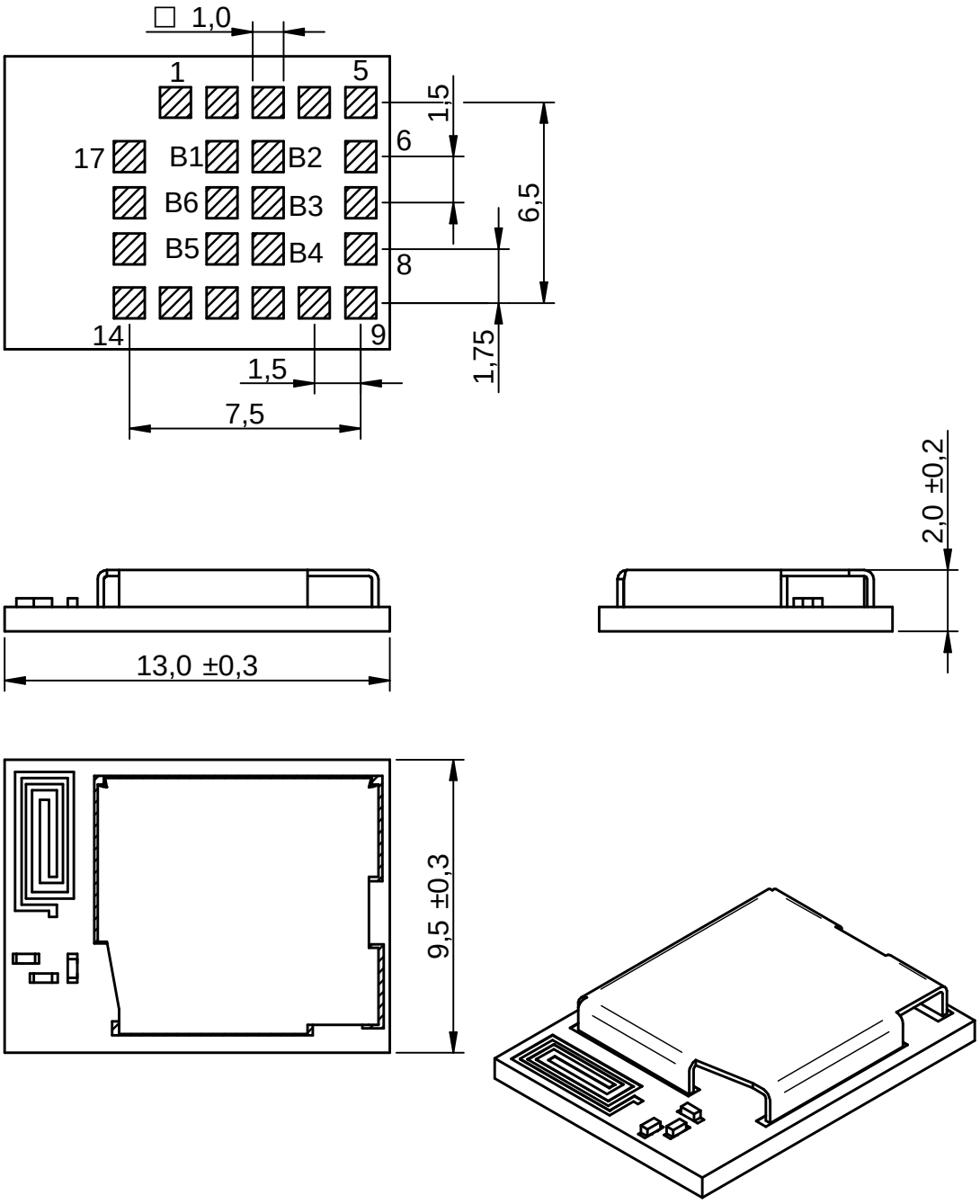


Figure 32: Module dimensions [mm]

