ENDUROSAT

USER MANUAL

UHF Transceiver Type II

Last Revision: 20/10/2020

CONTENTS

1 INTRODUCTION 6
1.1 Overview 6
1.2 Highlighted Features 6
2 SYSTEM DESCRIPTION 7
3 CONNECTOR PINOUT 9
3.1 Connectors Location 9
3.2 Pinout Diagrams 10
3.2.1 Stack Connectors 10
3.2.2 Antenna Release Connector 12
3.2.3 RS-485 Connector 12
3.2.4 Jumper 13
3.2.5 USB-C 13
4 LED INDICATORS 13
5 ELECTRICAL CHARACTERISTICS 14
6 RF CHARACTERISTICS 14
6.1 Transmitter 14
6.2 Receiver 17
7 BOOTLOADER 19
8 UPDATING FIRMWARE 20
8.1 Overview 20
8.2 Firmware Update Procedure Diagram 20
8.3 Update Step 1 21
8.4 Update Step 2 21
8.5 Update Step 3 21
8.6 Update Step 4 21
8.7 Update Step 5 21
8.8 DOWNLINK_XOR and UPLINK_XOR Values 21
8.9 Other Possible Replies 21
8.10 Updating at Different RF Modes 22
9 PROTOCOL DESCRIPTION 22
9.1 Features 22
9.2 Radio Packet Structure Description 22
9.3 AX.25 Protocol UI Frame Structure Description 23
9.4 ESTTC Protocol Packet Structure Description 24
9.5 ESTTC Protocol Packet CRC32 Description and Information 25

9.5.1 CRC32 Implementation Description 25
9.5.2 Sending ESTTC Commands with and without CRC 25
9.5.3 Calculating the CRC with the “xHF and OBC Configurator” Desktop Application 26
9.6 Transparent (PIPE) Mode Description 26
9.7 Automatic AX.25 UI-Frame Decoding 27
9.8 Communicating via I^{2}C 27
9.9 Common Answers Intrinsic to All ESTTC Commands 28
10 COMMAND TYPES AND DESCRIPTION 28
10.1 Status Control Word (SCW) [Application / Bootloader] 28
10.2 Radio Frequency Configuration [Application / Bootloader] 30
10.3 Read Uptime [Application / Bootloader] 31
10.4 Read Number of Transmitted Packets [Application / Bootloader] 31
10.5 Read Number of Received Packets [Application / Bootloader] 32
10.6 Read Number of Received Packets with CRC Error [Application / Bootloader] 32
10.7 Transparent (PIPE) Mode Timeout Period Configuration [Application / Bootloader] 33
10.8 Beacon Message Transmission Period Configuration [Application / Bootloader] 33
10.9 Audio Beacon Period Between the Transmissions [Application / Bootloader] 34
10.10 Restore Default Values [Application / Bootloader] 35
10.11 Internal Temperature Sensor Measurement Value [Application] 35
10.12 I^{2}C Pull-up Resistors Configuration Read/Write [Application] 36
10.13 Generic Write And/Or Read From an I^{2}C Device [Application] 36
10.14 UHF Antenna Release Configuration [Application] 37
10.15 UHF Antenna Read/Write [Application] 39
10.16 Low Power Mode [Application] 40
10.17 Destination Call Sign [Application / Bootloader] 40
10.18 Source Call Sign [Application / Bootloader] 41
10.19 Morse Code Call Sign [Application] 41
10.20 MIDI Audio Beacon [Application] 42
10.21 Read Software Version Build [Application / Bootloader] 44
10.22 Read Device Payload Size [Application / Bootloader] 44
10.23 Beacon Message Content Configuration [Application / Bootloader] 44
10.24 Device Address Configuration [Application / Bootloader] 45
10.25 FRAM Memory Read/Write [Application / Bootloader] 46
10.26 Radio Transceiver Property Configuration [Application / Bootloader] 46
10.27 Secure Mode [Application / Bootloader] 47
10.28 Firmware Update [Application / Bootloader] 48
11 MECHANICAL DRAWING 49
12 ENVIRONMENTAL AND MECHANICAL TESTING 50
13 MATERIALS AND PROCESSES 50
14 HANDLING AND STORAGE 50

ACRONYM LIST

AX.25	Amateur X.25 data link layer protocol
AFC	Automatic Frequency Correction
ASCII	American Standard Code for Information Interchange
CRC	Cyclic Redundancy Check
ECSS	European Cooperation for Space Standardization
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
ESTTC	EnduroSat's Telemetry and Telecommand
FRAM	Ferroelectric Random-Access Memory
FSK	Frequency-Shift Keying
GEVS	General Environmental Verification Standard
GFSK	Gaussian Frequency Shift Keying
GMSK	Gaussian Minimum Shift Keying
GND	Ground
IC	Integrated Circuit
I^2C	Inter-Integrated Circuit
LNA	Low-Noise Amplifier
MCU	Microcontroller Unit
MMCX	Micro-miniature Coaxial
NF	Noise Figure
OBC	On-Board Computer

OOK	On-Off Keying
PA	Power Amplifier
PCB	Printed Circuit Board
PER	Packet Error Ratio
RF	Radio Frequency
Rx	Receive
SCW	Status Control Word
SNR	Signal-to-noise ratio
SPI	Serial Peripheral Interface
SEL	Single Event Latch-up
Tx	Transmit
Tx/Rx	Transmit and Receive
UART	Universal Asynchronous Receiver/Transmitter
UHF	Ultra-High Frequency
USB	Universal Serial Bus
VCP	Virtual Com Port
OBC	On-Board Computer
OOK	On-Off Keying

1 INTRODUCTION

1.1 Overview

EnduroSat's UHF Transceiver Type II operates in the commercial frequency band - 400 to 403 MHz (Tx/Rx), and the amateur frequency band - 430 to 440 MHz (Tx/Rx). Furthermore, it features configurable data rates, which can be changed whilst the satellite is in orbit.

The output power can also be tuned in order to maximize the link budget depending on the orbital altitude, ground station performance and desired minimum elevation angle for communication. The typical output power is 1 W (30 dBm) with versions of the system allowing the power to be boosted up to 2 W (33 dBm).

The system has a USB-C (virtual COM port) which allows the connection of EnduroSat's PC software or a third-party terminal program for monitoring and configuring. The module is designed to fit within a CubeSat, but a second module can also be integrated into a ground station to easily create a complete uplink and downlink communication solution. The module uses the popular AX.25 data protocol for periodical beacon messages.

The UHF Transceiver is fully encapsulated in an aluminum box which is designed to dissipate the heat from the power amplifier, reduce EMI and EMC, and protect the electronics from particle radiation.

1.2 Highlighted Features

- Frequency ranges (Tx/Rx): Commercial (400 - 403 MHz) or Amateur (430 - 440 MHz)
- Modulation: 2GFSK (by default); OOK, GMSK, 2FSK, 4FSK and 4GFSK
- Power supply: 3.3 V (customizable to 5 V)
- Maximum transmit power: 1 W (customizable to 2 W)
- Typical current consumption during Receive Mode (Idle Mode) (Rx): 25mA @ 3.3V
- Frequency stability: ± 2.5 ppm
- Automatic frequency correction
- Sensitivity: up to -121 dBm
- Data rate in the air: 1.2 to 19.6 kbps configurable
- Protocols: ESTTC, transparent, AX.25
- Communication interfaces: UART, I^2C, USB (VCP), RS-485
- Configurable AX.25 telemetry beacon broadcast
- Audio beacon
- Morse code
- Local and remote (in-flight) secured application firmware update
- Direct link to EnduroSat’s UHF Antenna via an antenna release connector
- Ultra-low power MCU with FRAM

- External FRAM
- Type: Half-duplex
- Mass: 90 g

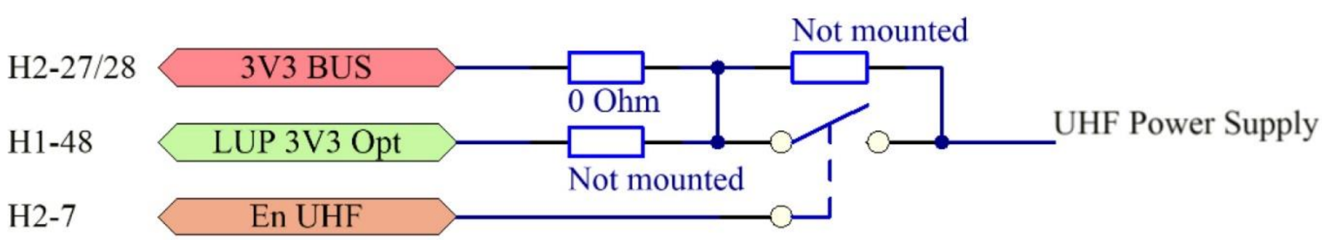
2 SYSTEM DESCRIPTION

The UHF Transceiver Type II works in the frequency range 400 to 403 MHz, and 430 to 440 MHz. Different modulation schemes are available, among them 2FSK, 4FSK, the spectrum efficient 2GFSK, 4GFSK, GMSK, and OOK as well.

The power supply block diagram is shown in Figure 1.

By default, the transceiver works in half-duplex mode with configurable data rate and modulation index (m). It has the option to transmit a beacon signal with predefined information. The default data and command interfaces are UART and I^{2}C. Optionally, RS-485 could be used. Additionally, it has a USB (virtual COM Port) for configuration by EnduroSat's PC software or a third-party terminal program. The module can also be used in a UHF ground station so that the AX.25 modem, receiver and transmitter sections can be used for communication purposes. All communication interfaces have dedicated hardware buffers for protection and when signal En UHF is pulled LOW, the switch is OFF (see Figure 1) and the interfaces of the module switch to high impedance.

The module can be powered either with 3.3 V or 3.3 V with latch-up protection with the corresponding enable pin pulled up in high state. Custom versions of the UHF Transceiver can be powered from the 5V bus.



Enable UHF:

ON 1V – 5.5V

OFF 0V – 0.3V

Figure 1: Power Supply Diagram

At the core of the RF section there is a high-performance transceiver IC. In the transmitter part of the device, there is a high efficiency RF power amplifier which by default is powered with 3.3V giving an output power up to 1 W. If a 5V bus is used, the output power can be boosted up to 2 W in specific versions of the device. In the receiver part, a Low Noise Amplifier (LNA) with a maximum Noise Figure (NF) of 0.9 dB improves the overall receiver performance in terms of sensitivity which is specified down to -121 dBm. The Associated Gain (Ga) of LNA is up to 23 dB. The device is equipped with an antenna release connector that facilitates connection and deployment of EnduroSat's UHF Antenna.

The device uses a PC-104 connector which is suitable for stackable configurations of other satellite modules. The RF connector to the antenna is MMCX.

