

Full-duplex Low-power S-band Transceiver

Introduction

The Satlab SRS-3 is a full-duplex, low-power, S-band transceiver designed for TM & TC on micro- and nano-satellites. The self-contained system operates on the ITU space operations S-band frequencies and features integrated transmit and receive filters, LNA and power amplifier, requiring only passive external antennas. SRS-3 is highly configurable, with transmit and receive frequencies, bit rates, output power and framing configurations being adjustable on-orbit.

Features

- Variable transmit symbol rate up to 512 kbps
- Variable receive symbol rate up to 128 kbps
- Configurable forward error correction and framing
- Adjustable output power up to 30 dBm with Automatic Level Control (ALC)
- On-board PA, LNA, transmit and receive filters
- CAN-bus and RS-422 interfaces using CubeSat Space Protocol (CSP)
- Ethernet interface with IP routing
- AES-256-GCM link-layer encryption and authentication
- Wide supply voltage range with over-current protection and external watchdog timer
- CubeSat Kit form factor compatible aluminum enclosure
- Delivered with source-level software support library for easy integration



Key Parameters

Parameter	Specification
Transmitter frequency range	2200 MHz to 2290 MHz
Transmitter symbol rate	9.6 kBd to 512 kBd
Transmitter output power	Adjustable 20 dBm to 30 dBm, with ALC
Receiver frequency range	2025 MHz to 2110 MHz
Receiver symbol rate	9.6 kBd to 128 kBd
Receiver sensitivity	-107 dBm (<1 % PER, 128 kBd, BT=0.5)
Modulation	GMSK
Supply voltage	5.0 V to 40.0 V
Typical power consumption (5 V input, 20 °C, 30 dBm output)	Idle/Awaiting frames: 550 mW Full-duplex transmit and receive: 5.0 W
Operating temperature	RX: -40 °C to 85 °C TX: -40 °C to 70 °C
Dimensions	87.0 mm × 93.0 mm × 17.0 mm
Mass	190 g

Table of Contents

1	Description	3
2	Hardware Overview	4
2.1	RF Design	4
2.2	Power Domains	4
2.3	Telemetry Sensors	5
3	Software Overview	6
3.1	System Properties	7
3.2	Configuration	7
3.3	Telemetry	8
3.4	EGSE Console	9
4	Framing Format	10
4.1	Encryption	11
4.2	Throughput	12
5	Qualification	13
5.1	Calibration and Acceptance Testing	13
5.2	Connector Pinout	14
6	Electrical Specifications	15
6.1	Absolute Maximum Ratings	15
6.2	Operating Conditions	16
6.3	Receiver	17
6.4	Transmitter	18
6.5	Communication Interfaces	20
7	Mechanical Specifications	21
7.1	Board Outline	21
8	Ordering Options	22
9	Customization	22
10	Revision History	23
11	Disclaimer	23

1 Description

The Satlab SRS-3 is a full-duplex, low-power, S-band transceiver designed for TM & TC on micro- and nano-satellites. The self-contained system operates on the ITU space operations S-band frequencies and features integrated transmit and receive filters, LNA and power amplifier, requiring only passive external antennas. SRS-3 is highly configurable, with transmit and receive frequencies, bit rates, output power and framing configurations being adjustable on-orbit.

Figure 1 shows a simplified block diagram of the external connections to the transceiver.

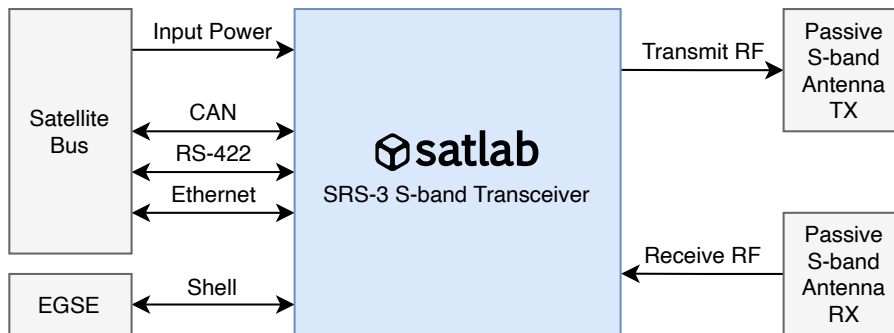


Figure 1: Simplified overview of the SRS-3 transceiver with external interfaces.

SRS-3 is powered from a single 5 to 40 V input and is compatible with ECSS-E-ST-20-20C compliant, 28 V unregulated power supplies. The power input and all onboard regulated voltages are protected against over-current.

The board is operated via CAN-bus and/or RS-422 using CubeSat Space Protocol (CSP) commands, and routes CSP packets between the space link interface and the satellite bus. CSP is a small network-layer delivery protocol designed for CubeSats, which allows subsystems to provide services and exchange messages using a common protocol on different physical layer interfaces (e.g. CAN-bus and RS-422). An open source reference implementation is available on <http://www.libcsp.org>. Both communication interfaces can be enabled simultaneously and serve as backup. Satlab supplies source-level client libraries in C and Python to wrap the CSP protocol, along with example code to simplify integration even further. Documentation for the support libraries is distributed separately along with the source code.

The Ethernet connection can be used to forward IP traffic between the space link and an internal satellite IP network. CSP and IP routing can be enabled simultaneously and coexist on the same space link interface.

Separate full detent Amphenol coaxial SMP connectors are used for the transmit and receive antennas, with on-board high-order ceramic monoblock filters allowing for flexibility in selection of the antenna configuration. The system monitors the output power of each transmitted packet and uses an Automatic Level Control (ALC) loop to adjust the output gain to achieve the target output power.

The transceiver uses a high performance polyimide PCB for thermal performance and reliability, and is delivered in a milled aluminium enclosure which provides a strong mechanical interface as well as EMI shielding and thermal contact. The main (P1) and EGSE (P2) connectors are latching, high-reliability Harwin Gecko connectors with gold-plated contacts.

A serial command line shell is available through the EGSE connector, which can be used for on-ground configuration, testing and performance verification.

Satlab provides a GNU Radio (<https://www.gnuradio.org>) example flowgraph that can be used with compatible Ettus Research™ USRP™ (<https://www.ettus.com>) software-defined radios for ground testing and validation of the radio interface.

2 Hardware Overview

Figure 2 shows the simplified block diagram of the transceiver with the external interfaces in orange. Two RF connectors, one for RX and one for TX, and the main connector P1. The EGSE connector P2 is used for software updates on ground and can also be used for configuration and performance testing. The microcontroller ties together the functions and interfaces of the board and handles configuration and calibration of the RF parts.

The system includes on-board transceivers for CAN-bus, RS-422 and Ethernet to simplify integration with different satellite busses. Via configuration, the Ethernet PHY is powered up/down as needed to save power when not in use. Configuration of the MCU allows for the use of one or more interfaces at a time while the MCU will buffer and route frames to the desired interface and subsystem address. Configuration and calibration values are stored persistently in an F-RAM device. Telemetry (TM) sensors include temperature, voltage, current and power measurements (see section 2.3).