16.4 Footprint

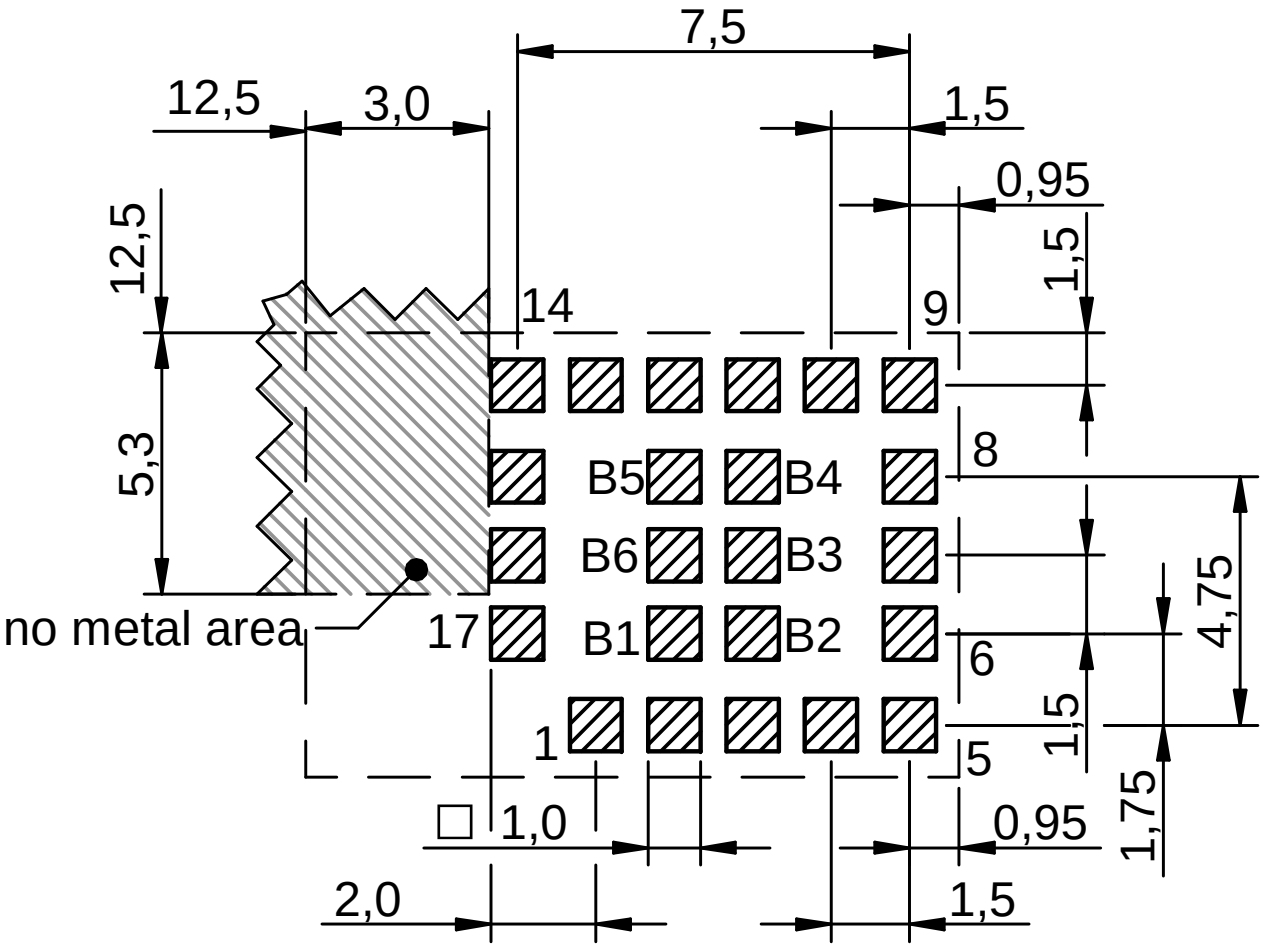


Figure 33: Footprint [mm]

16.5 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 λ/10 should be kept (see figure 33). Even though metal parts would influence the characteristic of the antenna, but the direct influence and matching keep an acceptable level.

17 Marking

17.1 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.