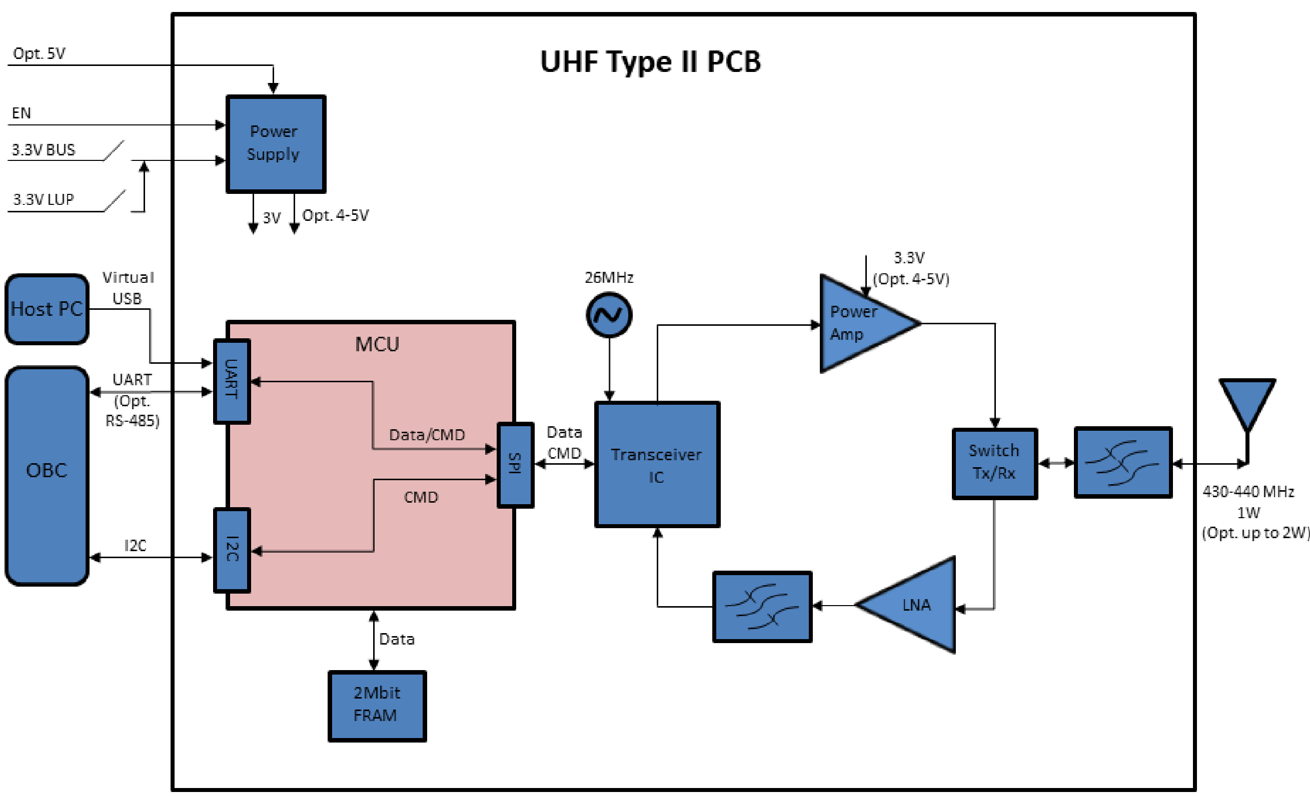


Figure 2: UHF Transceiver Type II Block Diagram

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3 CONNECTOR PINOUT

3.1 Connectors Location

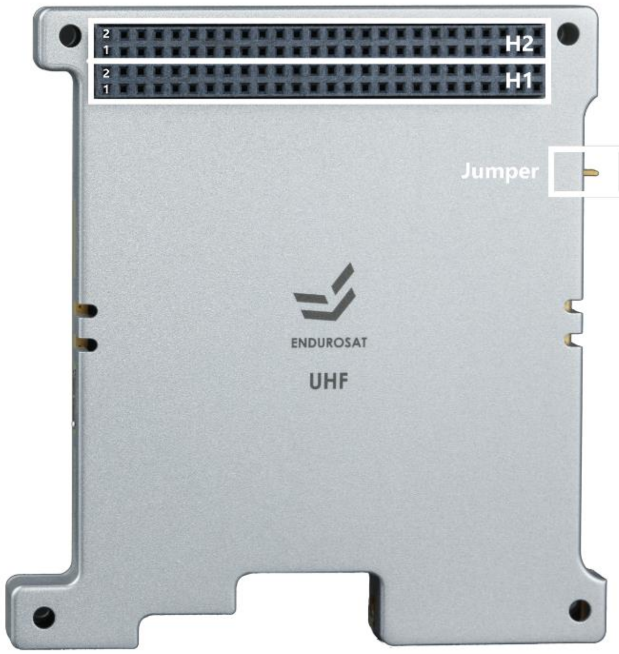

Figure 3: Main Stack Connector and Jumper Locations

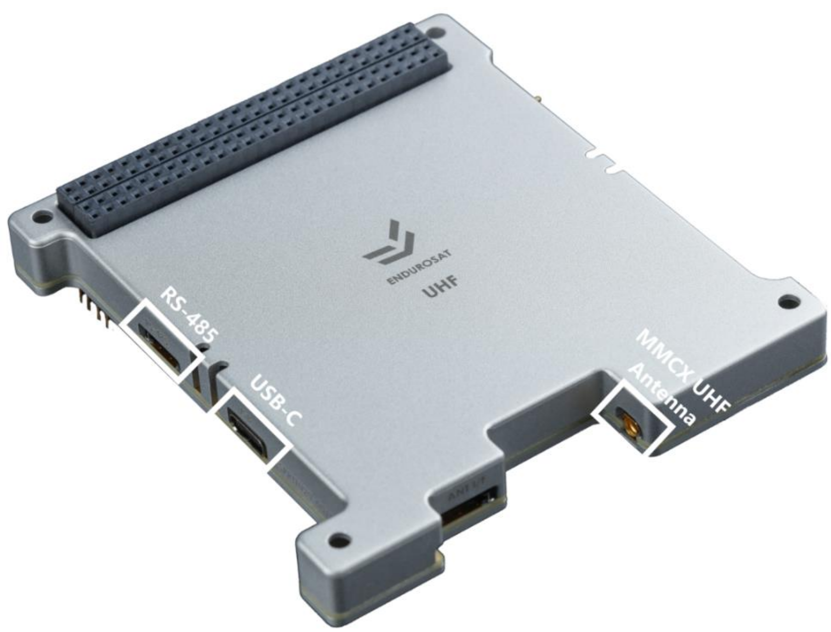

Figure 4: MMCX, USB-C and RS-485 Connectors Locations

Figure 5: Antenna Release Connector

3.2 Pinout Diagrams

3.2.1 Stack Connectors

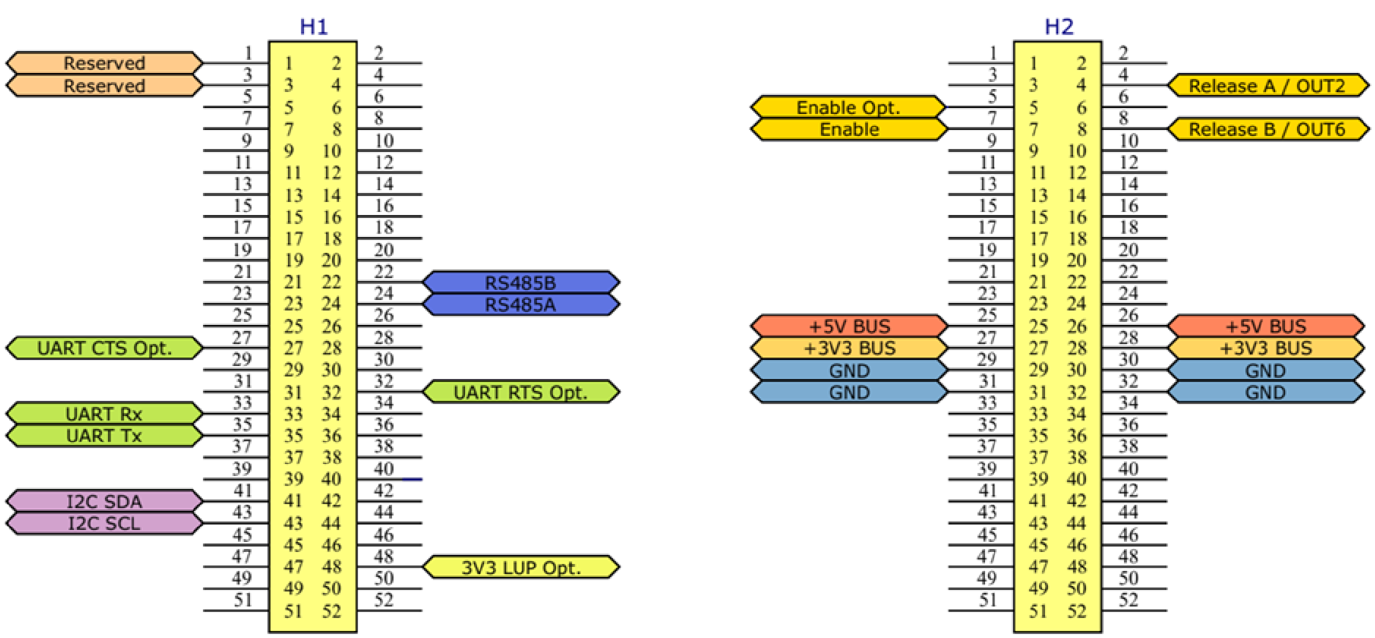

Figure 6: Stack Connectors Pinout

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Table 1: H1 Stack Connector Pinout

Pin	Mnemonic	Description
H1-1	Reserved	Reserved for internal use
H1-3	Reserved	Reserved for internal use
H1-22	RS485B	RS-485 Driver output or receiver input (complementary to A)
H1-24	RS485A	RS-485 Driver output or receiver input (complementary to B)
H1-27	UART CTS (optional)	UART Clear to Send flow control signal (optional)
H1-32	UART RTS (optional)	UART Request to Receive flow control signal (optional)
H1-33	UART Rx	UART receive data
H1-35	UART Tx	UART transmit data
H1-41	I^2C SDA	I^2C data
H1-43	I^2C SCL	I^2C clock
H1-48	3V3 LUP (optional)	Latch-up protected 3.3V power bus (input) (optional)

Table 2: H2 Stack Connector Pinout

Pin	Mnemonic	Description
H2-4	Release A / OUT2	Antenna release via primary burning resistors/ General output
H2-8	Release B / OUT6	Antenna release via back-up burning resistors/ General output
H2-5	Enable (optional)	UHF Power enable pin (optional)*
H2-7	Enable	UHF Power enable pin
H2-25	+5V BUS	+5V BUS Power Supply (optional)
H2-26	+5V BUS	+5V BUS Power Supply (optional)
H2-27	+3V3 BUS	+3.3V BUS Power Supply
H2-28	+3V3 BUS	+3.3V BUS Power Supply
H2-29	GND	Ground
H2-30	GND	Ground
H2-31	GND	Ground
H2-32	GND	Ground

* NOTE: can be used to control a secondary UHF module

3.2.2 Antenna Release Connector

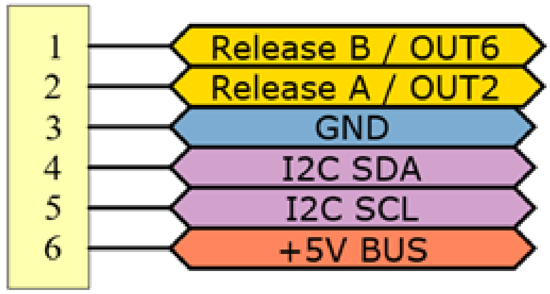

Figure 7: Antenna Release Connector Pinout

Table 3: Antenna Release Connector Pinout

Pin	Mnemonic	Description
1	Release B / OUT6	Antenna release via back-up burning resistors / General output
2	Release A / OUT2	Antenna release via primary burning resistors / General output
3	GND	Ground
4	I^2C SDA	I^2C data pin
5	I^2C SCL	I^2C clock pin
6	+5V BUS	+5V BUS

NOTE: All pins of the antenna release connector are directly connected to the H1&H2 stack connectors.

3.2.3 RS-485 Connector

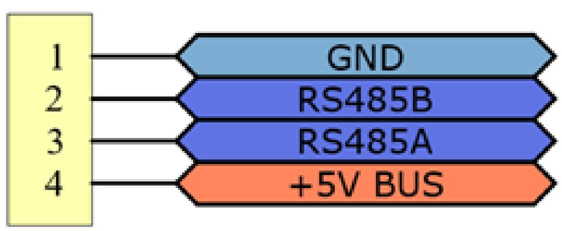

Figure 8: RS-485 Connector Pinout

Table 4: RS-485 Connector Pinout

Pin	Mnemonic	Description
1	GND	Ground
2	RS-485B	RS-485 Driver output or receiver input (complementary to A)
3	RS-485A	RS-485 Driver output or receiver input (complementary to B)
4	+5V BUS	+5V BUS

NOTE: All pins of the RS-485 connector are directly connected to the H1&H2 stack connectors.

3.2.4 Jumper

As shown in Figure 3, there is a 2-pin jumper on the side of the module. When the jumper is mounted, the UHF module immediately starts transmitting Morse code followed by the audio beacon.

3.2.5 USB-C

The USB-C shown in Figure 4 enables the device to be monitored and configured by EnduroSat's software or a third-party software. The module can be used as an AX.25 receiver.

4 LED INDICATORS

As shown in Figure 9, the system has LED indicators to give information about its status.

- Blinking blue LED (left side) – USB communication;
- Blinking green LED (right side) – transmitting;
- Blinking yellow LED (right side) – receiving.