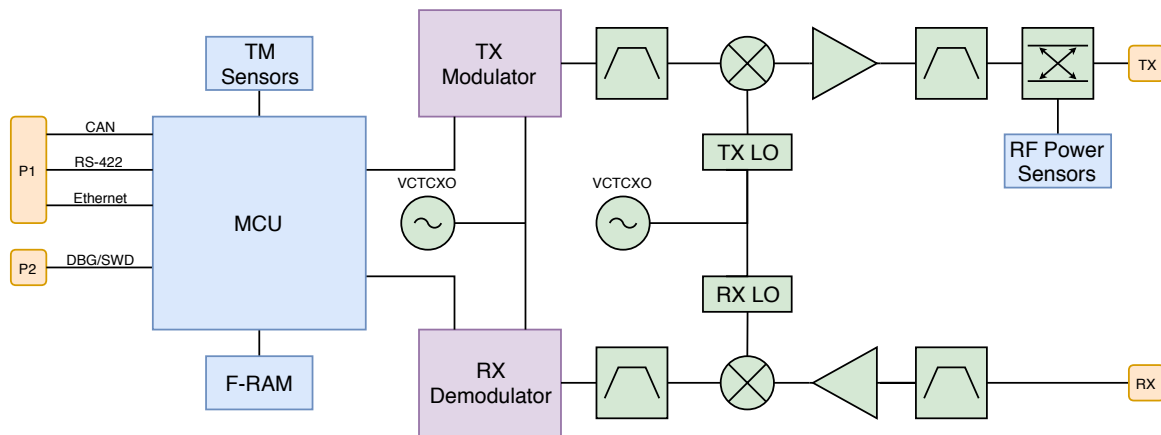


Figure 2: Overview of the S-band hardware design. Some blocks have been left out for clarity.

2.1 RF Design

The RF section is shown in green and purple on figure 2. The RF path is constructed as independent receiver and transmitter chains that share the same frequency sources (VCTCXOs). The RX and TX local oscillators can be programmed independently to allow individual selection of RX and TX frequencies. High-order ceramic monoblock filters are used on both RX and TX to lower the TX noise in the RX frequency band and to isolate the receiver from the TX frequency band. The IF and RF signals are filtered using local SAW filters before and after the mixing stage.

RF output power and reflected power is monitored via a directional coupler and power sensors to allow the Automatic Level Control (ALC) to keep output power stable over frequency and temperature. The reflected RF power measurement is used for transmitter protection and for telemetry. This also allows the transmitter to monitor antenna/cable return loss on the TX frequency both before and after launch.

The SRS-3 is supplied in a milled aluminium enclosure. The enclosure provides shielding to/from the outside but also internally in nine divided sections.

2.2 Power Domains

Figure 3 shows the local power domains of the SRS-3. Each power domain of the transceiver features over-current protection for error mitigation. The first buck converter generates a local 3.75 V regulated voltage from the input voltage. A 3.3 V LDO from the input voltage is used to drive the dedicated watch dog timer (WDT) circuit. The WDT circuit is also used as a power on reset timer that actively discharges the internal power nets of the transceiver before starting

the powering ON sequence, and as a latching self-resetting over-current protection. During an over-current event, or if the MCU does not reset the WDT, the power on reset sequence with active discharge will be re-initiated. The transmit PA and PA pre-driver are supplied from the 3.75 V via a protected (limiting) switch that is also used to enable and disable transmissions by the MCU during normal operation. The MCU and the remaining parts are supplied from a 3.3 V buck converter (and a 1.2 V converter for the MCU only).

Key RF components in the receiver and transmitter chain are supplied through LDOs to keep the impact of power supply noise to a minimum. These are omitted in figure 3.

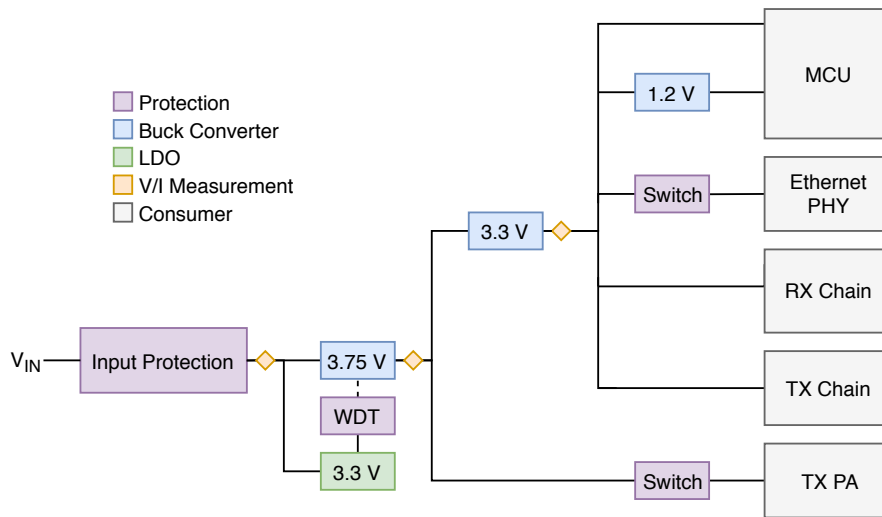


Figure 3: SRS-3 power domains and voltage/current measurement points.

2.3 Telemetry Sensors

Voltage, current and power can be measured on the V_{IN} , 3.75 V, and 3.3 V rails and can be downloaded using telemetry properties (see figure 3).

The SRS-3 has five temperature measurement points, located on-die or near key components on the PCB. The temperature and power sensors are listed in table 1 along with their telemetry property name. For additional telemetry available from the MCU, refer to section 3.1.

Table 1: Onboard telemetry sensors

Property	Description
<code>tm.{volt,cur,power}.vin</code>	V_{IN} voltage, current and power
<code>tm.{volt,cur,power}.vreg</code>	V_{REG} voltage, current and power (3.75V)
<code>tm.{volt,cur,power}.3v3</code>	$V_{3.3V}$ voltage, current and power
<code>tm.temp.pa</code>	Power amplifier temperature
<code>tm.temp.power</code>	Buck converters temperature
<code>tm.temp.lna</code>	LNA and front end components
<code>tm.temp.mcu</code>	MCU temperature

3 Software Overview

Figure 4 shows the main software components and packet flow in the SRS-3 transceiver. The transceiver essentially functions as a router of CSP (CubeSat Space Protocol) and IP packets between the radio interface and satellite bus.