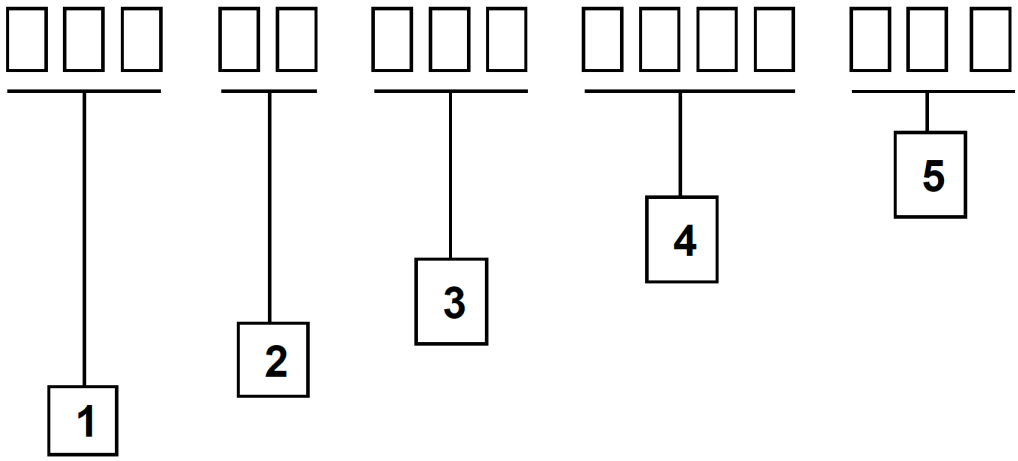


Figure 34: Lot number structure

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.

17.2 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.

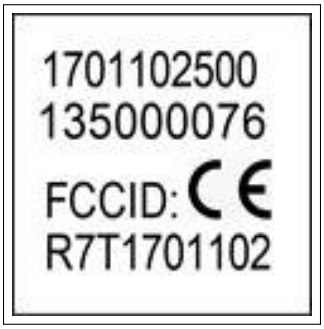


Figure 35: Label of the Stephano-I

18 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 power of the module is 15 dBm for internal antenna.
- The total amount of capacitance of all capacitors is 3.61 µF.
- The total amount of inductance of all inductors is 27.9 nH.

19 Bluetooth SIG listing/qualification

Type	Data
Design name	Stephano-I
Declaration ID	D066310
QDID	227283 (Controller Subsystem)[1]
Specification name	Bluetooth® LE 5.0
Project type	End product

Each product containing intellectual property of the Bluetooth® Special Interest Group (SIG) must be qualified by the SIG to obtain the corresponding declaration ID.
Due to the qualification of the Stephano-I as "Controller Subsystem", no further Bluetooth® LE tests are required. The only arising expenses are those for purchasing a Bluetooth® declaration ID.
To obtain the Bluetooth® listing of the end device, refer to the application note ANR027 [17].

19.1 Details of the Stephano-I's listing

The listing of the Stephano-I has been generated by combining 3 parts:

1. Bluetooth® conformance tests of the Stephano-I's hardware: The Stephano-I has been tested at a certified test house w.r.t. Bluetooth® LE 5.4 specification.
2. Espressif Bluetooth® LE stack certification: The Bluetooth® LE stack integrated in the Stephano-I has been certified by Espressif w.r.t. Bluetooth® 5.3 specification.
3. Espressif ESP32-C3 chip certification: The ESP32-C3 chip, which is used in Stephano-I, has been certified w.r.t. Bluetooth® LE 5.0 specification[2] by Espressif.

The Stephano-I must be listed w.r.t. the lowest Bluetooth® LE version of the available components, which results in Bluetooth® LE 5.0.

Independent of the Bluetooth® LE version for which the Stephano-I is listed, i.e. 5.0 or 5.3, the Stephano-I would contain the same set of functions. Any Bluetooth® LE 5.3 extra features, like "Connection Subrating"[3], are defined as optional by the Bluetooth® specification and therefore are not included in the Stephano-I.

[1] For listing of the end device, the Stephano-I's controller subsystem QDID (227283) must be used in addition to the QDID of the Bluetooth® LE stack. In Stephano-I the stack "ESP-IDF Bluedroid Host" with QDID 198312 listed as "Host Subsystem" is used.
[2] If Espressif updates this certification, the Stephano-I can be listed w.r.t. Bluetooth® LE 5.3 or higher.
[3] Connection subrating: Connections can be temporarily slowed down to save power.

End devices integrating a Bluetooth® LE 5.0 radio module can be listed until February 2032. The use of those end devices is unlimited.