Figure 9: LED Indicators

5 ELECTRICAL CHARACTERISTICS

Table 5: Electrical Characteristics

Parameter	Condition	Min	Typical Value	Max
Supply Voltage [V]		3.2	3.3[1]	5V (optional)
Current Consumption [mA]	Receive mode (Idle mode)	20	25[2]	30
	Transmit mode		413[3]	
	Continuous wave mode	700	780[4]	800
Operating temperature [°C]		-35		80

NOTES:

[1] - This voltage directly supplies the internal power amplifier. Changes in the supply voltage will reflect in the output transmit power;
[2] - Typical current consumption at 3.3Vdc power supply using only the UART and I²C interfaces (RS-485 is turned off);
[3] - Typical current consumption depends on the ratio of transmit vs receive mode duration. For 50% Tx / 50%, then the consumption would be as follows: 0.5*800 mA (Tx CW) + 0.5*25 mA (Rx) = 413 mA @ 3.3 V;
[4] - Typical current consumption at 3.3Vdc and 435MHz working frequency

6 RF CHARACTERISTICS

6.1 Transmitter

Table 6: RF Characteristics in Transmit Mode

Parameter	Unit	Min	Typical Value	Max
Frequency Range	MHz		400÷403 430÷440	
Output Power	W		1	2
Spurious Level	dBc	60		
Baud Rate in the Air	bps	1200		19200

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Table 7: Modulation Error

Modulation Type	FSK		GFSK		4FSK		4GFSK	
Parameter / RF Mode	FSK Err [m%rms]	FSK Mag Err [m%rms]	FSK Err [m%rms]	FSK Mag Err [m%rms]	FSK Err [m%rms]	FSK Mag Err [m%rms]	FSK Err [m%rms]	FSK Mag Err [m%rms]
1200 – 600	805	212	491	100	965	402	269	88
2400 – 600	1117	404	329	91	721	360	209	91
4800 – 1200	719	426	545	120	1593	925	176	113
9600 – 2400	652	1083	311	131	1932	941	342	117
9600 – 4800	1210	2172	553	114	2047	1624	232	248
19200 – 4800	1903	1168	1213	119	1738	1349	968	182
19200 – 9600	1461	2509	674	145	4082	1299	880	321
19200 – 19200	1117	109	857	390	2451	2771	1004	495

Figure 10: Tx Spectrum at 9600 bps, 100 kHz Span, m=0.5

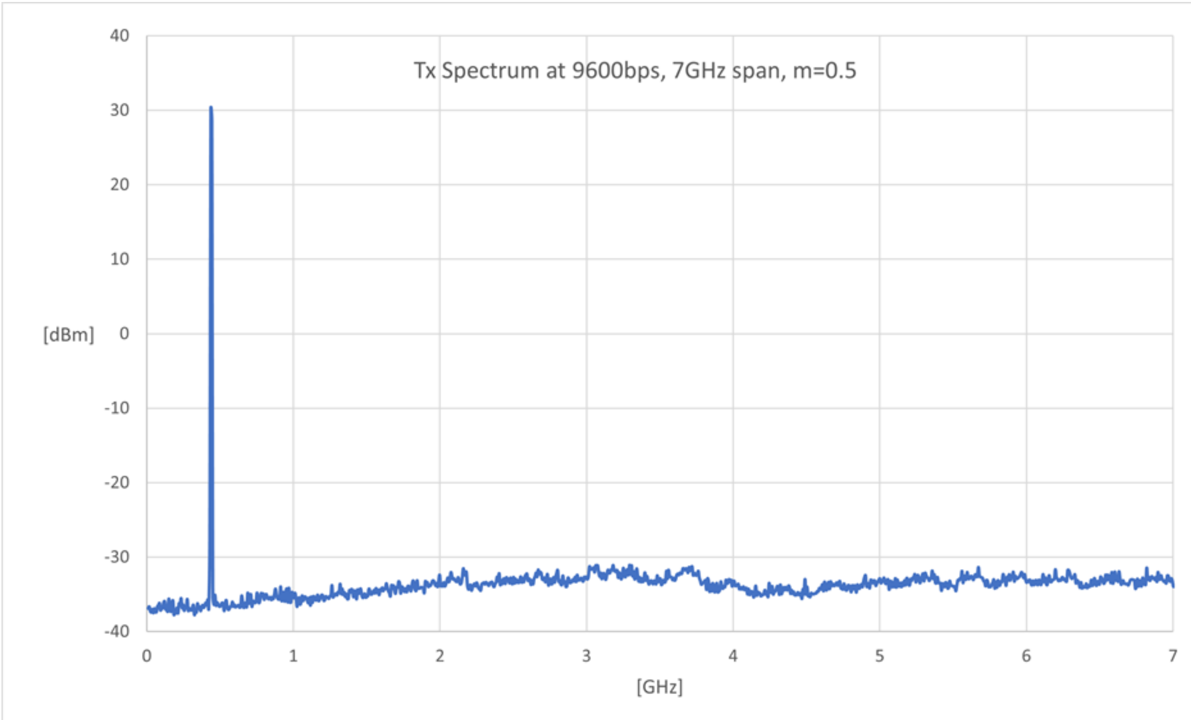

Figure 11: Tx Spectrum at 9600 bps, 7 GHz Span, m=0.5

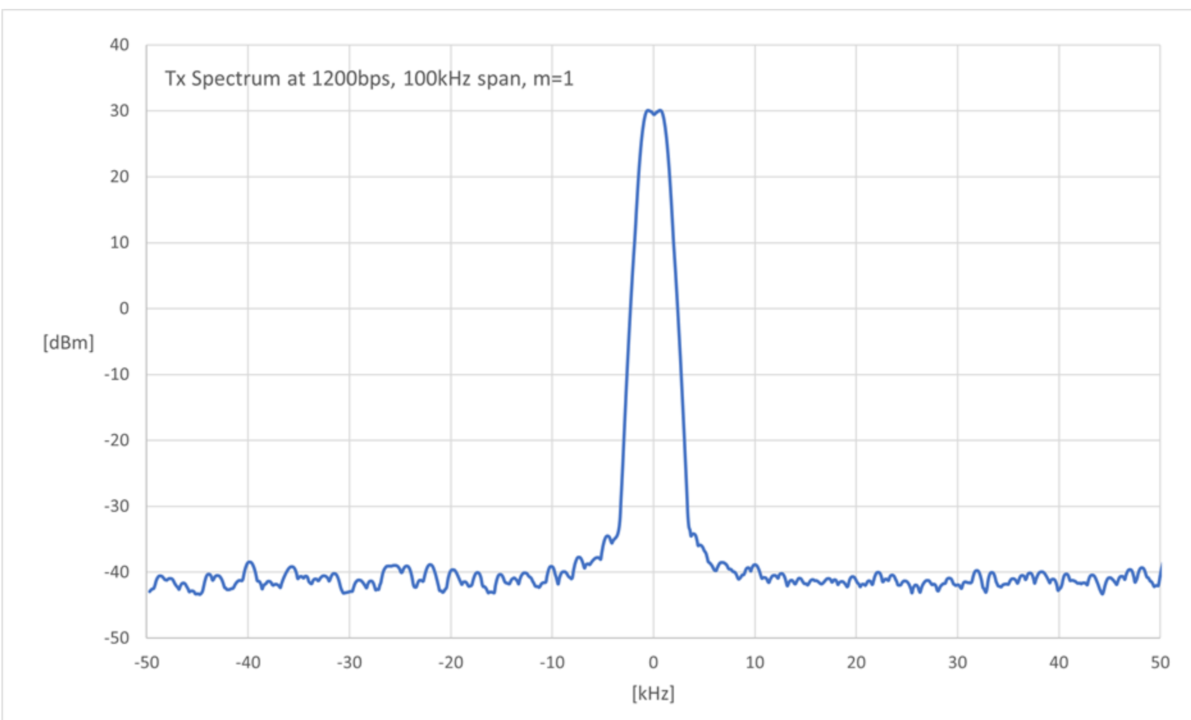

Figure 12: Tx Spectrum at 1200 bps, 100 kHz Span, m=1

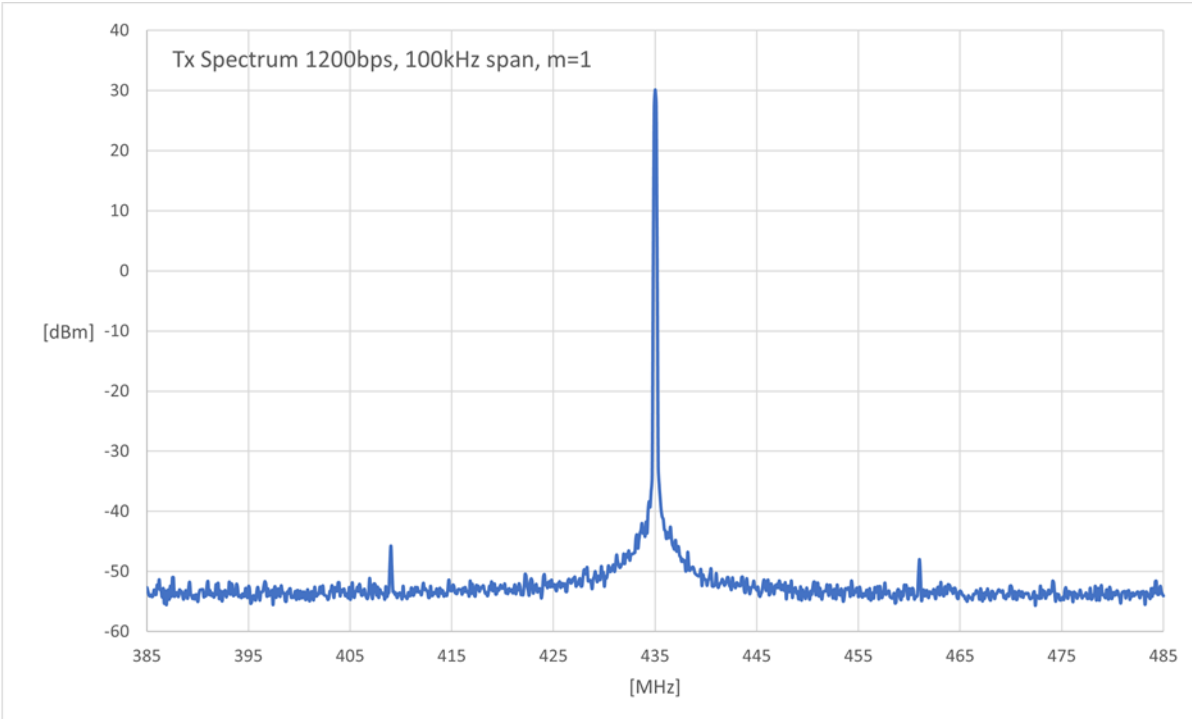

Figure 13: Tx Spectrum at 1200 bps, 100 MHz Span, m=1

6.2 Receiver

Table 8: RF Characteristics in Receive Mode

Parameter	Condition	Unit	Min	Typical Value	Max
Frequency Range		MHz		400÷403 430÷440	
Baud Rate in the Air		bps	1200		19200
SNR	PER<1% @9600bps	dB		14	
Input Power		dBm			10

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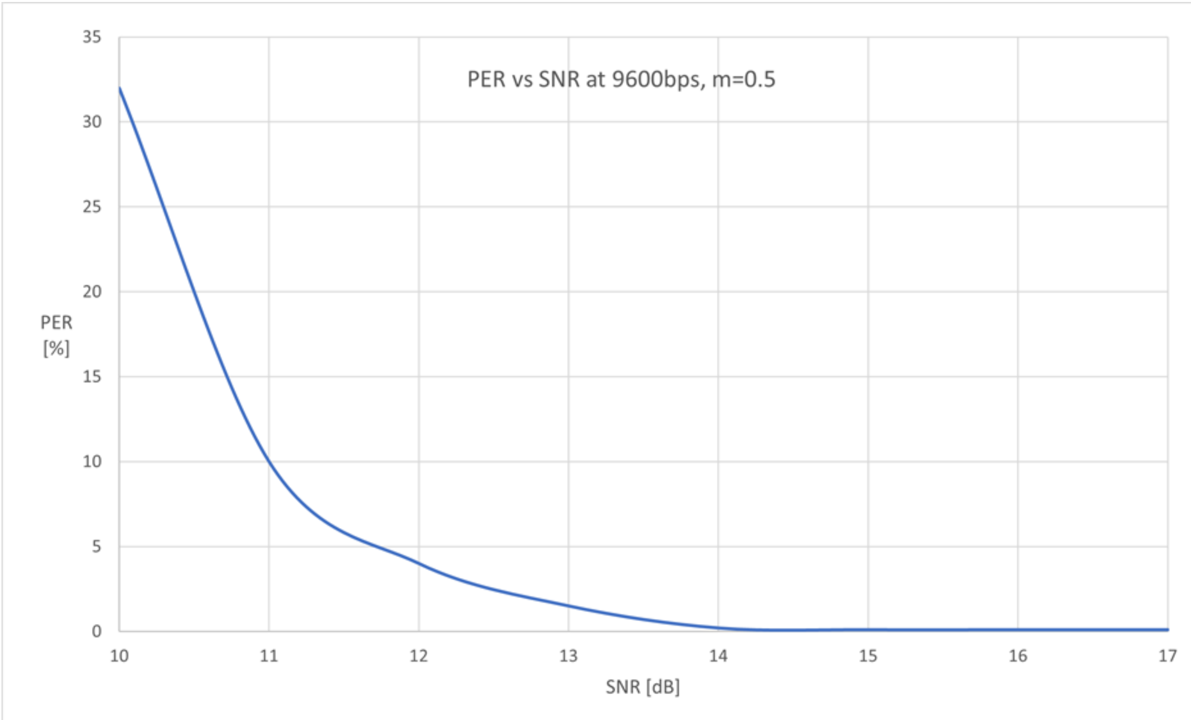