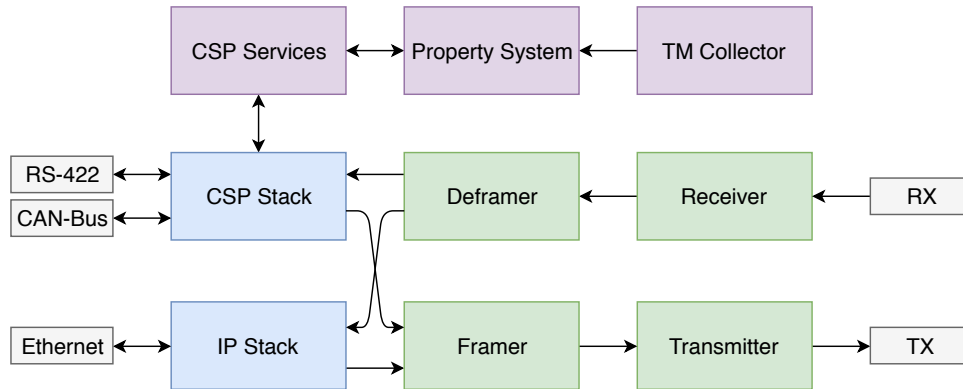


Figure 4: Overview of the transceiver software components and data flow. The property system indirectly interfaces with all other components, but the connections have been left out for clarity.

The receiver module is responsible for configuration and interfacing with the external RX chain and demodulator. Received frames are passed onto the deframer module, which verifies the frames using the configured framing format and FEC, and forwards valid frames to either the CSP or IP protocol stack depending on the frame type. Equivalently, the framer module accepts frames from the protocol stacks, applies error correction data and enqueues them with the transmitter module which handles the external TX chain and modulator. The transmitter module includes the ALC loop that monitors the output power of each frame, and adjusts the transmit gain accordingly to achieve the configured output power.

The CSP protocol stack receives frames from the system interfaces, and forwards them according to the current routing table. Both the CAN-bus and RS-422 interfaces can be enabled simultaneously and used for CSP communication. The SRS-3 can also be configured to route CSP packets between these interfaces, so nodes on the CAN-bus can communicate directly with nodes on RS-422 and vice versa. Alternatively, both interfaces can be connected to the same systems and serve as backup routes using the CSP routing table.

Configuration and telemetry readout is handled through a local CSP service that interfaces with the onboard property system. See section 3.1 for more information on the property system. The TM Collector module is responsible for periodically collecting telemetry values from on-board sensors, and updating system properties accordingly. See section 3.3 for more details.

The Ethernet interface is used for IP packet forwarding and the SRS-3 does not currently provide any local IP services except replying to ICMP echo (“ping”) requests. A CSP connection on CAN-bus or RS-422 is required to access the property system.

3.1 System Properties

Configuration, status and telemetry download from the SRS-3 is handled using a number of system property variables. Each variable has a type (signed/unsigned integers of various sizes, floating point numbers, strings, etc.) and a default value. Some properties are used for configuration and can be modified and stored in (optionally write-protected) non-volatile memory using the console or remotely via CSP commands. Others are read-only and used for telemetry purposes. These properties are periodically updated by the system during operation, and can also be viewed using either the console or downloaded via CSP.

Most property changes take effect immediately, while others require a store and a system reset after update.

The system properties are divided into a number of property groups, each covering a specific part of the firmware. Property values can be read and updated remotely using CSP. The `prop-client` support library contains wrapper functions around the CSP protocol to read and update properties. The `satctl` Linux application can be used as a reference for the use of the library.

A full list of system properties and a description of their values is included in the SRS-3 software documentation.

3.2 Configuration

On boot, the system loads stored properties from F-RAM. Default settings are hardcoded into the system firmware and used as fallback values if no valid stored properties are found.

It is possible to change properties runtime without saving them to F-RAM. It is strongly recommended not to alter write-protected properties on-orbit (e.g. CSP address), since setting them to a invalid value could render the device unresponsive.

Listing 3.1 shows the use of the `prop list` command to show properties and their values from the `rx` and `tx` groups.

Listing 3.1: List properties and values from the receiver and transmitter property groups.

```
[srs-3] prop list rx
Property      Type      Value
freq          u32      2029500000 hz
rate          u32      128000 bps
rs            bool      true
cc            bool      true
rand          bool      true
crc           bool      true
size          u16      217 bytes
frames        u32      1693 frames
rssi          flt      -91.00 dBm
[...]
[srs-3] prop list tx
Property      Type      Value
freq          u32      2229500000 hz
rate          u32      512000 bps
pout          flt      30.00 dBm
rs            bool      true
cc            bool      true
rand          bool      true
crc           bool      true
size          u16      217 bytes
frames        u32      1693 frames
pwr.fwd       flt      30.00 dBm
overpower     u16      0
alc.mode      u8        2
alc.kp        flt      40.00
alc.limit     u16      200
alc.gain      u16      1208
[...]
```

3.3 Telemetry

The property system is also used to read the telemetry variables from the SRS-3. Telemetry values are collected every second and are available through the `tm` property group. The example below shows the use of the `tm show` shell command which uses the property system to read and output formatted telemetry values. In the example, the board is connected to a 5.0 V bench supply and waiting for incoming frames. Note that the voltage and current measurements are instantaneous, while the power measurements are averaged which is why the multiple of the voltage and current values are not exactly equal to the power measurements.

The ambient temperature in the example was approximately 30°C and the average board temperature about 35°C with the MCU core temperature at 35.38°C being the warmest. The transmit section and power amplifier is powered down when the system is not transmitting, so the PA sensor is the coldest at 34.50°C.

Telemetry data from the transmitter and receiver is also listed. The number of transmitted and received frames, along with measured output power (30 dBm) and RSSI (-91 dBm) of the last transmitted and received frame is included.

Listing 3.2: List telemetry properties and values.

```
[srs-3] tm show
Power Channels
Ethernet      Off

Power Rails
VIN           5000.00 mV   110.00 mA   537.00 mW
VREG          3758.00 mV   130.00 mA   491.00 mW
3V3           3332.00 mV   143.00 mA   477.00 mW

Temperature Sensors
MCU core      35.38 C
MCU           35.06 C
Power         35.00 C
LNA           34.68 C
PA            34.50 C

Transmitter
Frames        1693 Frames
Forward power 30.00 dBm

Receiver
Frames        1693 Frames
Last RSSI     -91.00 dBm
```


3.4 EGSE Console

The system provides a serial console on the RX/TX pins in the EGSE connector (see section 5.2). The serial configuration is 8N1 at 115200 baud, and the console requires an “Enter” key press to be activated.

Listing 3.3 shows the nominal output on the serial console during boot. A number of timestamped log messages are printed during boot from various logging groups. Additional logging can be enabled at runtime using the `trace` commands. The `help` command can be used to list available commands and their usage.

The installed software version and build information is also printed in the console during boot.

Listing 3.3: Example output from console.

```
[ 0.000050] system: Copyright (c) 2016-2021 Satlab A/S <satlab@satlab.com>
[ 0.000228] system: boot: 1 reset cause: general reset
[ 0.000394] system: board serial #30808b36

Satlab SRS-3 v2.6.0

[srs-3] help
Available commands:
boot          Bootloader commands
csp           CSP commands
help          Show available commands
history       Show previous commands
prop          System configuration properties
reboot        Reboot system
time          Time command execution
tm            Telemetry commands
trace         Trace subcommands
uptime        Show system uptime
watch         Run command periodically
```

4 Framing Format

The SRS-3 transmits and receives fixed size frames on the radio interface. Payload data size and FEC options are individually configurable through system properties for the transmitter and receiver. The actual length of transmissions is a function of the configured payload data size and FEC options as described below. The maximum payload data size is currently fixed at 1024 bytes.