20 Regulatory compliance information

20.1 Important notice EU

The use of RF frequencies is limited by national regulations. The Stephano-I has been designed to comply with the RED directive 2014/53/EU of the European Union (EU).
The Stephano-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 itself is not fused the voltage supply shall be fed from a power source which is class PS2 according to EN 62368-1.

20.2 Important notice FCC

The use of RF frequencies is limited by national regulations. The Stephano-I has been designed to comply with the FCC Part 15.
The Stephano-I can be operated without notification and free of charge in the area of the United States of America. However, according to the FCC Part 15, restrictions (e.g. in terms of maximum allowed RF power and antenna) may apply.

20.3 Conformity assessment of the final product

The Stephano-I is a subassembly. It is designed to be embedded into other products (products incorporating the Stephano-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 Stephano-I carried out by Würth Elektronik eiSos does not replace the required conformity assessment of the final product.

20.4 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.

20.5 EU Declaration of conformity

CE

EU DECLARATION OF CONFORMITY

Radio equipment: **Stephano-I / 2617011025000**

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: Stephano-I / 2617011025000

The object of the declaration described above is in conformity with the relevant Union harmonisation legislation Directive 2014/53/EU and 2011/65/EU with its amending Annex II EU 2015/863 . Following harmonised norms or technical specifications have been applied:

EN 300 328 V2.2.2 (2019-07)
EN 301 489-1 V2.2.3 (2019-11)
EN 301 489-17 V3.2.4 (2020-09)
EN 62311
EN 62368-1:2014 + AC:2015 + A11:2017 + AC:2017

i.A. G. Erlandt

Trier, 10th of November 2023
Place and date of issue

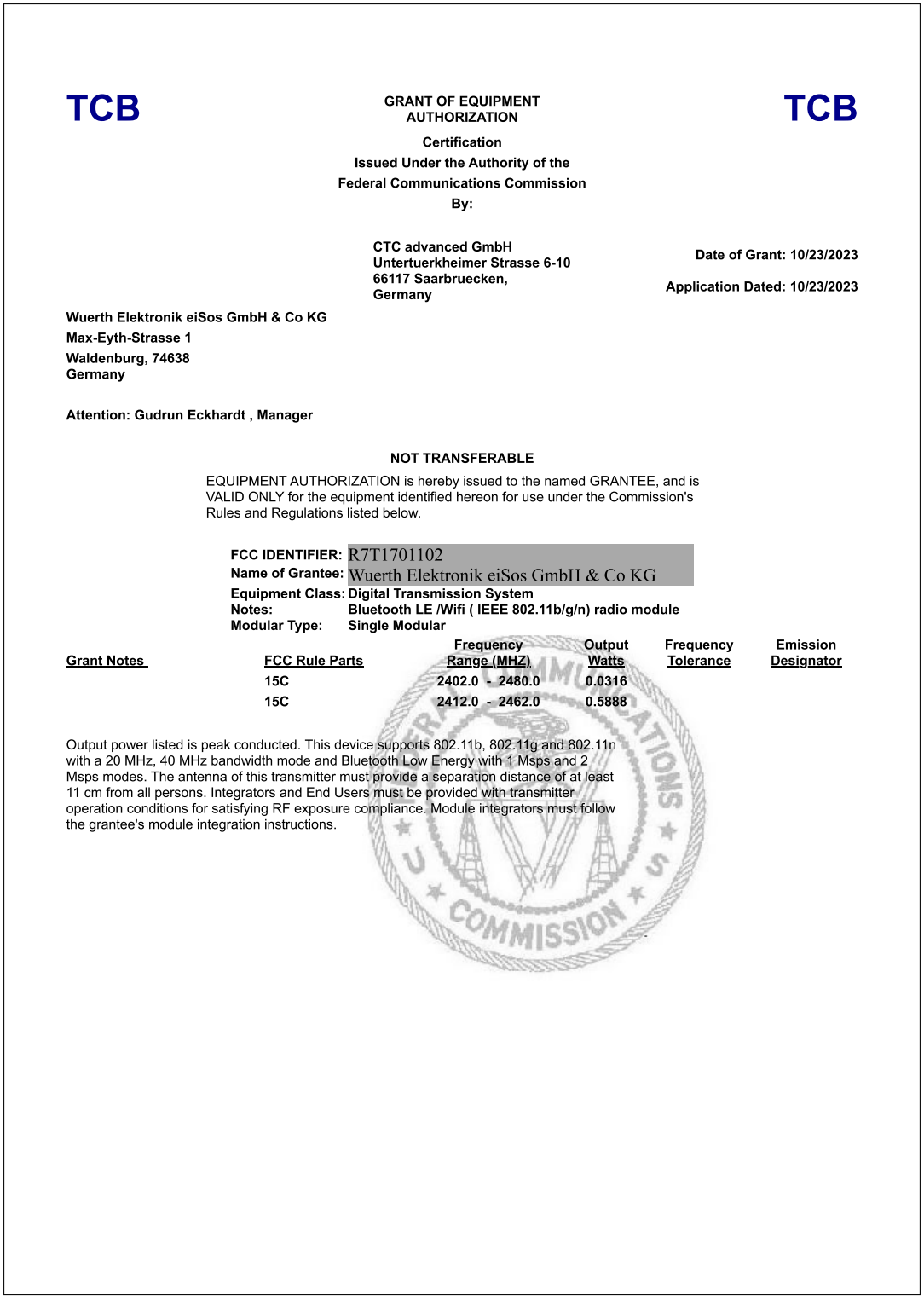
20.6 FCC Compliance Statement (US)