Figure 14: PER vs SNR at 9600 bps, m=0.5

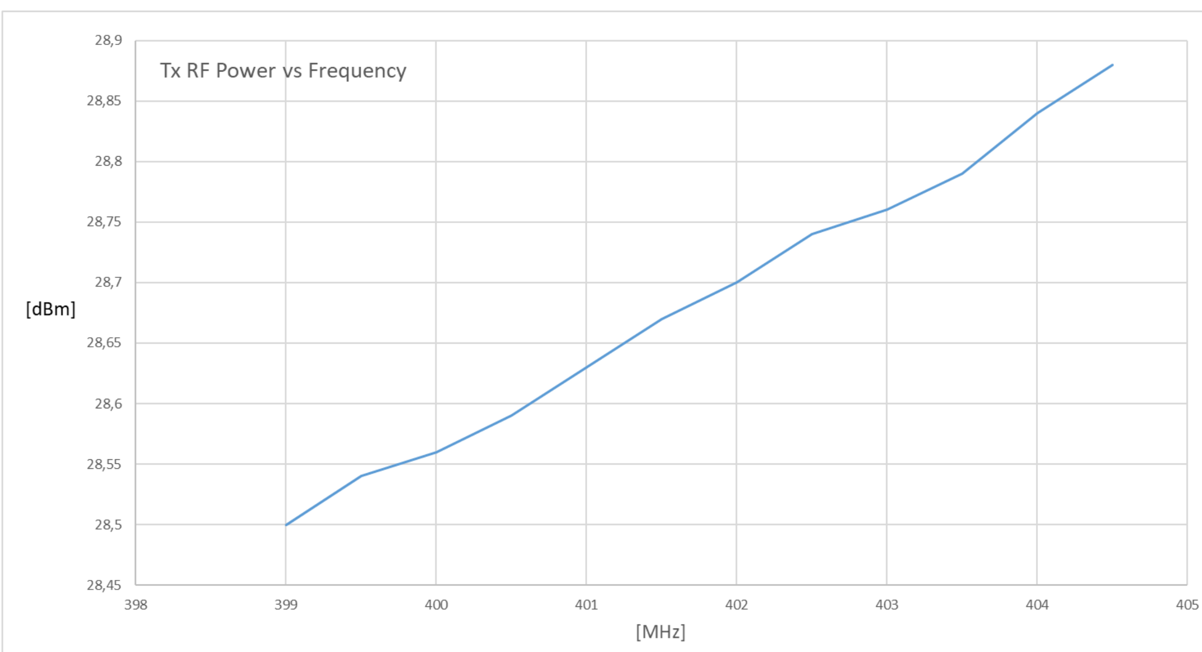

Figure 15: Tx RF Power vs Frequency [399 to 404 MHz] at 3.3Vdc, 24°C

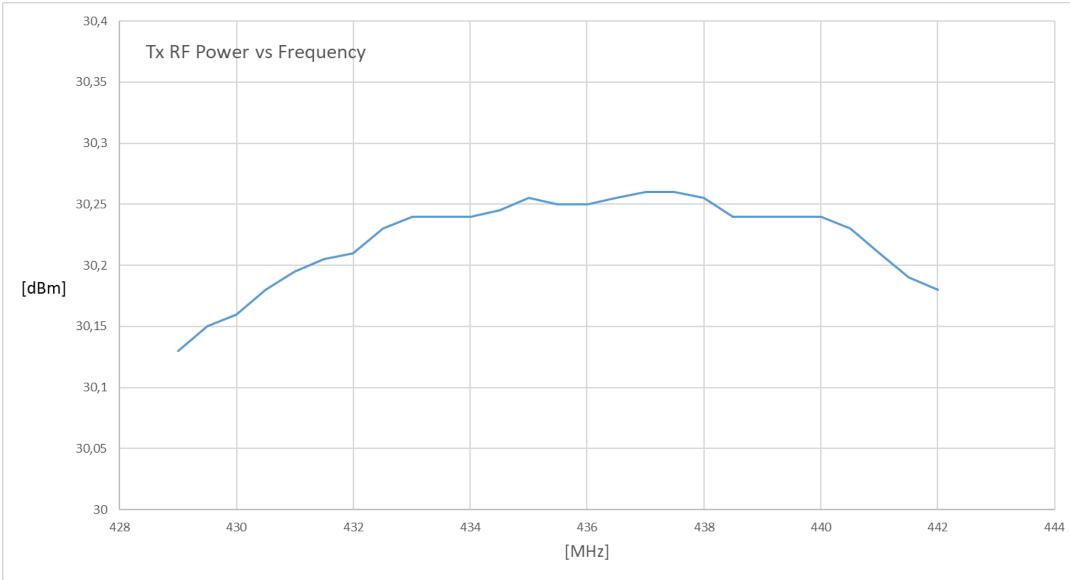

Figure 16: Tx RF Power vs Frequency [429÷442MHz] at 3.3Vdc, 24°C

7 BOOTLOADER

EnduroSat's UHF Transceiver is equipped with a bootloader and an application. The bootloader allows for secure in-flight firmware updates but can also be used for standard (low throughput) command and data handling. It only partially supports the ESTTC protocol and can operate only with some of the RF modes. If the version of the bootloader is below v.2.0.0, then all RF modes are supported except for the following: 19200 – 9600 bauds and 19200 – 19200 bauds. If one of these two RF modes is chosen, the Status Control Word (SCW) will display the chosen value, but the actual RF mode will be the default one, 9600 – 2400 bauds. In case the bootloader version is v.2.0.0 or higher, the only supported RF mode is 9600 – 2400 bauds. Again, the SCW will display the chosen RF mode, but the actual RF mode will be the default one. In either bootloader version case, if the user switches back to application mode, the SCW displayed RF mode will be loaded and used. For example, if the user chooses 19200 – 4800 bauds while in application mode and then switches to bootloader mode, then the displayed SCW will be 19200 – 4800, but the actual RF mode will be 9600 – 2400 (for bootloader version v.2.0.0). If the transceiver switches back to application, the displayed and actual RF modes will be again 19200 – 4800 bauds.

The main bootloader supported features are:

- Secure firmware updates;
- AX.25 beacon messages (but no AX.25 automatic decoding of incoming messages);
- Transparent mode;
- FRAM read/write.

The ESTTC commands supported by the bootloader are marked for each command (see section 10. Command Types and Description) and span the basic configuration of the UHF module. As of bootloader version v.2.0.0, all commands support CRC32 as described in section 9.5 ESTTC Protocol Packet CRC32 Description and Information.

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8 UPDATING FIRMWARE

8.1 Overview

The UHF Transceiver is designed to allow secure application firmware updates. An update can be executed via radio or UART while the device is in bootloader or application mode. The update files are provided by EnduroSat and are in a proprietary .SCRM format.

8.2 Firmware Update Procedure Diagram

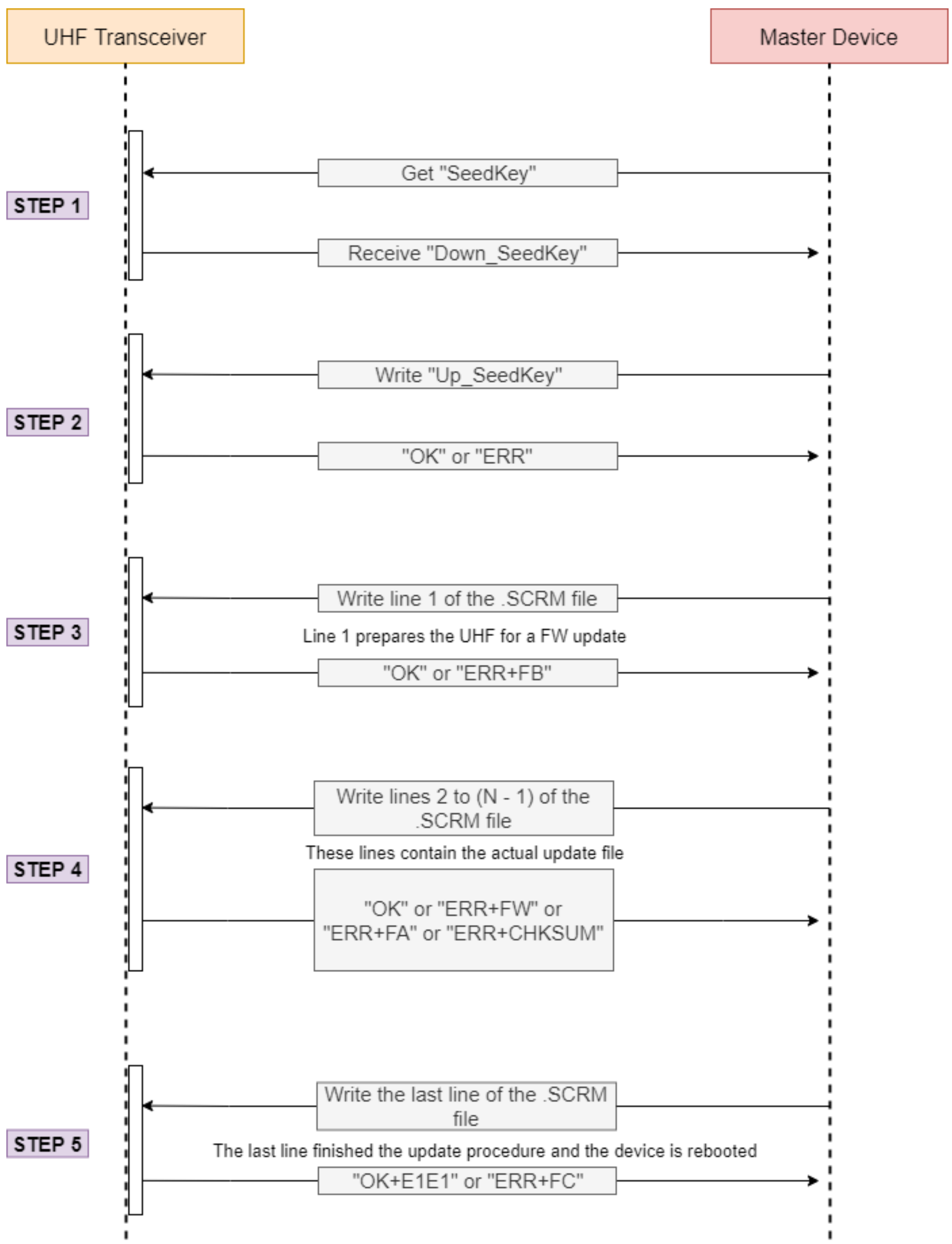

Figure 17: Update Flow of the UHF Transceiver Application Firmware

8.3 Update Step 1

- The **Master** requests the ***SeedKey*** from the **UHF** by sending **Secure mode** command in read format;
- The **UHF** returns the ***Down_SeedKey***, which is: ***SeedKey*** ^ DOWNLINK_XOR.

8.4 Update Step 2

- The **Master** XORs the received ***Down_SeedKey*** to get the ***SeedKey***, or: ***SeedKey = Down_SeedKey*** ^ DOWNLINK_XOR;
- The **Master** writes the ***Up_SeedKey*** by issuing a **Secure mode** write command, where: ***Up_SeedKey = SeedKey*** ^ UPLINK_XOR;
- The UHF XOR's the ***UP_SeedKey*** to get the original ***SeedKey*** or: ***SeedKey = UP_SeedKey*** ^ UPLINK_XOR;
- The UHF replies with "***OK***" if the original key has been restored or with "***ERR***" if not.

8.5 Update Step 3

- The **Master** sends the first line of the .SCRM file by issuing a **FW update** command;
- The **UHF** replies with "***OK***" or with "***ERR+FB***" if there is a memory error. The Master device should start a new update procedure.

8.6 Update Step 4

- The **Master** sends all but the last line of the .SCRM file using the **FW update** command;
- The **UHF** replies after each received line with "**OK**" if reception is successful, with "***ERR+CHKSUM***" if the line has been received corrupted, with "***ERR+FW***" if an error during storing the line has occurred. If the **Master** receives one of the above errors, it must resend the last line until an "***OK***" reply is received. If the **Master** receives no reply, it must repeat the line as it is unclear whether it has been received or not.

8.7 Update Step 5

- The **Master** sends the last line of the .SCRM file using the **FW update** command;
- The **UHF** replies with "***OK+F1F1***" if the update was successful and reboots, loading the new application firmware. If the **UHF** replies with "***ERR+FC***" then the update was unsuccessful, and the **Master** device must start the entire update procedure from the beginning.

8.8 DOWNLINK_XOR and UPLINK_XOR Values

- DOWNLINK_XOR = 0xAB7563CD
- UPLINK_XOR = 0x6ACD3B57

8.9 Other Possible Replies

In the unlikely event that an "***ERR***" or "***ERR+FA***" message is received during the update procedure, please contact EnduroSat for support.

8.10 Updating at Different RF Modes

Firmware updates can be successfully performed under any RF mode supported by the UHF Transceiver. However, it should be noted that at the low speed RF modes (such as 1200 – 600 bauds) the reply after each line can take longer time (due to the low speed) and should be considered. Otherwise, the update will not be possible as both the transmitting and receiving radios (the updating and the updated) will transmit at the same time.