Figure 5 shows the frame structures with the default payload data size of 217 bytes. Although the radio interface uses fixed size frames, the data contents can be variable length (up to the configured maximum). A two byte header is always prepended to every frame, to specify the content type and actual length of the data. The system supports encapsulation of two different frame types in the payload field: CSP frames and IP frames. Protocol overhead must also fit in the payload data field, so in the default configuration the maximum CSP MTU is 213 bytes because the CSP header occupies 4 byte of the payload field.

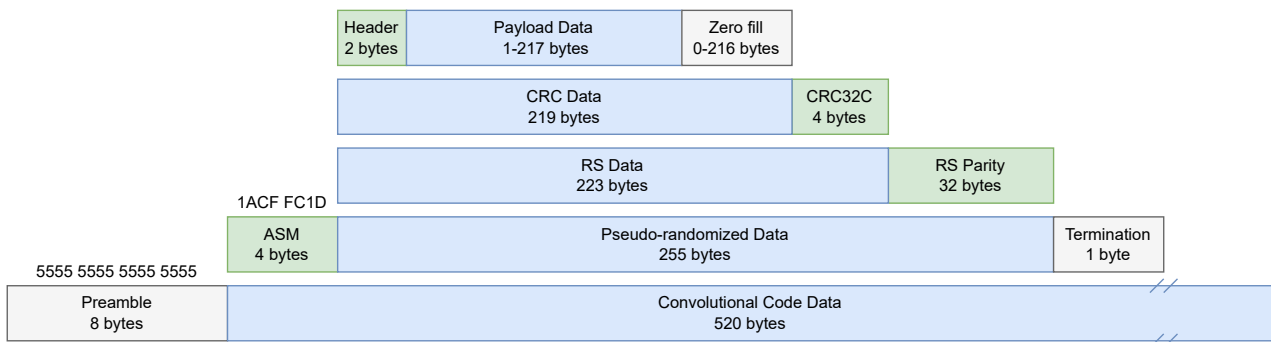


Figure 5: Default configuration frame with payload data length set to fit in 1 Reed-Solomon block.

The contents of the two byte header is shown in figure 6. The reserved bit is transmitted first and is always set to 0. The type field is set to 0 for CSP frames and 1 for IP frames. Frames with other type values are invalid and will be dropped. The length field denotes the number of payload data bytes following the header. With the default payload data size configuration in figure 5, it will have a value of 1-217. All fields are transmitted most significant bit first.

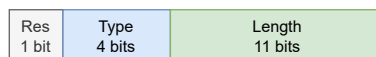


Figure 6: Two byte frame header

After the header is prepended, the frame is zero-padded to the configured frame size plus the header size (219 bytes in the example). A CRC32C checksum can optionally be appended to the frame for increased error detection. Using the `tx.id` property, a 16-bit satellite ID field can also be added immediately after the header, and used for filtering on the receiver.

If the `tx.rs` property is set to `true`, a (255,223) Reed-Solomon code is used to append 32 parity bytes to the frame as specified by [1] for each block of up to 223 data bytes. If the configured frame size results in fewer than 223 bytes input to the Reed-Solomon encoder, the code block length is shortened using virtual fill. If the frame size is larger than the Reed-Solomon data block size, the RS data is divided into (approximately) even blocks, and interleaved according to [1]. This ensures that each payload data byte has approximately the same error correction probability. The interleaving depth is determined from the frame size and can not be changed from $I = \lceil \text{size} / 223 \rceil$. Note that compliance with [1] requires the frame size to be a multiple of the interleaving depth. If the configured frame size is not a multiple of the interleaving depth, the last blocks will have an additional virtual fill byte. The default 217 byte frame size is chosen such that a maximum length payload frame results in a single RS data block of 223 bytes.

Pseudo-randomization, as described in [1], can be applied to ensure a sufficient number of bit transitions in the frame.

A 4 byte Attached Sync Marker (ASM, 1ACFFC1D) is appended before each frame.

Convolutional coding using the $r=1/2$, constraint length 7 code from [1] can be enabled using the `tx.cc` property. One byte zero termination is appended to the input data to return the encoder to the all-zero state, resulting in a coded frame size of 520 bytes in the example. Punctured code rates are not supported.

Finally, a configurable number of preamble bytes (`tx.preamble`, default 8) are prepended to the frame before transmission. If more outgoing frames are queued when a transmission completes (or idle frames are enabled), the next frame is transmitted immediately following the last byte of the first frame. A configurable number of midamble bytes can be inserted between the frames and postamble bytes can be appended after the frame transmission, e.g. to flush a streaming Viterbi decoder in the receiver.

To conserve power, the SRS-3 does not normally transmit idle frames when no data is queued for transmission. Using the `tx.idleframes` property (default 0), the SRS-3 can be configured to continue to transmit a number of idle frames after each data frame. Any data frames queued for transmission while sending idle frames take priority and resets the idle counter to `tx.idleframes`. When the idle counter reaches 0, the radio is keyed down. Idle frames consists of all-zero data but with FEC and CRC applied.

4.1 Encryption

The SRS-3 can optionally encrypt and/or authenticate frames using AES-256-GCM encryption. Encryption is applied after frame padding but before the frame is passed to the CRC and FEC stages.

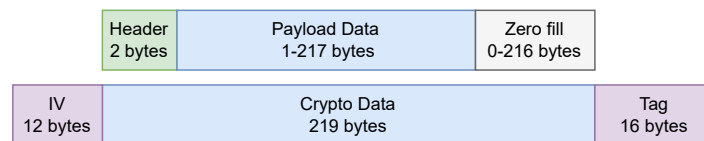


Figure 7: Encryption and authentication headers.

The 256 bit encryption keys are configured using the `tx.crypto.key` and `rx.crypto.key` properties. If encryption or authentication is enabled using `tx.crypto.encrypt` or `tx.crypto.auth`, a 96 bit random nonce/IV is prepended to the frame, thus increasing the frame size by 12 bytes. If `tx.crypto.auth` is enabled, a 128 bit tag is appended and the frame size is increased by 16 bytes. Similarly, `rx.crypto.decrypt` and `rx.crypto.auth` enable decryption and authentication on the receive interface.

Encryption and authentication can be enabled independently on both the RX and TX interfaces. Authentication can be enabled without encryption (GMAC mode) but it is recommended to always enable authentication when encryption is enabled, since the encryption itself does not protect against malicious messages.

[1] CCSDS, 131.0-B-3 TM Synchronization and Channel Coding, 2017.

4.2 Throughput

The channel bit rates are configurable through the `tx.rate` and `rx.rate` properties, but the achievable throughput (“goodput”) depends on configured frame size and FEC options. The preamble and ASM also adds a fixed per-packet overhead, which must be taken into account when calculating the achievable data rate. Figure 8 shows throughput as a percentage of the channel bit rate, as a function of the packet size and FEC configuration.