FCC ID: R7T1701102

This device complies with Part 15 of the FCC Rules.
Operation is subject to the following two conditions:
(1) this device may not cause harmful interference, and
(2) this device must accept any interference received, including interference that may cause undesired operation.
(FCC 15.19)

Modifications (FCC 15.21)
Caution: Changes or modifications for this equipment not expressly approved by Würth Elektronik eiSos may void the FCC authorization to operate this equipment.

20.6.1 FCC certificate



TCB

GRANT OF EQUIPMENT AUTHORIZATION

Certification

Issued Under the Authority of the

Federal Communications Commission

By:

TCB

CTC advanced GmbH
Untertuerkheimer Strasse 6-10
66117 Saarbruecken,
Germany

Date of Grant: 10/23/2023

Application Dated: 10/23/2023

Wuerth Elektronik eiSos GmbH & Co KG
Max-Eyth-Strasse 1
Waldenburg, 74638
Germany

Attention: Gudrun Eckhardt , Manager

NOT TRANSFERABLE

EQUIPMENT AUTHORIZATION is hereby issued to the named GRANTEE, and is VALID ONLY for the equipment identified hereon for use under the Commission's Rules and Regulations listed below.

FCC IDENTIFIER: R7T1701102
Name of Grantee: Wuerth Elektronik eiSos GmbH & Co KG
Equipment Class: Digital Transmission System
Notes: Bluetooth LE /Wifi (IEEE 802.11b/g/n) radio module
Modular Type: Single Modular

Grant Notes	FCC Rule Parts	Frequency Range (MHZ)	Output Watts	Frequency Tolerance	Emission Designator
	15C	2402.0 - 2480.0	0.0316		
	15C	2412.0 - 2462.0	0.5888		

Output power listed is peak conducted. This device supports 802.11b, 802.11g and 802.11n with a 20 MHz, 40 MHz bandwidth mode and Bluetooth Low Energy with 1 Msps and 2 Msps modes. The antenna of this transmitter must provide a separation distance of at least 11 cm from all persons. Integrators and End Users must be provided with transmitter operation conditions for satisfying RF exposure compliance. Module integrators must follow the grantee's module integration instructions.

Figure 36: FCC certificate

20.7 IC Compliance Statement (Canada)

Certification Number: 5136A-1701102
HVIN: 1701102
This device complies with Industry Canada licence-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.
Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes : (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

20.7.1 IC certificate

CTC advanced
member of RWTÜV group

CTC advanced GmbH
CAB Identifier DE0001

based on the Comprehensive Economic and Trade Agreement (CETA) between the European Community and Canada

DAkkS Deutsche Akkreditierungsstelle D-ZE-12076-01-00

TECHNICAL ACCEPTANCE CERTIFICATE - CANADA

Certificate Holder	**Würth Elektronik eiSos GmbH & Co. KG** Max-Eyth-Str. 1 74638, Waldenburg Germany
ISED Certification Number	5136A-1701102
Product Description	Bluetooth LE /Wifi (IEEE 802.11b/g/n) radio module
CTC advanced Registration No.	1-4723/22-02-12
OATS Facility	**CTC advanced Gmbh member of RWTÜV group** Untertuerkheimer Str. 6-10 D-66117 Saarbruecken Germany (Federal Republic Of) Phone:49 681 598 8723 Fax: 49 681 5989075
OATS Facility ID	3462C