9 PROTOCOL DESCRIPTION

9.1 Features

EnduroSat's Telemetry and Telecommand (ESTTC) protocol highlighted features are as follows:

- Supported interface UART TTL full duplex w/o flow control, default 115200, 8, n, 1;
- Module configuration, control and status;
- Transmission power adjustable via command (please contact EnduroSat);
- Direct access to radio transceiver properties;
- Local and remote (in-flight) secured application firmware update;
- ESTTC mode for handling UHF transceiver read/write commands (default mode);
- Transparent mode for passing TX/RX data from the UART to the radio and vice versa;
- Beacon transmission in AX.25 UI-frame in disconnected mode;
- Beacon transmission in MIDI audio format and Morse code;
- All parameters and configurations are stored in non-volatile FRAM memory;
- User-accessible non-volatile 256 KB FRAM memory.

9.2 Radio Packet Structure Description

The radio packet structure utilized in Endurosat's UHF module contains a preamble, a sync word, payload (separated in two data fields) and CRC16 (depicted in Figure 18). These fields are described in detail in Table 9.

Preamble	Sync.Word	Data Field 1	Data Field 2	CRC16
5 Bytes	1 Byte	1 Byte	0 - 128 Bytes	2 Bytes

Figure 18: UHF TYPE II Packet Structure (Uplink/Downlink)

Table 9: Packet Fields Description

Field	Length [Bytes]	Description	Bit/Byte Order of Transmission
Preamble	5	Value: 0xAAAAAAAAAA	LSBit First
Sync Word	1	Value: 0x7E	LSBit First
Data Field 1	1	Length of "Data Field 2"	MSBit First
Data Field 2	0-128	Payload (variable number of bytes)	MSBit First
CRC	2	CRC-16/CCITT-FALSE Polynomial: x16 + x12 + x5 + 1, Seed (initial value): all 1's Transmitted MSByte first. The CRC is applied to Data Field 1 + Data Field 2.[1]	MSBit First, MSByte First

[1] **NOTE**: For testing purposes, please use https://crccalc.com/ with settings Calc CRC-16 and Algorithm CRC-16/CCITT-FALSE, or an alternative.

9.3 AX.25 Protocol UI Frame Structure Description

The AX.25 protocol UI frame used in the UHF Transceiver is depicted in Figure 19. Notice that it fits inside Data Field 2 and is surrounded by a Preamble and Postamble.

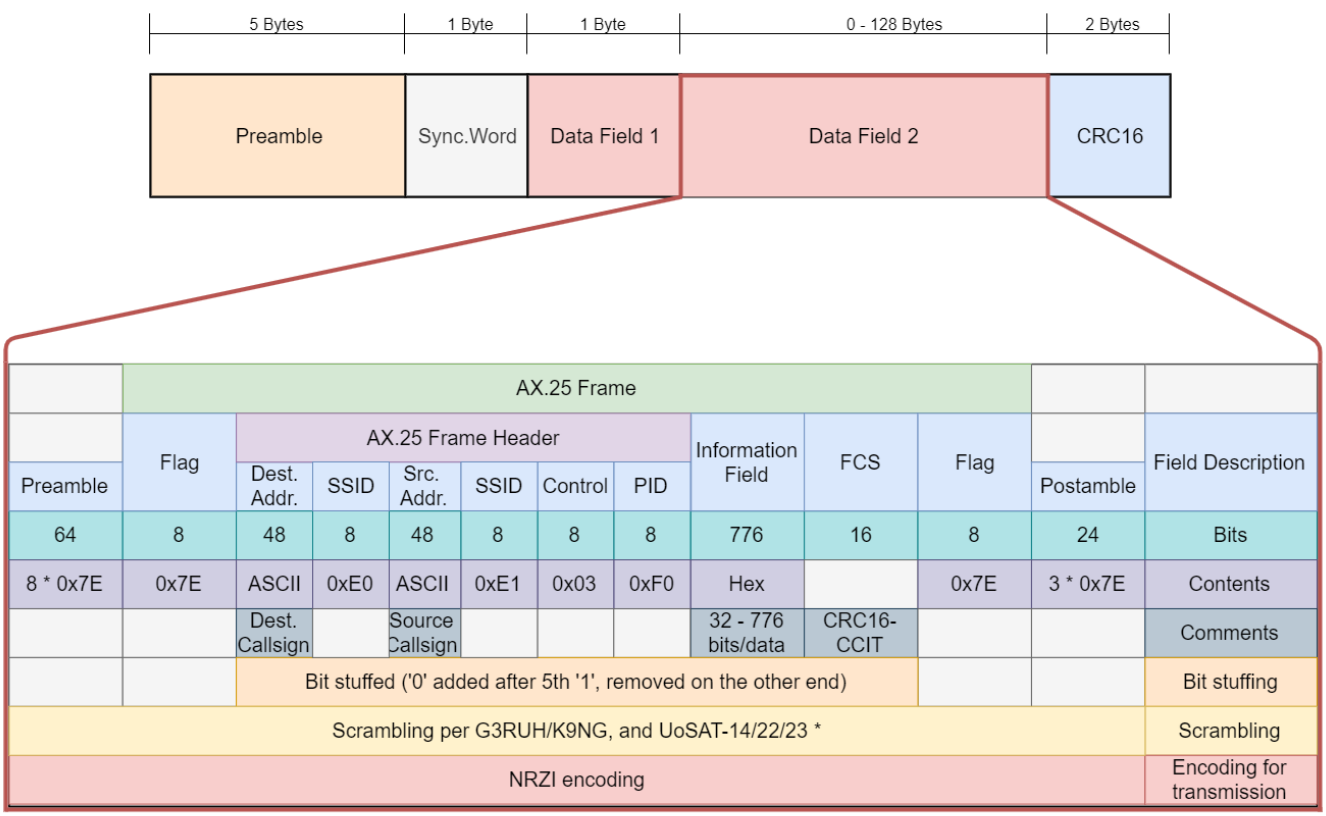

Figure 19 AX.25 Protocol UI Frame Structure

The used scrambling polynomial is 1 + X12 + X17. This means the currently transmitted bit is the EXOR of the current data bit, plus the bits that have been transmitted 12 and 17 bits earlier. Likewise, the unscrambling operation simply EXORs the bit received now with those sent 12 and 17 bits earlier. The unscrambler perforce requires 17 bits to synchronize.

9.4 ESTTC Protocol Packet Structure Description

The ESTTC protocol packet utilizes the 128 bytes of the payload (Data Field 2 from Figure 18 and Figure 19) for read/write commands and firmware update when the UHF Transceiver is in ESTTC mode. Each command consists of header, command type, address and command code, followed by a different number of command specific data, blank (optional), CRC32 (optional) and ends with <CR>, as depicted in Figure 20 and Table 10. All commands are in ASCII format.

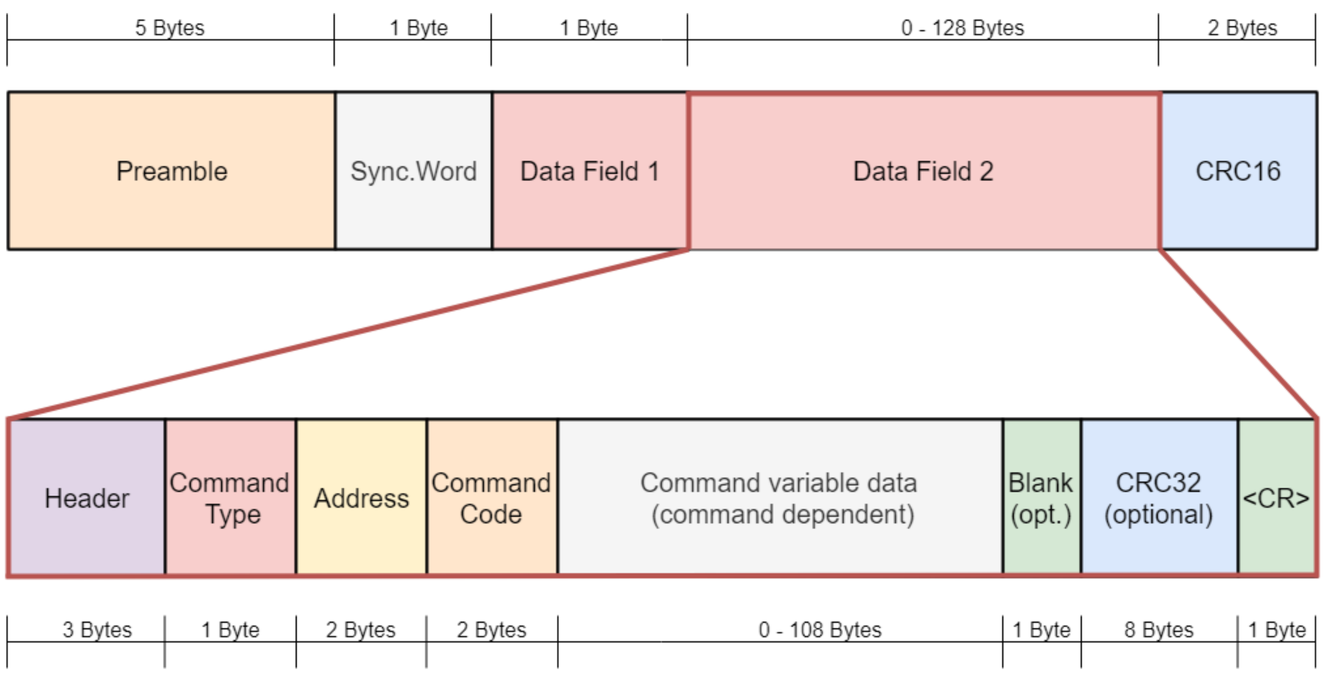

Figure 20 ESTTC Protocol Packet Structure as a Part of the Radio Packet

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Table 10: ESTTC Protocol Packet Fields Description

Field	Length [Bytes]	Description
Header	3	Value: ES+[1]
Command Type	1	Values: R, W
Address	2	Values: 22, 23
Command Code	2	Values: 00 – FF
Command variable data	0 – 108	Depending on the command type this data can be FRAM addresses, registers, values, etc. See section 10. Command Types and Description for further information
Blank (optional)	1	Value: 0x20 HEX or SPACE as ASCII
CRC32 (optional)	8	Calculated CRC32 value as ASCII symbols
<CR>	1	Value: 0x0D HEX or CR as ASCII

[1] NOTE: Unless otherwise stated, all values are given as ASCII symbols.

9.5 ESTTC Protocol Packet CRC32 Description and Information

9.5.1 CRC32 Implementation Description

The different parameters used in EnduroSat's CRC32 implementation are presented in Table 11.

Table 11: CRC32 Implementation Description

CRC Parameter	Value
Polynomial	0x04C11DB7 or $(x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^{8} + x^{7} + x^{5} + x^{4} + x^{2} + x + 1)$
Initial value	0xFFFFFFFF
Final XOR	0xFFFFFFFF
Input reflection	TRUE
Output reflection	TRUE

Following the above implementation, the calculated value for the standard sequence of ASCII characters **"123456789"** would be: **0xCBF43926**

9.5.2 Sending ESTTC Commands with and without CRC

All ESTTC commands can be sent with or without CRC as of Application/Bootloader FW version 2.00. If commands without CRC are preferred, the answer to these commands will be without CRC and the command structure described in section 10. Command Types and Description can be followed by simply dropping the blank space and the following eight ASCII symbols, which represent the calculated CRC.

For example, for command 10.1 Status Control Word (SCW), the typical read command containing CRC would be (ASCII):

ES+R2200 BD888E1F<CR>

and the typical read command without CRC would be (ASCII):

ES+R2200<CR>

9.5.3 Calculating the CRC with the "xHF and OBC Configurator" Desktop Application

A simple CRC calculator is embedded in the "xHF and OBC Configurator" application, which is distributed with the UHF module. The calculator can be located under Tools and is useful if a third-party terminal program or script is used for communicating with the transceiver.

NOTE: EnduroSat strongly recommends sending commands with CRC as this ensures proper command reception and subsequent execution.

9.6 Transparent (PIPE) Mode Description

In Transparent (PIPE) mode the UHF Transceiver transmits the data received via UART over the radio and vice versa, data received by the radio is transmitted over UART. This requires no additional commands, but only activation of the Transparent mode (see section 10.1 Status Control Word (SCW)).

To achieve optimal transmission speeds, the user data must be split into 128 bytes chunks before being sent to the UHF Transceiver as the maximum length of the radio packet Data Field 2 is 128 bytes (Figure 18). There must also be a reasonable time gap between two consecutive packets as the UHF Transceiver takes a certain period of time to send each packet. If more data is sent to the UHF, data is buffered. However, the buffers have a finite size and data may be lost if data transmission rate is too high. To prevent this case, the user can consult Table 12, which relates RF modes and baudrates to the minimum required time between two consecutive packets with size 128 bytes for reliable and optimal communication. Of course, if the packets are shorter, then the times described in Table 12 will be different.

Table 12: RF Mode and Baudrate (relation to minimum time between two consecutive packets)

RF Mode / Baud Rate	115200	19200	9600
1200 – 600	> 920[ms]	> 920 [ms]	> 920 [ms]
2400 – 600	> 460[ms]	> 460 [ms]	> 460 [ms]
4800 – 1200	> 240 [ms]	> 240 [ms]	> 240 [ms]
9600 – 2400	> 120 [ms]	> 120 [ms]	> 3* [ms]
9600 – 4800	> 120 [ms]	> 120 [ms]	> 3* [ms]
19200 – 4800	> 60 [ms]	> 3* [ms]	> 3* [ms]
19200 – 9600	> 60 [ms]	> 3* [ms]	> 3* [ms]
19200 – 19200	> 60 [ms]	> 3*[ms]	> 3* [ms]

*See description in text.