In the CRC-only case, the throughput approaches 100% of the channel rate as the frame size is increased, because the overhead is fixed (preamble, ASM and 4 bytes CRC field). The jumps in throughput in the RS cases occur every time the frame size requires a new Reed-Solomon block to hold the data bytes. The throughput approaches the rate of the Reed-Solomon code, $R_{RS} = 223/255 = 87.5\%$ of the channel rate. Similarly, when convolutional coding is enabled, the throughput approaches the rate of the concatenated code $R_{RS}R_{CC} = 223/255/2 = 43.7\%$.

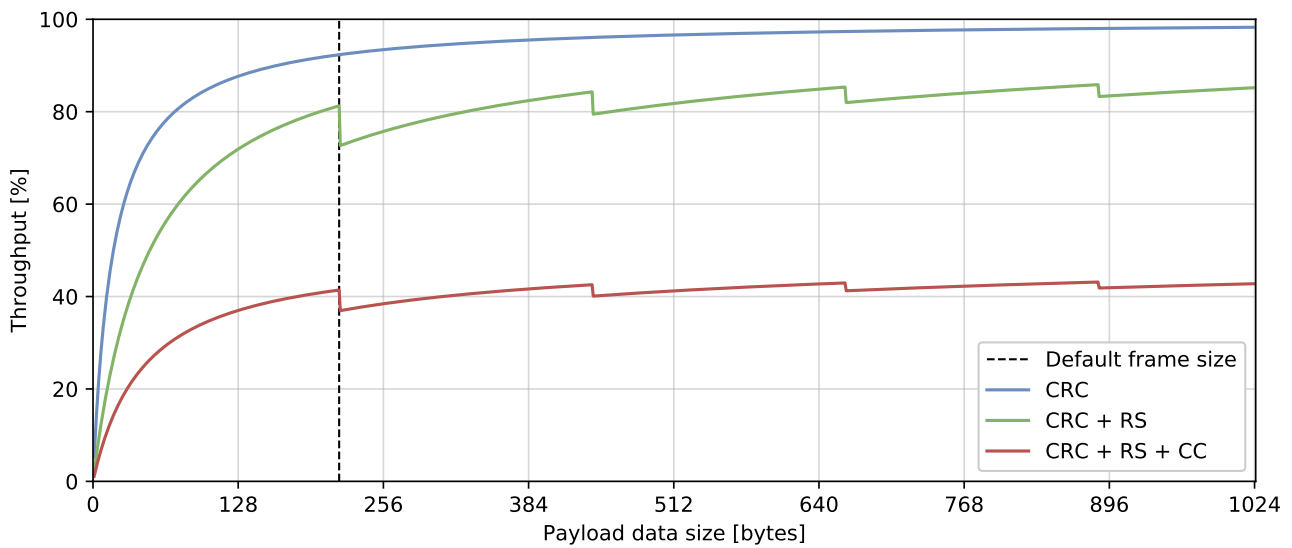


Figure 8: Achievable throughput as function of payload data size.

As described in the previous section, the default frame size is chosen to exactly fit in a single Reed-Solomon block. For the default frame size, table 2 lists the throughputs at the maximum transmit rate of 512 kbps and the maximum receive rate of 128 kbps.

Table 2: Achievable throughput with default 217 bytes payload data size.

FEC configuration	Throughput	Max. transmit throughput	Max. receive throughput
CRC	92.3%	472.8 kbps	118.2 kbps
CRC + RS	81.3%	416.1 kbps	104.0 kbps
CRC + RS + CC	41.1%	210.4 kbps	52.6 kbps

Protocol overhead of the encapsulating network protocol (CSP or IP) is not included in the calculations above.

5 Qualification

The SRS-3 has been through a number of test campaigns to verify its performance over temperature, vibration and radiation. An overview of the testing performed on the SRS-3 is shown in table 3. As this list is non-exhaustive, please contact Satlab for further information if needed.

Table 3: Qualification Parameters

Parameter	Value
Thermal soak (RX)	-40 °C to +85 °C
Thermal soak (RX+TX)	-40 °C to +70 °C
Vibration	14.1 G _{rms}
TID	20 kRad(Si) board level
First flight	2018

It should be noted that the levels which are listed in table 3 is a superset of the different tests the receiver has been through during various test campaigns.

5.1 Calibration and Acceptance Testing

All units are production calibrated at 20 °C. Calibration includes adjusting default gain values for the output level range over the full TX band and calibration of the VCTCXO to a reference frequency source. The RF power sensors are calibrated against a reference sensor. As part of acceptance testing, each board is subject to a full RF performance test covering RX and TX over the temperature interval from -30 °C to +70 °C.

5.2 Connector Pinout

P1 and P2 are latching, high-reliability Harwin Gecko connectors with 1.25 mm pitch and gold-plated contacts. P1 (G125-MH11605L3P) is the main connector for power and communication interfaces. P2 (G125-MH10605L3P) is used for the EGSE console and programming via SWD. Typically, the P2 connector is only used for test and firmware upgrade on ground and left unconnected in flight configuration. The EGSE console UART can be connected to another system in the spacecraft if desired, as the board includes protection against reverse supply from these pins. It is strongly recommended to leave the JTAG/SWD pins unconnected in flight configuration.

The S-band transceiver is supplied with termination resistors on the CAN-bus (120 ohm) and on the RS-422 receive pair (100 ohm). The Ethernet connection is designed to be used in systems both with and without magnetics.

The coaxial RF connectors are full detent type SMP (Amphenol SMP-MSFD-PCE-1).

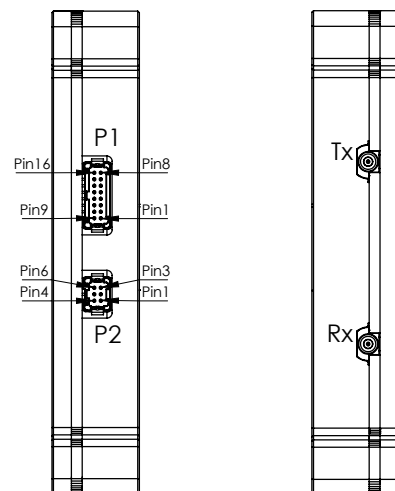
The P1 and P2 connector pinouts are shown here together with the pin numbering of the male connectors. “TX” pins denote outputs from the SRS-3 and “RX” pins denote inputs to the SRS-3.

All pins in P1 and P2 uses TVS diodes for ESD suppression. The two RF connectors are DC grounded. However, proper care should still be observed while handling the device.

P1 — Main Connector			
VIN	16	8	VIN
DNC	15	7	DNC
GND	14	6	GND
RS-422 RX-	13	5	RS-422 RX+
RS-422 TX-	12	4	RS-422 TX+
CAN-L	11	3	CAN-H
ETH RX-	10	2	ETH RX+
ETH TX-	9	1	ETH TX+

P2 — SWD/Serial EGSE connector			
EGSE TX	6	3	SWDCLK
V _{Target} (sense)	5	2	GND
EGSE RX	4	1	SWDIO

DNC = Do Not Connect



ATTENTION: Although all external interfaces on the SRS-3 are protected against ESD, proper precautions and grounding must still be observed when handling the device.