Certification of equipment means only that the equipment has met the requirements of the above-noted specification. License applications, where applicable to use certified equipment, are acted on accordingly by the ISED issuing office and will depend on the existing radio environment, service and location of operation. This certificate is issued on condition that the holder complies and will continue to comply with the requirements and procedures issued by ISED. The equipment for which this certificate is issued shall not be manufactured, imported, distributed, leased, offered for sale or sold unless the equipment complies with the applicable technical specifications and procedures issued by ISED.

La certification du matériel signifie seulement que le matériel a satisfait aux exigences de la norme indiquée ci-dessus. Les demandes de licences nécessaires pour l'utilisation du matériel certifié sont traitées en conséquence par le bureau de délivrance d'ISDE et dépendent des conditions radio ambiantes, du service et de l'emplacement d'exploitation. Le présent certificat est délivré à la condition que le titulaire satisfasse et continue de satisfaire aux exigences et aux procédures d'ISDE. Le matériel à l'égard duquel le présent certificat est délivré ne doit pas être fabriqué, importé, distribué, loué, mis en vente ou vendu à moins d'être conforme aux procédures et aux spécifications techniques applicables publiées par ISDE.

I hereby attest that the subject equipment was tested and found in compliance with the above-noted specification.
J'atteste par la présente que le matériel a fait l'objet d'essai et jugé conforme à la spécification ci-dessus.

Place, date of issue

Saarbruecken, 2023-10-20

CTC advanced GmbH

Daniel Gillo / FCB

CTC advanced GmbH
Untertuerkheimer Str. 6–10 | 66117 Saarbruecken | Germany | www.ctcadvanced.com

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This certificate becomes valid when published in REL at :
Le présent certificat n'entre en vigueur qu'après être publié en REL sur :
https://sms-sgs.ic.gc.ca/equipmentSearch/searchRadioEquipments?execution=e1s1&lang=en_CA

Figure 37: IC certificate

20.8 FCC and IC requirements to OEM integrators

This module has been granted modular approval. OEM integrators for host products may use the module in their final products without additional FCC/IC (Industry Canada) certification if they meet the following conditions. Otherwise, additional FCC/IC approvals must be obtained. The host product with the module installed must be evaluated for simultaneous transmission requirements.

- The users manual for the host product must clearly indicate the operating requirements and conditions that must be observed to ensure compliance with current FCC/IC RF exposure guidelines.
- A label must be affixed to the outside of the host product with the following statements:
  This device contains FCCID: R7T1701102
  This equipment contains equipment certified under ICID: 5136A-1701102
- The final host / module combination may also need to be evaluated against the FCC Part 15B criteria for unintentional radiators in order to be properly authorized for operation as a Part 15 digital device.
- If the final host / module combination is intended for use as a portable device (see classifications below) the host manufacturer is responsible for separate approvals for the SAR requirements from FCC Part 2.1093 and RSS-102. Using the maximum output power, the mounted Stephano-I must respect a distance of 200 mm in WiFi mode and 25 mm in Bluetooth® mode to a human body. If a reduced output power is configured, the safety distance can be recalculated corresponding to the KDB447498 and RSS-102 Issue 5.

OEM requirements:
The OEM must ensure that the following conditions are met.

- End users of products, which contain the module, must not have the ability to alter the firmware that governs the operation of the module. The agency grant is valid only when the module is incorporated into a final product by OEM integrators.
- The end-user must not be provided with instructions to remove, adjust or install the module.
- The Original Equipment Manufacturer (OEM) must ensure that FCC labeling requirements are met. This includes a clearly visible label on the outside of the final product. Attaching a label to a removable portion of the final product, such as a battery cover, is not permitted.
- The label must include the following text:
  Contains FCC ID: R7T1701102
  The enclosed device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions:
  (i.) this device may not cause harmful interference and
  (ii.) this device must accept any interference received, including interference that may cause undesired operation.