The device stays in Transparent mode for as long as data is received from the radio/UART. If no data is received for a certain period of time, which is user-configurable (see section 10.7 Transparent (PIPE) Mode Timeout Period Configuration), then the UHF Transceiver exits Transparent mode and enters Normal mode, where it listens for valid ESTTC commands or AX.25 UI-frames.

9.7 Automatic AX.25 UI-Frame Decoding

When the device is not in Transparent mode, it listens actively for valid ESTTC commands or AX.25 UI-frames following the implementation described in section 9.3 AX.25 Protocol UI Frame Structure Description. If a valid frame is detected, it is decoded, and the message is transmitted over the UART interface.

9.8 Communicating via I^{2}C

- The UHF Transceiver is a slave device, but it can switch to master mode if commanded so by a radio command or UART ;
- 7-bit address in the range **0x22 ÷ 0x23**;
- Clock speed is 400kHz;
- Pull-up resistor value is user configurable.

The ESTTC commands format is the same when the command is sent via I^{2}C, UART or radio. However, there are some commands that are not available via I^{2}C (see section 10. Command Types and Description). To send a command to the UHF and to read the result, the I^{2}C Master must first initiate a write and then a read following the standard I^{2}C flow (Figure 21).

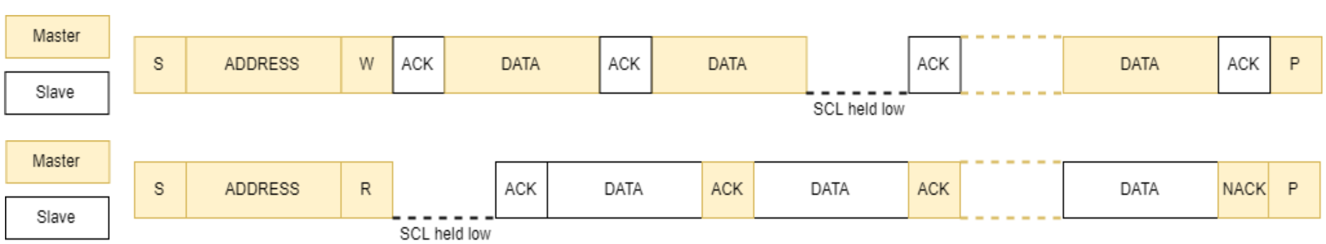

Figure 21 Slave Receiver (top) and Slave Transmitter (bottom) Modes on the I^{2}C Bus

To read the entire command response, the master is expected to generate the necessary number of clocks. If it fails to do so, the response is lost prior to the next I^{2}C command. If the master reads more data than the reply message length, the UHF replies with 0x00.

After each read request there is some delay before the UHF is ready to send a response. During this time the SCL line is held low. This delay may be as long as 150 ms, and during this time the SCL line is held low by the UHF.

The pull-up resistors value choice is flexible and can be selected to be 10k, 4k7, 10k and 4k7 in parallel or None. This is configured with command 10.12 I^{2}C Pull-Up Resistors Configuration Read/Write [Application].

9.9 Common Answers Intrinsic to All ESTTC Commands

Table 13: Common Command Answers

Answer	Meaning
E_CRC_ERR	Command has been sent with a wrong CRC attached, command is received with an error or the received command CRC has an error
E_CRC_ERR_LEN	Command length does not comply with ESTTC protocol commands description with or without CRC
I2C_NACK	Typically received if the UHF Antenna is not attached and command F3 is executed

10 COMMAND TYPES AND DESCRIPTION

10.1 Status Control Word (SCW) [Application/Bootloader]

Table 14: SCW Format

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res	HFXT	UartBaud		Reset	RfMode			Echo	BCN	Pipe	Boot	CTS	SEC	FRAM	RFTS
0	0	r/w-3		r/w-0	r/w-3			r/w-0	r/w-0	r/w-0	r-X	r-X	r-X	r-X	r-X

Table 15: Available RF Modes

Bit Field	Meaning
[15]	Reserved: For future use (default value is 0)
[14]	HFXT: High frequency oscillator status, 0 – oscillator OK, 1 – oscillator error
[13, 12]	UartBaud: Speed of the UART interface. Possible values 00-9600, 01 - reserved, 10-19200, 11-115200 (default). NOTE: 230.400 kbps UART interface speed supported (optional)
[11]	Reset: Write 1 to reset the device, 0 – no effect (default)
[10, 9 ,8]	RFMode: see Table 16
[7]	Echo: Local UART echo of the transmitted symbols over the radio when a valid ESTTC command is received via radio; 1 – Echo on, 0 – Echo off (default)
[6]	BCN: Beacon message control; 1 – enabled, 0 – disabled (default)
[5]	Pipe: Transparent mode communication control; 1 – Pipe mode on, 0 – Pipe mode off (default)
[4]	Boot: Indicates whether the device is in bootloader or application mode 1 – Bootloader, 0 – Application
[3]	CTS: Reserved for future use (default value is 0)
[2]	SEC: Reserved (default value is 0)

[1]	FRAM: Indicates whether FRAM is initialized correctly after reset; 1 – OK, 0 – FRAM Error
[0]	RFTS: Indicates whether radio transceiver is initialized correctly after reset; 1 – OK, 0 – Radio Error

To switch back and forth between bootloader and application, the user will have to set both bit 4 and bit 11 bearing in mind their effect as described in Table 15. If only bit 4 is set/cleared, the device will stay in its current mode (bootloader or application).

Table 16: Available RF Modes

RF Mode #	Modulation	Data rate, [bps]	Fdev, [Hz]	ModInd
0 [000]	2GFSK	1200	600	1
1 [001]	2GFSK	2400	600	0.5
2 [010]	2GFSK	4800	1200	0.5
3 [011] (default)	2GFSK	9600	2400	0.5
4 [100]	2GFSK	9600	4800	1
5 [101]	2GFSK	19200	4800	0.5
6 [110]	2GFSK	19200	9600	1
7 [111]	2GFSK	19200	19200	2

NOTE: For other modulations schemes please contact EnduroSat for support.

Table 17: Status Control Word

Status Control Word	
Write	Answer
ES+W[AA]00[WWWW][B][C..C]<CR>	1) OK+[WWWW][B][C..C]<CR> : successful configuration 2) OK+C3C3[B][C..C]<CR>: response when the UHF is commanded to enter Bootloader from Application 3) OK+8787[B][C..C]<CR>: response when the UHF is commanded to enter Application from Bootloader 2) +ESTTC[B][C..C]<CR>: response at exit of PIPE mode (not valid if command is sent via I^2C)
Read	Answer
ES+R[AA]00[B][C..C]<CR>	OK+[RR][AA][BB][WWWW][B][C..C]<CR>

[AA] is the device address in HEX format;

[WWWW] is a 16-bit value in HEX format used to modify the SCW bit fields in “Write” command and current SCW content as a result of “Write” and “Read” command execution;

[RR] is the last received signal strength indicator (RSSI);

[BB] is the reset counter. It counts the number of times whereby the device has undergone reset (power down, reset via command, new SW via bootloader);

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

Example commands:

- ES+R2200 BD888E1F<CR>
- ES+W22003323 589B0F83<CR>

10.2 Radio Frequency Configuration [Application/Bootloader]

Table 18: Radio Frequency

Radio Frequency	
Write	Answer
ES+W[AA]01[FFFFFF][NN][B][C..C]<CR>	OK[B][C..C]<CR>: successful configuration ERR[B][C..C]<CR>: configuration failed
Read	Answer
ES+R[AA]01[B][C..C]<CR>	OK+[RR][FFFFFF][NN][B][C..C]<CR>

[AA] is the device address in HEX format;

[FFFFFF] is the fractional part and [NN] is the integer divider of the radio PLL synthesizer in HEX format;

[RR] is the last RSSI;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32;

The values can be calculated according to SILICON LABS Si4463/4 revB1B Command/Property API Documentation FREQ_CONTROL Grp 0x40 or Si4463 datasheet, Ch.5.3. Synthesizer using the formula: RF_channel,[Hz]=(F_cint+F_cfrac⁄2^19)×NPRESC×F_(req_xo)/outdiv, where NPRESC=2, F_(req_xo)=26000000,outdiv=8.

The entire F_cfrac word is 20-bits in length, but the most significant bit should always be set to 1, and thus the term F_cfrac⁄2^19 will always be between 1 and 2 in value. As a result, the integer term F_cint should be reduced by 1. **The default value is 76620F41 = 435000000 Hz**.

Example: A total desired divide ratio of (F_cint+F_cfrac⁄2^19)=60.135 should be implemented as F_cint=59, F_cfrac⁄2^19 =1.135.

Example commands:

ES+R2201 CA8FBE89<CR>

ES+W220150E90942 36F6ADAB<CR>

10.3 Read Uptime [Application/Bootloader]

Table 19: Read Uptime

Uptime	
Read	Answer
ES+R[AA]02[B][C..C]<CR>	OK+[RR][PPPPPPPP][B][C..C]<CR>

[AA] is the device address in HEX format;

[PPPPPPPP] is the uptime value in seconds in HEX format;

[RR] is the last RSSI;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

Example commands:

- ES+R2202 5386EF33<CR>

10.4 Read Number of Transmitted Packets [Application/Bootloader]

Table 20: Transmitted Packets

Transmitted Packets	
Read	Answer
ES+R[AA]03[B][C..C]<CR>	OK+[RR][PPPPPPPP][B][C..C]<CR>

[AA] is the device address in HEX format;

[PPPPPPPP] is the value in HEX format;

[RR] is the last RSSI;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

Example commands:

- ES+R2203 2481DFA5<CR>

10.5 Read Number of Received Packets [Application/Bootloader]

Table 21: Received Packets

Received Packets	
Read	Answer
ES+R[AA]04[B][C..C]<CR>	OK+[RR][PPPPPPPP][B][C..C]<CR>

[AA] is the device address in HEX format;

[PPPPPPPP] is the value in HEX format;

[RR] is the last RSSI;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

Example commands:

- ES+R2204 BAE54A06 <CR>

10.6 Read Number of Received Packets with CRC Error [Application/Bootloader]

Table 22: Received Packet with CRC Error

Received Packet with CRC Error	
Read	Answer
ES+R[AA]05[B][C..C]<CR>	OK+[RR][PPPPPPPP][B][C..C]<CR>

[AA] is the device address in HEX format;

[PPPPPPPP] is the value in HEX format;

[RR] is the last RSSI;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

The read value indicates the number of packets that have been received, but the CRC of the radio packet was found to be wrong. This value should not to be mixed with the CRC32 that is a part of the ESTTC protocol packet structure.

Example commands:

- ES+R2205 CDE27A90<CR>

10.7 Transparent (PIPE) Mode Timeout Period Configuration [Application/Bootloader]

Table 23: Transparent Mode

Transparent Mode	
Write	Answer
ES+W[AA]06000000[TT][B][C..C]<CR>	1) OK[B][C..C]<CR>: successful configuration 2) ERR[B][C..C]<CR>: unsuccessful configuration
Read	Answer
ES+R[AA]06[B][C..C]<CR>	OK+[RR]000000[TT][B][C..C]<CR>

[AA] is the device address in HEX format;

[TT] is the period in HEX format in seconds;

[RR] is the last RSSI;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

This timeout defines the time in which the device stays in Transparent mode after the last transfer of incoming UART data to the radio or vice versa. If there is no incoming data for longer than the timeout period, then the module returns to ESTTC (default) mode. Minimum value is 0x01 = 1 second. Maximum value is 0xFF=255 seconds. The default value is 10 seconds.

Example commands:

- ES+R2206 54EB2B2A<CR>
- ES+W220600000060 9F610824<CR>

10.8 Beacon Message Transmission Period Configuration [Application/Bootloader]

Table 24: Beacon Transmission

Beacon Transmission	
Write	Answer
ES+W[AA]070000[TTTT][B][C..C]<CR>	1) OK[B][C..C]<CR>: successful configuration 2) ERR[B][C..C]<CR>: try to configure zero period.
Read	Answer
ES+R[AA]07[B][C..C]<CR>	OK+[RR]0000[TTTT][B][C..C]<CR>

[AA] is the device address in HEX format;

[TTTT] is the period in HEX format in seconds;

[RR] is the last RSSI;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32;

When beacon transmission is enabled, the device transmits the beacon message at a pre-configured 2-byte period of 1-65535 seconds. The default value is 60 seconds.