6 Electrical Specifications

All electrical parameters in all tables are specified under the following conditions, unless stated otherwise:

- Typical values are based on $T_{AMB}=20^{\circ}\text{C}$ and $V_{IN}=5.0\text{ V}$, by production test and/or design characterization.
- Minimum and maximum values represent the worst conditions across supply voltage, process variation, and operating temperature.
- All values refer to levels specified on the connectors, i.e. not including cable loss.

6.1 Absolute Maximum Ratings

The table below lists the minimum and maximum allowable levels on the connector pins. Exceeding these may damage the product permanently.

Table 4: Absolute Maximum Ratings

Parameter	Min	Max	Unit
Storage Temperature	-40	85	$^{\circ}\text{C}$
Input Voltage	-43	43	V
Input Voltage Transient (<10 ms)	-55	55	V
RF input power (TX Connector)	-	+20	dBm
RF input power (RX Con., TX freq. range)	-	+30	dBm
RF input power (RX Con., remaining freq. range)	-	+10	dBm
CAN-L/H	-7	12	V
RS-422	-7	12	V
Ethernet	-0.5	5	V
EGSE-UART (TTL)	-0.5	5	V

6.2 Operating Conditions

Operating conditions refer to four modes defined as:

- Idle Mode: Ready to transmit and receive, awaiting packets
- RX Mode: Actively receiving packets
- TX Mode: Actively transmitting packets
- RX+TX Mode: Full-duplex receiving and transmitting packets

The nominal power consumption is specified with the CAN-bus interface enabled and RS-422 and Ethernet disabled.

Table 5: General Operating Conditions

Parameter	Min	Typ	Max	Unit
Operational Temperature (Idle, RX)	-40	-	85	°C
Operational Temperature (TX)	-40	-	70	°C
Input Voltage	4.75	-	40	V
Input power (Idle)	-	550	-	mW
Input power (RX+TX, 30 dBm output power)	-	5.0	-	W
Additional input power for Ethernet enabled	-	185	-	mW
Additional input power for RS-422 enabled	-	110	-	mW
V _{reg} voltage rail	3.55	3.75	3.95	V
V _{3.3V} voltage rail	3.20	3.33	3.45	V
V _{reg} latching current limit protection	2.5	2.7	3.0	A
Power on reset timer	330	420	500	ms
External watchdog timer timeout	-	36	-	s
V _{IN} input equivalent at power-on	-	30	-	μF
Recommended antenna isolation (TX connector to RX connector)	10	-	-	dB

6.3 Receiver

In figure 9 the typical measured performance of the receiver is shown. The receiver performance plot shows the -117 dBm to -95 dBm range but continues to receive up to -30 dBm (refer to table 6). The receiver is configured for 128 kbps with RS and CC enabled, with the default packet size (217 payload data bytes) and BT = 0.50. Refer to the Framing Format section for a description of the framing format and configuration options. For each temperature the average PER is measured for 3 frequencies (bottom, middle and top of the band) each with 3 different frequency errors (-20 , 0 and $+20$ kHz).

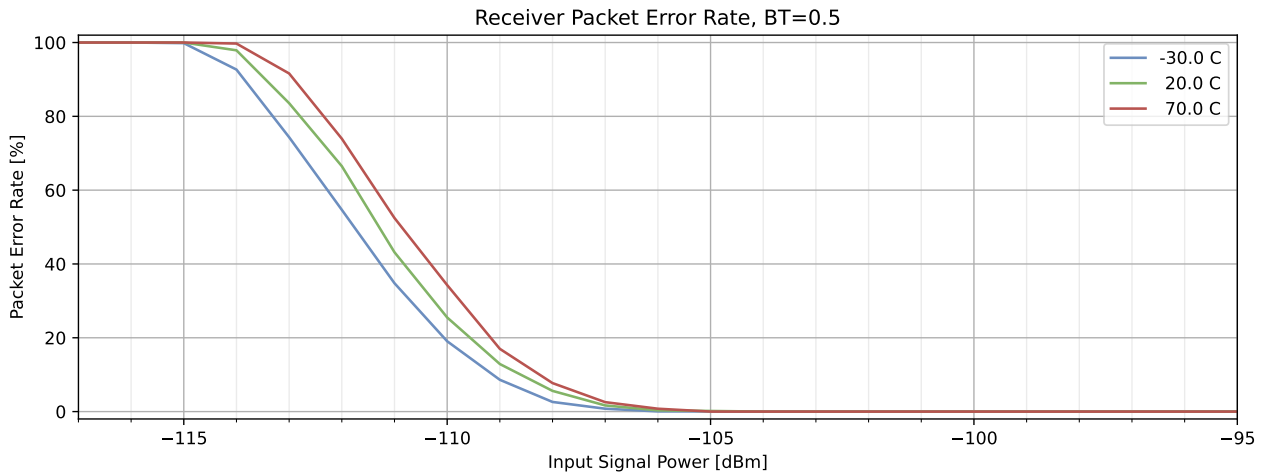


Figure 9: Typical receiver performance (PER) at 70, 20 and -30°C . Averaged over test frequencies and frequency errors with 128 kbps channel rate, all FEC enabled, and default payload data length.

Table 6 shows the key receiver characteristics.

Table 6: Receiver Characteristics

Parameter	Min	Typ	Max	Unit
Center frequency	2025	–	2110	MHz
Center frequency resolution	–	20	–	Hz
Bit rate	1	–	128	kbps
Receive sensitivity (<1% PER)	–	-107	–	dBm
Max receive power (<1% PER)	-30	–	–	dBm
Noise Figure	–	2	–	dB
Blocking adj. channel	50	60	–	dB
Last RSSI resolution ¹	–	0.5	–	dB
Frequency error	See transmitter specification			

¹ The RSSI measurement is not calibrated over frequency, but should be done on ground if relied on in orbit.

6.4 Transmitter

In figure 10 the normalized output power spectrum is shown with BT=0.50 Gaussian filter and 3 different output power levels. Measured using idle frames transmitted at 2245 MHz using 512 kbps channel rate.