  When the device is so small or for such use that it is not practicable to place the statement

above on it, the information required by this paragraph shall be placed in a prominent location in the instruction manual or pamphlet supplied to the user or, alternatively, shall be placed on the container in which the device is marketed. However, the FCC identifier or the unique identifier, as appropriate, must be displayed on the device.

- The user manual for the end product must also contain the text given above.
- Changes or modifications not expressly approved could void the user's authority to operate the equipment.
- The OEM must ensure that timing requirements according to 47 CFR 15.231(a-c) are met.
- The OEM must sign the OEM Modular Approval Agreement.
- The OEM shall perform testing in accordance to 996369 D04 Module Integration Guide V01.

20.9 TELEC radio law approval

Japanese Radio Law Compliance

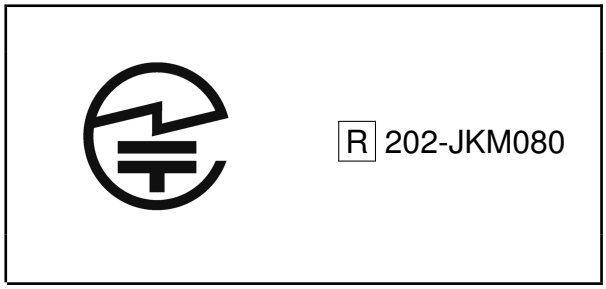
This device has passed the Radio Law approval for Japan through the registered certification body TELEC. The corresponding ARIB (Association of Radio Industries and Businesses) standard has been applied. Accordingly, the market approval is given by the MIC (Ministry of Internal Affairs and Communications).

This device should not be modified (otherwise the granted designation number will become invalid)

20.9.1 Label

Due to the small size of the Stephano-I label, the certification label of the Stephano-I is not placed onto the module label.

2617011025000:



After integration of the Stephano-I in the end device, the corresponding certification label must be recognized from the outside. Otherwise this information must be referenced on the housing as well as in the user manual. E labeling is allowed.

20.9.2 Certified antennas

The Stephano-I is pre-certified with the following antennas.

Product	Certified antenna
Stephano-I (2617011025000)	PCB antenna included in the Stephano-I

20.9.3 TELEC certificate

CTC advanced
member of RWTÜV group

CTC advanced GmbH
RCB Identifier 202

authorized by the German Federal Regulatory body BNetzA to act as a CAB(Conformity Assessment Body) in accordance with the MRA EU-Japan

Bundesnetzagentur

BNetzA-CAB-03/25-51

CONSTRUCTION TYPE CERTIFICATE

Certificate Holder	**Würth Elektronik eiSos GmbH & Co. KG** Max-Eyth-Str. 1 74638, Waldenburg Germany
CTC advanced Registration No.	1-4723/22-02-14
Model Name	Stephano-I
Product Description	Bluetooth LE /Wifi (IEEE 802.11b/g/n) radio module
Name of Manufacturer	**Würth Elektronik eiSos GmbH & Co. KG** Max-Eyth-Str. 1 74638, Waldenburg Germany

This is to certify that the above-mentioned certification by type has been granted in accordance with the provisions of Article 38-24, Paragraph 1 of the Japan Radio Law.

This device must be labelled appropriately physically or electronically

R 202-JKM080

Place, date of issue

Saarbruecken, 2023-10-24

CTC advanced GmbH

Daniel Gillo / RCB

CTC advanced GmbH
Untertuerkheimer Str. 6–10 | 66117 Saarbruecken | Germany | www.ctcadvanced.com

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Figure 38: TELEC certificate

20.10 Certification of the end device

For the certification of the end device, which integrates the Stephano-I, it is necessary to set the Stephano-I to transmission mode and check the radio emissions.

To do that, a special test firmware that must be programmed using the "Espressif Flash Download Tool" [16] and the debug UART (UART0) of the radio module. All Espressif PC tools need to access the debug UART (UART0) and it's control pins in the same way. Please refer to chapter 14.3 for more information on that.

As soon as the test firmware is available on the Stephano-I, the "Espressif RF Test Tool" [16] is used to control the radio test modes of the Stephano-I via the debug UART (UART0) interface. For more details with respect to the "Espressif RF Test Tool", please refer to the "Espressif Test Guide" [16].

21 References

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22 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.

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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 22 and 22 remains unaffected.
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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.

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