Example commands:

- ES+R2207 23EC1BBC<CR>
- ES+W220700000060 881A1C67<CR>

10.9 Audio Beacon Period Between the Transmissions [Application/Bootloader]

Table 25: Audio Beacon Period

Audio Beacon Period	
Write	Answer
ES+W[AA]080000[TTTT][B][C..C]<CR>	1) OK[B][C..C]<CR>: successful configuration 2) ERR[B][C..C]<CR>: [TTTT] = [1..30]
Read	Answer
ES+R[AA]08[B][C..C]<CR>	OK+[RR]0000[TTTT][B][C..C]<CR>

[AA] is the device address in HEX format;

[TTTT] is the period in HEX format in seconds;

[RR] is the last RSSI;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

To enable the transmission [TTTT] > 30, to disable the transmission [TTTT] = 0. Any other values are incorrect and lead to an error. By default, the audio beacon is disabled.

NOTE: A period of at least 30 seconds between the consecutive transmissions is guaranteed to reduce the power consumption and to enable the temperature dissipation.

Example commands:

- ES+R2208 B353062D<CR>
- ES+W220800000060 57A3D3B6<CR>

10.10 Restore Default Values [Application/Bootloader]

Table 26: Default Values

Default Values	
Write	Answer
ES+W[AA]09[B][C..C]<CR>	OK[B][C..C]<CR>: successful configuration

[AA] is the device address in HEX format;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32;

By using this command, the user can restore initial values for:

- Destination/Source/Morse code call sign;
- Audio beacon period and message;
- Text beacon period;
- Pipe timeout period.

Example commands:

- ES+W2209 0CB4B9CB<CR>

10.11 Internal Temperature Sensor Measurement Value [Application]

Table 27: Temperature Measurement

Temperature Measurement	
Read	Answer
ES+R[AA]0A[B][C..C]<CR>	OK[B][TTTT][B][C..C]<CR>

[AA] is the device address in HEX format;

[TTTT] is the signed measured temperature in DEC format with 0.1 °C accuracy;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

Example commands:

- ES+R220A 9A8ACFB5<CR>

ENDUROSAT

10.12 I²C Pull-Up Resistors Configuration Read/Write [Application]

Table 28: I²C Pull-Up Resistors

I²C Pull-Up Resistors	
Write	Answer
ES+W[AA]0B[CC][B][C..C]<CR>	1) OK[B][C..C]<CR>: command accepted
Read	Answer
ES+R[AA]0B[B][C..C]<CR>	1) OK+[II][B][C..C]<CR>

[AA] is the device address in HEX format;

[II] is the currently selected I²C pull-up resistor configuration in HEX, where 0x01 enables the 10k resistor, 0x02 enables the 4k7 resistors, 0x03 enables both the 10k and 4k7 resistors. Any other value will turn-off all pull-up resistors;

[CC] is the user desired I²C pull-up resistor configuration in HEX;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

Example commands:

- ES+R220B 03839E0F<CR>
- ES+W220B03 E358CBB2 <CR>

10.13 Generic Write And/Or Read From an I²C Device [Application]

Table 29: Write and/or Read from an I²C Device

Write and/or Read from an I²C Device	
Write	Answer
ES+W[AA]F1[C][XX][WW][D...D][RR][B][C..C]<CR>	1) OK+[RD..RD][B][C..C]<CR>: data read successfully 2) OK+SENT[B][C..C]<CR>: successful write on the I²C bus (no read requested) 3) ERR+I2C_NOINIT[B][C..C]<CR>: I²C not successfully initialized 4) ERR+WRT_LEN[B][C..C]<CR>: write length exceeded 5) ERR+READ_LEN[B][C..C]<CR>: read length exceeded 6) ERR+NA[B][C..C]<CR>: cmd unavailable via I²C 7) Consult Table 13

[AA] is the device address in HEX format;

[C] indicates the way the data is sent. There are three options:

- 'S' – sends the data written in [D...D] and then attaches a blank space and the CRC32 checksum (calculated according to the implementation described in ESTTC protocol packet CRC32 description and information);
- 'C' – sends the data and attaches a <CR> at the end as a termination symbol;
- 'D' – sends the data as it is with nothing additional;

[XX] is the I^{2}C slave device address in HEX format;

[WW] is the length of data in HEX format. This data is limited to 32 bytes (64 ASCII symbols);

[D...D] is the data to be placed on the I^{2}C bus in HEX format;

[RR] is the number of bytes to read from the slave device in HEX format;

[RD...RD] is the read data in HEX format. This read length is limited to 32 bytes (64 ASCII symbols);

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

This is a generic command allowing access via the UHF to all devices connected to the I^{2}C bus. When this command is sent, the UHF Transceiver switches to master mode. The above command can be sent via UART or radio and supports write only, write and read and read only modes.

To send a write only command, the read length should be set to 0x00. Likewise, to send a read only command, the write length should be set to 0x00.

NOTE: This command is not available via I^{2}C.

Example commands:

- ES+W22F1S230845532b523232303316 71E32F28<CR>

10.14 UHF Antenna Release Configuration [Application]

Table 30: UHF Antenna Release Configuration

UHF Antenna Release Configuration	
Write	Answer
ES+W[AA]F2[FFFF][B][C..C]<CR>	1) OK+[FFFF][B][C..C]<CR>: successful configuration 2) ERR<CR>: invalid command value
Read	Answer
ES+R[AA]F2[B][C..C]<CR>	OK+[PPPP][B][C..C]<CR>

[AA] is the device address in HEX format;

[PPPP] indicates the current UHF Antenna release configuration. The first byte denotes the enable automatic antenna deployment flag and the enable robust deployment flag. By default, these flags are not set (deployment is disabled). The second byte specifies the time in minutes (in HEX) after power-up after which the deployment sequence should be executed.

[FFFF] is presented in the table below.

Table 31: FFFF

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved			**First**	**Reserved**			**EN**	**Time**							
0	0	0	r/w-0	0	0	0	r/w-0	r/w-0	r/w-0	r/w-0	r/w-0	r/w-0	r/w-0	r/w-0	r/w-0

The upper byte can be used to enable/disable the automatic release sequence by setting/clearing the EN bit. The First bit indicates if the robust automatic release sequence is to be executed. If set, the release logic will check (after power-up/reset and first antenna connection) if any rods are opened. If such are found, the logic will consider that some issues have occurred and will try to deploy them first. If this algorithm is successfully executed, the First flag will be cleared automatically, otherwise it will stay set and the UHF Transceiver will try to deploy all open rods again at the next power-up/reset cycle.

The lower byte specifies the time in minutes after device power-up when antenna deployment should happen. This value is in HEX and can be anything between 0x0A and 0xFF including.

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32;

Bear in mind that if a release command is given to the device and the device has been powered up longer than the time indicated by the lower byte, the antenna release sequence will begin immediately! In case the command is sent via I^2C, the user may not get an appropriate reply as the UHF Transceiver will switch to I^2C master mode.

To prepare the UHF to release the antenna after the next power-up, power-up the UHF module, set the appropriate command values and power-off the device. At the next power-up the UHF will wait until the set time has elapsed and will release the antenna. If the device is not powered-off after the release command is set, the release will happen as soon as the internal UHF timer reaches the set time.

If no connection to the antenna has been established or if all rods have not deployed, the EN flag will not be cleared and at next power-up/reset the release logic will be restarted (release after the set time). Only once the antenna has returned a status that all rods are opened the EN flag will be cleared.

The release algorithm embedded in the UHF Transceiver will analyse the antenna rods statuses and will try to release all of them by turning on the different algorithms intrinsic to the UHF Antenna. For further information on the antenna, please consult EnduroSat's UHF Antenna documentation.

Example commands:

- ES+R22F2 2AE33143<CR>
- ES+W22F201FF 852DF0FE<CR>

10.15 UHF Antenna Read/Write [Application]

Table 32: UHF Antenna

UHF Antenna	
Write	Answer
ES+W[AA]F3[CC][B][C..C]<CR>	1) OK[B][C..C]<CR>: command accepted 2) ERR[B][C..C]<CR>: invalid command value
Read	Answer
ES+R[AA]F3[B][C..C]<CR>	1) OK+[PPPPPPPP] [B][C..C]<CR> 2) ERR+I2C_UNINIT[B][C..C]<CR>: I^{2}C not init. 3) ERR+NA[B][C..C]<CR>: cmd not available via I^{2}C 4) Consult Table 13

[AA] is the device address in HEX format;

[PPPPPPPP] is the current antenna status;

[CC] is the antenna deployment algorithm command;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

Consult EnduroSat's UHF Antenna documentation or contact EnduroSat for a list of commands and current antenna status replies.

NOTE: This command is not available via I^{2}C.

Example commands:

- ES+R22F3 5DE401D5<CR>
- ES+W22F31F C14B8267<CR>

10.16 Low Power Mode [Application]

Table 33: Low Power Mode

Low Power Mode	
Write	Answer
ES+W[AA]F4[B][C..C]<CR>	1) OK[B][C..C]<CR>: entered low power mode 2) ERR[B][C..C]<CR>: already in low power mode
Read	Answer
ES+R[AA]F4[B][C..C]<CR>	OK+[KK][B][C..C]<CR>

[AA] is the device address in HEX format;

[KK] indicates low power mode status. When KK = 01 the device is in low power mode and when KK = 00 the device is in normal mode. By default, the device is in normal mode;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

This command places the device in low power (sleep) mode. The command can be sent via UART or I^{2}C only and care must be taken to implement the necessary wake-up procedure. Otherwise, the transceiver will remain in sleep mode indefinitely! Upon entering low power mode, the current UHF configuration is saved and will be used once the device is brought back from sleep. To exit low power mode, any ESTTC command except for the current one can be used. However, it must be issued via UART or I^{2}C as radio communication is off.
Power consumption of the UHF Transceiver in sleep mode is 8.37 mA and 24.61 mA in normal mode.

Example commands:

- ES+R22F4 C3809476<CR>
- ES+W22F4 0B601B06<CR>

10.17 Destination Call Sign [Application/Bootloader]

Table 34: Destination Call Sign

Destination Call Sign	
Write	Answer
ES+W[AA]F5[DDDDDD][B][C..C]<CR>	OK[B][C..C]<CR>: successful configuration
Read	Answer
ES+R[AA]F5[B][C..C]<CR>	OK+DDDDDD[B][C..C]<CR>

[AA] is the device address in HEX format;

[DDDDDD] is the call sign in ASCII format (the first 6 symbols are used only);

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

The Destination Call Sign is used in the AX.25 protocol format. By default, the content is = “CQ“.

Example commands:

- ES+R22F5 B487A4E0<CR>
- ES+W22F5ABCDEF EB1BA8B1<CR>

10.18 Source Call Sign [Application/Bootloader]

Table 35: Source Call Sign

Source Call Sign	
Write	Answer
ES+W[AA]F6[DDDDDD][B][C..C]<CR>	OK[B][C..C]<CR>: successful configuration
Read	Answer
ES+R[AA]F6[B][C..C]<CR>	OK+DDDDDD[B][C..C]<CR>

[AA] is the device address in HEX format;

[DDDDDD] is the call sign in ASCII format (the first 6 symbols are used only);

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

The Source Call Sign is used in the AX.25 protocol format. By default, the content is = “XX0UHF”.

Example commands:

- ES+R22F6 2D8EF55A<CR>
- ES+W22F6FEDCBA 3C6B73DC<CR>

10.19 Morse Code Call Sign [Application]

Table 36: Morse Code Call Sign

Morse Code Call Sign	
Write	Answer
ES+W[AA]F7[LL][C...C][B][C..C]<CR>	1) OK[B][C..C]<CR>: successful configuration 2) ERR[B][C..C]<CR>: incorrect string length
Read	Answer
ES+R[AA]F7[B][C..C]<CR>	OK+[LL][C...C][B][C..C]<CR>

[AA] is the device address in HEX format;

[LL] is the number of symbols in DEC format (<37);

[C…C] is the symbol string, which consists of DASH (HEX 0x2D, ASCII -), DOT (HEX 0x2E, ASCII) and SPACE (HEX 0x20, ASCII). Any other symbol breaks further string parsing;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

By default, the Morse Code is = “-..- -..- ----- ..- .... ..-. “ X-ray X-ray Zero Uniform Hotel Foxtrot.

Example commands:

- ES+R22F7 5A89C5CC<CR>
- ES+W22F705…-- C2FFF8E7<CR>

10.20 MIDI Audio Beacon [Application]

Table 37: MIDI Audio Beacon

MIDI Audio Beacon	
Write	Answer
ES+W[AA]F8[LL][NND]…[NND][B][C..C]<CR>	1) OK[B][C..C]<CR>: successful configuration 2) ERR+MIDI[B][C..C]<CR>: incorrect midi number 3) ERR[B][C..C]<CR>: incorrect string length
Read	Answer
ES+R[AA]F8[B][C..C]<CR>	OK+[LL][NND]…[NND][B][C..C]<CR>

[AA] is the device address in HEX format;

[LL] is the number of notes in DEC format (<37);

[NND] is a note in ASCII format as NN is the number of the MIDI (Musical Instrument Digital Interface) piano key for that note/octave and D is its duration (see Table 38). The allowed MIDI numbers are [12 – 99].