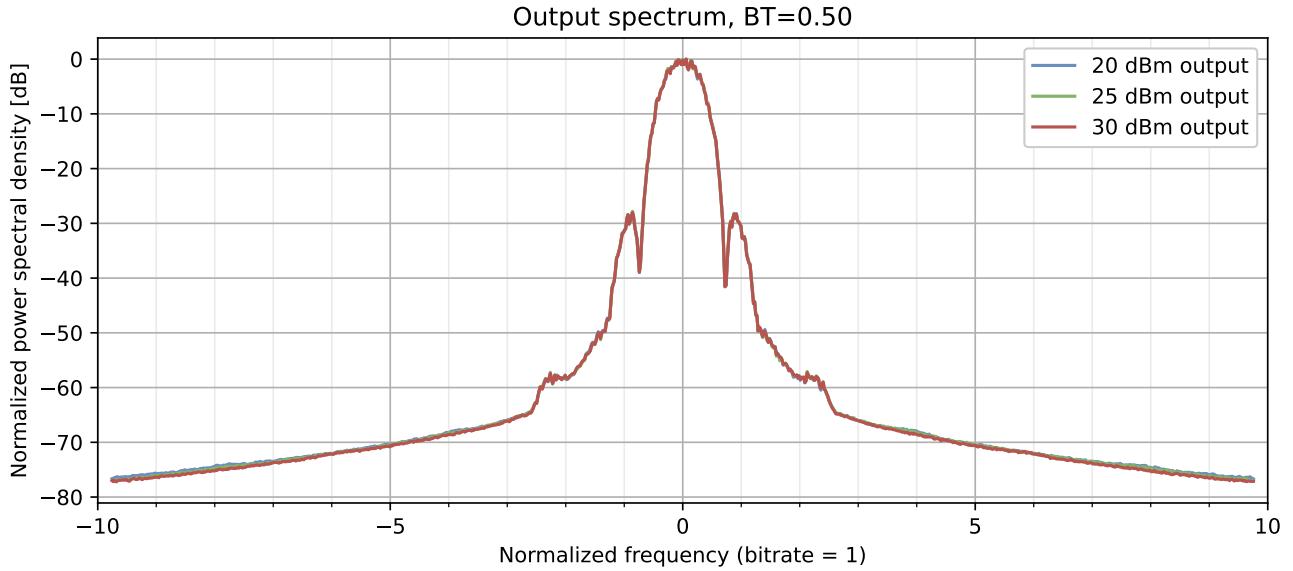


Figure 10: Normalized transmitter power spectrum (typical)

Figure 11 shows the typical RF output power stability over the 90 MHz TX frequency band for 3 different power settings and the associated DC power consumption (Idle+TX at 20°C and 5.0V supply). ALC is enabled.

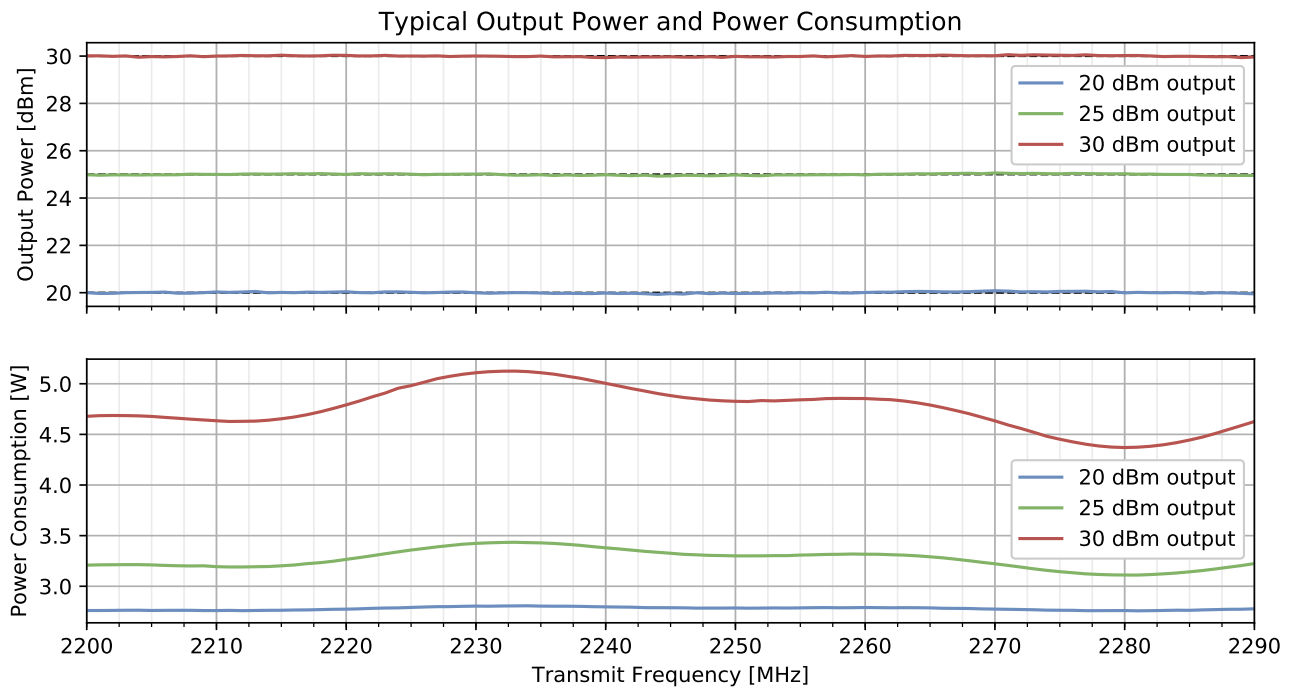


Figure 11: RF output power and DC power consumption as a function of configured TX frequency and output power.

Table 7 shows the transmitter key characteristics.

Table 7: Transmitter Characteristics

Parameter	Min	Typ	Max	Unit
Center frequency	2200	–	2290	MHz
Center frequency resolution	–	20	–	Hz
Bit rate	1	–	512	kbps
GMSK BT product	0.30	0.50	0.60	–
Output power	20	–	30	dBm
Output power adjust resolution	–	–	0.1	dB
Occupied BW (99.0%, norm. freq., BT=0.50)	–	1.07	–	–
Occupied BW (99.9%, norm. freq., BT=0.50)	–	1.67	–	–
SFDR	60	–	–	dBc
Output harmonics	60	–	–	dBc
Adjacent Channel Power (CH BW = 512 kHz, CH Spacing = 750 kHz, BT = 0.50)	–	–37	–	dB
RF Power sensor directivity	11	18	–	dB
ALC loop resolution (20 to 30 dBm output power)	–	–	0.1	dB
Initial frequency error (20 °C)	–	–	0.5	ppm
Frequency error (over temperature)	–	1.0	2.5	ppm
Frequency error (aging per year)	–	–	1.0	ppm
Frequency error (20 kRad(Si) board level)	–	1.0	–	ppm
PA protection threshold (reflected power)	–	25	–	dBm

6.5 Communication Interfaces

Table 8: Communication Interface Specification

Parameter	Min	Typ	Max	Unit
CAN-bus:				
Bit rate	125	1000	1000	kbps
Termination resistor	–	120	–	Ω
CAN-L/H	-2	–	7	V
CAN-L/H recessive level	–	2.3	–	V
CAN-L output dominant level	0.5	–	1.3	V
CAN-H output dominant level	2.4	–	3.35	V
CAN dominant L/H difference	1.1	2.0	3.0	V
RS-422:				
Bit rate	115.2	1000	3000	kbps
Receive termination resistor	–	100	–	Ω
RS-422 RX differential level $ Rx+ - Rx- $	0.15	–	6.0	V
RS-422 TX differential output	1.2	2.0	3.5	V
Ethernet:				
Bit rate	100	–	100	Mbps
ETH-TX Out diff. across 100 ohm termination (Assumes 1:1 transformer)	0.8	1.0	1.2	V
EGSE-UART (TTL):				
TX output high	2.3	3.3	3.4	V
TX output low	0.0	–	0.5	V
RX input low	0.0	–	1.2	V
RX input High	1.9	–	4.0	V

7 Mechanical Specifications

The PCB material is glassfiber polyamide conforming to IPC-4101/41 ($T_g > 250^\circ\text{C}$).