Table 38: Duration Code Table

Symbol	Duration
‘w’	Whole note, no gap
‘W’	Whole note
‘h’	1/2 Note, no gap
‘H’	1/2 Note, no gap
‘D’	1/4 Note + 1/8 Note (‘D’ = ‘q’ + ‘o’)

‘q’	1/4 Note, no gap
‘Q’	1/4 Note
‘o’	1/8 Note, no gap
‘O’	1/8 Note
‘-‘	1/8 + 1/16 Dash delay
‘x’	1/16 Note, no gap
‘X’	1/16 Note
‘.’	Dot delay
Any other symbol	1/32 Note

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32;

NOTE: Default = “Ode to Joy“: 1571Q71Q72Q74Q74Q72Q71Q69Q67Q67Q69Q71Q71D69O69H

NOTE: No answer will be received if 37 or more notes are sent via radio frequency channel.

NOTE: In Bootloader mode Morse code and MIDI audio beacon are not supported.

Example commands:

- ES+R22F8 CA36D85D<CR>
- ES+W22F80371Q71Q71Q 78DEE43E<CR>

10.21 Read Software Version Build [Application/Bootloader]

Table 39: Software Version

Software Version	
Read	Answer
ES+R[AA]F9[B][C..C]<CR>	OK+[V.vv]<date, time>[B][C..C]<CR>

[AA] is the device address in HEX format;

In [V.vv] the first digit is related to the version and the second/third ones to the increment;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

Example commands:

- ES+R22F9 BD31E8CB<CR>

10.22 Read Device Payload Size [Application/Bootloader]

Table 40: Payload Size

Payload Size	
Read	Answer
ES+R[AA]FA[B][C..C]<CR>	OK+[PPPP][B][C..C]<CR>

[AA] is the device address in HEX format;

[PPPP] is the payload size in HEX format (refer to Data Field 2, Figure 18);

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

Example commands:

- ES+R22FA E3EF11C5<CR>

10.23 Beacon Message Content Configuration [Application/Bootloader]

Table 41: Beacon Content

Beacon Content	
Write	Answer
ES+W[AA]FB[LL][B…B][B][C..C]<CR>	1) OK[B][C..C]<CR>: successful configuration 2) ERR[B][C..C]<CR> - [LL] is greater than 0x61
Read	Answer
ES+R[AA]FB[B][C..C]<CR>	1) OK+[BB][HH…HH][B][C..C]<CR> 2) ERR+REMOTE<CR>

[AA] is the device address in HEX format;

[LL] is the number of bytes in [B…B] in HEX format, where [LL] < 0x62;

[B…B] is the beacon message variable size content in ASCII format;

[BB] is beacon message size in HEX;

[HH … HH] is AX.25 encoded message content in HEX format;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

The ESTTC protocol is in ASCII format and uses <CR> (0D-HEX/13-DEC) as a termination symbol. It is therefore necessary for the users to avoid the byte value 13-DEC in ”write” commands, due to possible command parser errors. Any other byte values are generally allowed, but ASCII readable symbols are recommended for an easy decoding by any terminal application.

NOTE: The default content of the beacon message is = “Hello, world!”

NOTE: The read message size is always greater than the write message size due to AX.25 encoding.

NOTE: In case of a remote read request, the beacon content cannot be sent via the radio due to its unknown length.

NOTE: After reset the beacon message content defaults to “Hello, world!”.

Example commands:

- ES+R22FB 7AE6407F<CR>
- ES+W22FB0BHello Earth E361E6C8<CR>

10.24 Device Address Configuration [Application/Bootloader]

Table 42: Address

Address	
Write	Answer
ES+W[CurrAddr]FC[NewAddr][B][C..C]<CR>	OK+[NewAddr][B][C..C]<CR>:successful configuration

[CurrAddr] is the address HEX value and can be 0x22 or 0x23;

[NewAddr] is the address HEX value and can be 0x22 or 0x23;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

The 1-byte address is used to determine the recipient of the command via UART according to the ESTTC protocol as well as the slave 7-bit address via I^{2}C interface. It is used when two modules are integrated in one system. The default value is 0x22.

NOTE: If this command is sent via I^{2}C, there will be no reply as the device will reconfigure the internal I^{2}C periphery to align with the new address.

Example commands:

- ES+W22FC23 9EF83C47<CR>

10.25 FRAM Memory Read/Write [Application/Bootloader]

Table 43: FRAM Memory

FRAM Memory	
Write	Answer
ES+W[AA]FD[AAAAAAAA][D0...D15][B][C..C]<CR>	1) OK[B][C..C]<CR>: data is stored in FRAM successfully 2) ERR[B][C..C]<CR>: fail writing to FRAM
Read	Answer
ES+R[AA]FD[AAAAAAAA][B][C..C]<CR>	1) OK+[D0...D15][B][C..C]<CR>: data read from FRAM in HEX format 2) ERR[B][C..C]<CR>: fail reading from FRAM location

[AA] is the device address in HEX format;

[AAAAAAAA] is FRAM 32-bit address location in HEX;

[D0...D15] is the 16 bytes (HEX) of data to be written. The FRAM memory has flat structure and linear addressing space from 0x00 to 0x3FFF0;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

NOTE: FRAM addresses 0x8000-0x83A4, 0x83FE-0x24000 are reserved and cannot be used to store user data.

Example commands:

- ES+R22FD00024001 73B3F69C<CR>
- ES+W22FD00024001ABABABABDDDDDDDDFFFFFFFFAAAAAAAA 149E3006<CR>

10.26 Radio Transceiver Property Configuration [Application/Bootloader]

Table 44: Radio Property

Radio Property	
Write	Answer
ES+W[AA]FE[GG][NN][SS][D...D][B][C..C]<CR>	1) OK[B][C..C]<CR>: successful configuration 2) ERR[B][C..C]<CR>: fail to set property
Read	Answer
ES+R[AA]FE[GG][NN][SS][B][C..C]<CR>	1) OK+[Y...Y][B][C..C]<CR> 2) ERR[B][C..C]<CR>: fail to read property

[AA] is the device address in HEX format;

[GG] is the property group in HEX;

[NN] is the number of bytes in HEX;

[SS] is the start offset of the property in HEX;

[D...D] is the variable size data to be written in HEX format;

[Y...Y] is the property content in HEX format;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32;

NOTE: Do not use this command without EnduroSat's approval!

Example commands:

- ES+R22FE220101 B5D9879D<CR>
- ES+W22FE2201017F E47DB270<CR>

10.27 Secure Mode [Application/Bootloader]

Table 45: Secure Mode

Secure Mode	
Write	Answer
ES+W[AA]FF[B][C..C]<CR>	1) OK[B][C..C]<CR>: successfully entered secure mode 2) ERR[B][C..C]<CR>: authentication failed
Read	Answer
ES+R[AA]FF[B][C..C]<CR>	1) OK+[K...K][B][C..C]<CR>

[AA] is the device address in HEX format;

[K...K] are the four bytes comprising the secure key in HEX format;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

Example commands:

- ES+R22FF 7D8B8466<CR>

ENDUROSAT

10.28 Firmware Update [Application/Bootloader]

Table 46: Firmware Update

Firmware Update	
Update command format	Answer
ES+D[AA][D…D][B][C..C]<CR>	See section 10.28 Firmware Update for more information about the possible answers

[AA] is the device address in HEX format;

[D…D] is the variable length data which comprises a single line of the .SCRM file;

[B] is the blank space ASCII character;

[C..C] are the 8 ASCII characters representing the calculated CRC32.

Example commands:

- ES+D22S3220D119E261D2309A92D9DAA6677494576CD02556F794EE76B49F175EDE2B615858DAD F2AC3BA3<CR>

ENDUROSAT

11 MECHANICAL DRAWING

The drawings on Figure 22 show the external dimensions of the UHF Transceiver Type II module.

STEP files can be provided upon request. All dimensions are in mm.

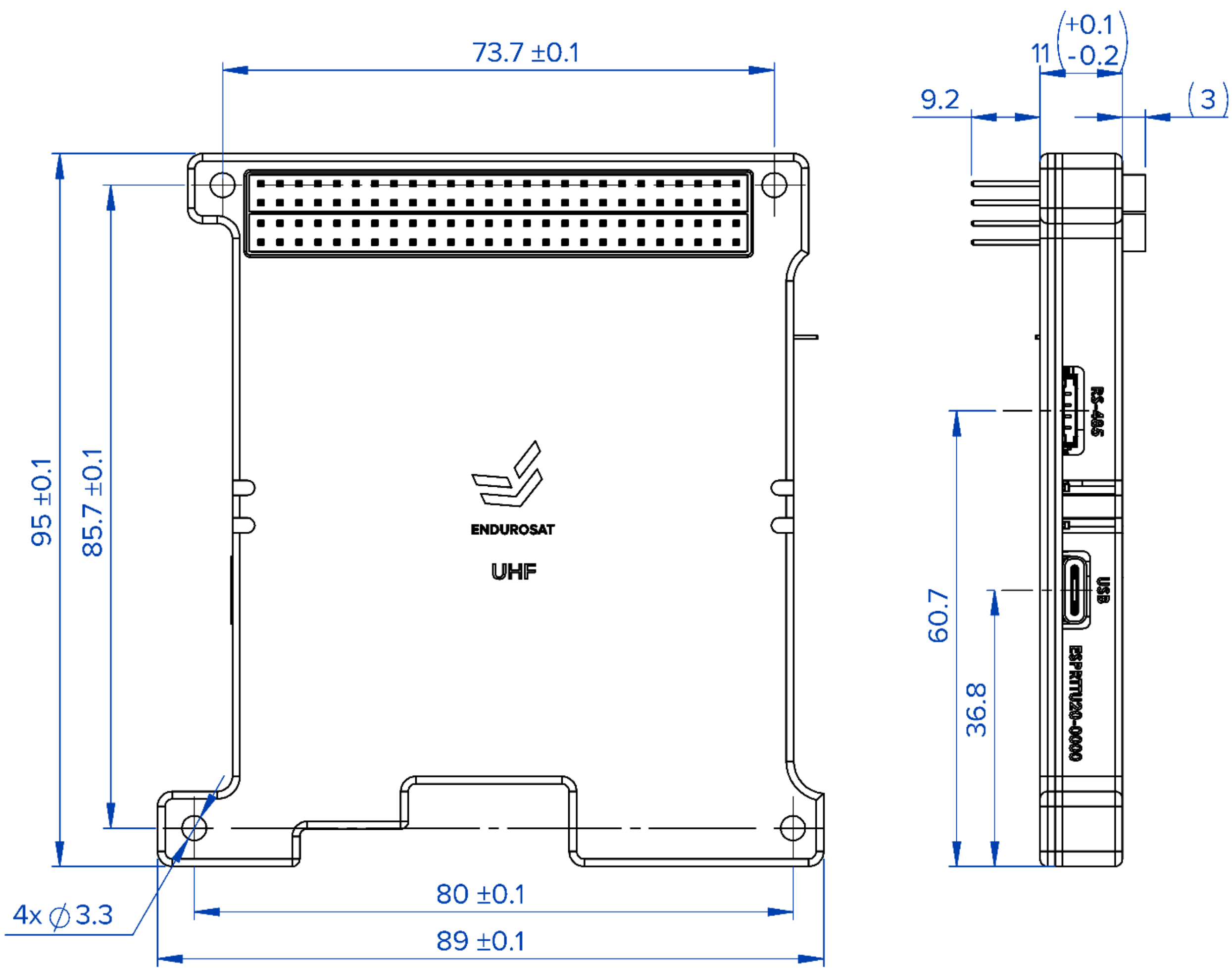

Figure 22: UHF Transceiver Type II - Top and Side Views

ENDUROSAT

12 ENVIRONMENTAL AND MECHANICAL TESTING

A full campaign of tests at qualification level has been performed on a qualification engineering model: qualification tests, level and duration tests following the ESA standard ECSS-E-ST-10-03C and GEVS standard GSFC-STD-7000A.

- Random Vibration;
- Sinusoidal Vibration;
- Pyroshock Test;
- Thermal Cycling;
- Thermal Vacuum;
- Total Ionizing Dose.

13 MATERIALS AND PROCESSES

- Surface mount technology component placement;
- Standard: IPC-A-610E Class 3;
- Aluminum 6061 T651 box;
- Visually inspected;
- Functionally verified.

14 HANDLING AND STORAGE

Particular attention shall be paid to avoid damage of the communication module during handling, storage and preservation. The handling of the communication module should be performed in compliance with the following instructions:

- Handle using PVC, latex, cotton (lint free) or nylon gloves;
- The environment where the device will be handled shall meet the requirements for a class environment 100,000, free of contaminants such dust, oil, grease, fumes and smoke from any source;
- Store in such a manner as to preclude stress and prevent damage;
- To prevent the deterioration of the module, then the module shall be stored in a controlled environment (i.e. the temperature and humidity levels shall be maintained within the proper ranges):
    - Ideal storage temperature range: 15°C to 27°C;
    - Ideal storage humidity range: 30% to 60% relative humidity (RH).