Table 9: Mechanical Specifications

Parameter	Min	Typ	Max	Unit
Mass	185	190	195	g
X-dimension	87.10	87.20	87.50	mm
Y-dimension	92.90	93.00	93.20	mm
Z-dimension	16.35	16.65	16.95	mm

7.1 Board Outline

Figure 12 shows the transceiver from the top side (Z+) and from the connector sides (X+ and X-). Note that the four mounting holes use the “CubeSat Kit” (PC/104) layout and are not symmetrical. CAD models are available on the Satlab website.

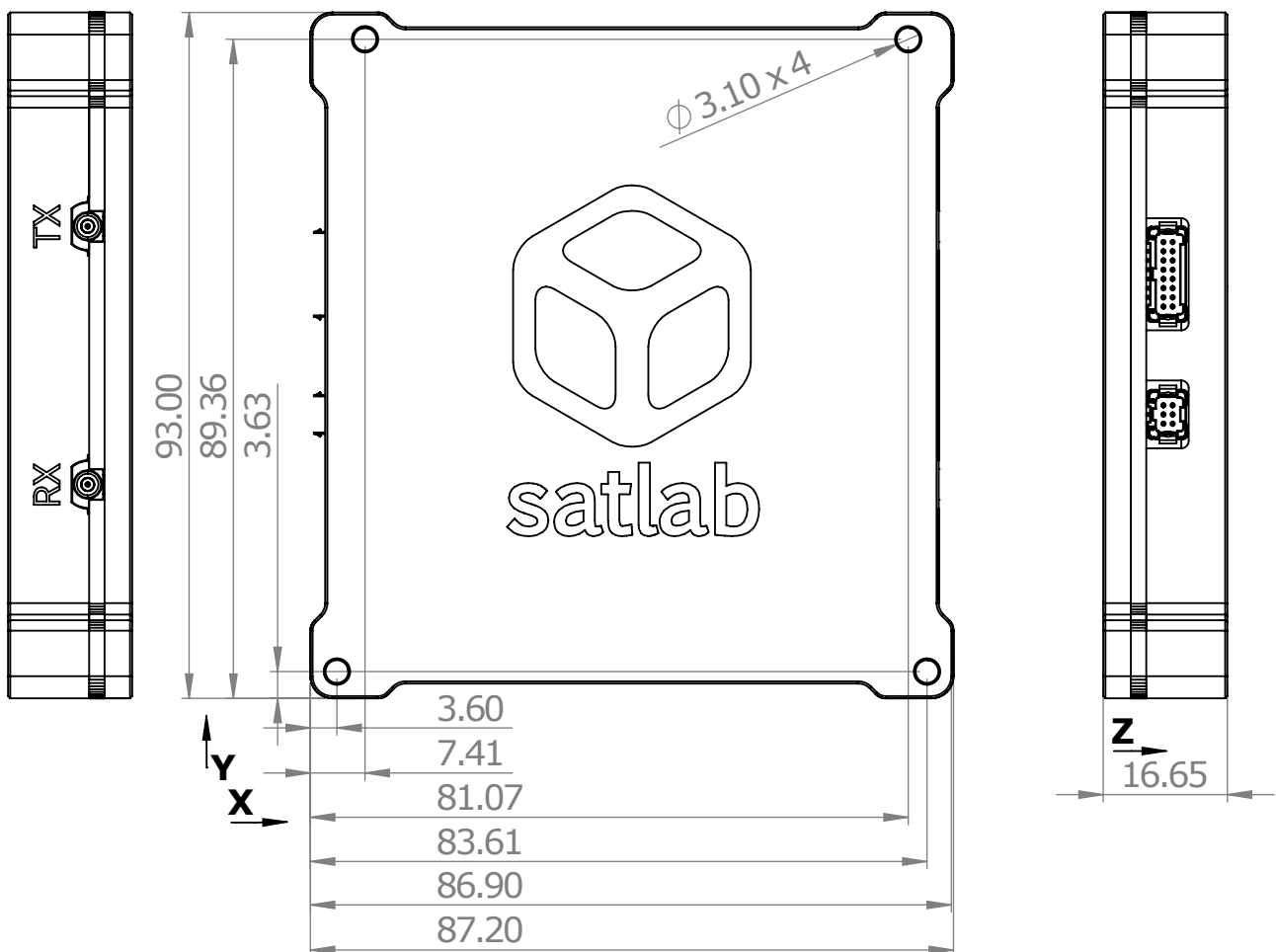


Figure 12: Board outline and side views showing the X+, X-, and Z+ faces. All dimensions in mm and ± 0.1 mm tolerance. The Z-dimension may vary up to ± 0.3 mm due to combined PCB and enclosure tolerances.

8 Ordering Options

As default, the SRS-3 S-band transceiver is delivered with a PTFE flying leads cable for the main connector (P1) with all pins included and the connector potted. A USB EGSE adapter and serial interface is included for on-ground programming and testing on first order.

For contamination control and vibration protection, the PCB is coated with *Nusil CV-1152* conformal coating. If to be omitted, this can be selected below.

The aluminum enclosure is normally delivered with *SurTec 650 ChromitAL TCP* chromate conversion coating (MIL DTL 5541, type II), but can optionally be delivered with *Henkel/Bonderite Alodine 1200S* coating instead (MIL DTL 5541, type I).

Satlab can deliver additional and/or customized cables upon request.

SRS-3 Order Options		
CAN-bus termination	Do not include 120 Ω resistor	<input type="checkbox"/>
RS-422 termination	Do not include 100 Ω resistor	<input type="checkbox"/>
Conformal Coating	Do not conformal coat PCB	<input type="checkbox"/>

9 Customization

Customized versions of SRS-3 hardware and/or software tailored for specific customer requirements can be delivered at additional NRE cost. Please contact Satlab for more information about this option.

10 Revision History

The document ID of this datasheet is **SLDS-SRS3-1.3** and the revision number is **1.3**.

Revision	Date	Description
1.0	2018-08-02	First released version.
1.1	2018-08-13	Correct input voltage transient rating (table 4) and typical power consumption while waiting for frames (front page).
1.2	2023-12-01	Updated data sheet to include BT=0.5 performance and updated protocol section to reflect firmware v2.x along with general textual edits.
1.3	2024-08-16	Document frame header and compliant CCSDS frame sizes in section 4.

11 Disclaimer

This datasheet is subject to change without notice. All information in the document is believed to be accurate and reliable at the time of publication, but it is presented without guarantee, warranty, or responsibility of any kind, expressed or implied. It is the responsibility of the customer to validate that the product with the properties described herein is suitable for use in a particular application. All trademarks are the property of their respective owners.