sysmocom

sysmocom - systems for mobile communications GmbH

sysmoRFDSATT User Manual

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REVISION HISTORY

NUMBER	DATE	DESCRIPTION	NAME
v1	May 2021	Initial	hw
v1.1	December 2023	Updated block diagram, information about signal flow	sk

Contents

1 Introduction

sysmoRFDSATT is a family of programmable, software-controlled digital step attenuators for radio frequency (RF) use cases.

The first member of this family is the sysmoRFDSATT-4-62, featuring four independent channels with 0..62 dB of attenuation each.

This kind of device can be very useful in any kind of laboratory or test setup where RF signal strength must be adjusted programmatically.

A classic use case is e.g. the testing of power-based hand-over within lab setups of cellular radio network, such as GSM BTS, UMTS NodeB, LTE eNodeB or 5G gNodeB.

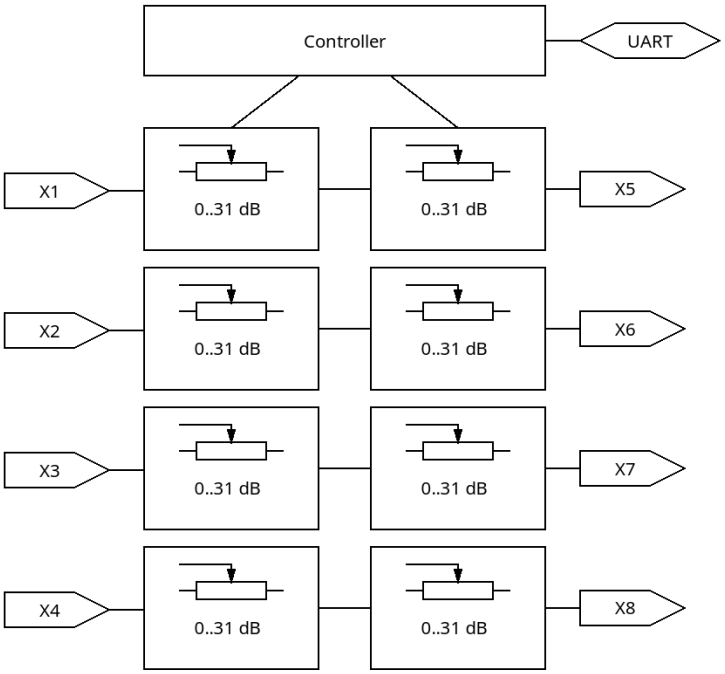

Figure 1: Block Diagram of sysmoRFDSATT-4-62

1.1 Key differentiators

This section explains some of the differentiators to existing programmable digital step products on the market.

1.1.1 Cost efficiency

While there are existing products in the market for this use case, their cost is often prohibitively high for most users. With a primary use case of producing *metrology grade* equipment, the RF performance (isolation, insertion loss) of such products is excellent, we find that many use cases don't need metrology grade equipment, but often prefer a lower-cost option with lower performance.

Examples:

- sysmoRFDSATT is built on a standard FR4 substrate without any RF-optimized material. That means more insertion loss, but lower cost.
- sysmoRFDSATT is is built without a custom, milled aluminium enclosure with individual shield compartments for each channel. That means lower isolation figures, but lower cost.

1.1.2 Open Source

The full software stack, from boot loader up to the application firmware (Section 5) is Open Source Software. This means anyone can adjust it in any way.

This means the firmware can be modified to accommodate any specific requirements. For example, the following modifications are easily possible:

- support of the SCPI protocol for integration into existing lab software solutions
- support of any application-specific control protocol
- support of autonomous execution of entire scenarios, like ramping attenuation with certain slope.

1.1.3 UART instead of USB or Ethernet

It was a very specific design decision to go for a seemingly old-fashioned UART instead of a USB or Ethernet based control interface.

The rationale for this is quite simple: RF isolation between test setup and control computer.

A UART is a very low-speed signal, which can be RF-filtered by a low-pass to avoid any leakage of noise from the control computer to the RF side, as well as leakage of RF to the control computer.

This is contrary to Ethernet and USB, which both have very high frequency components that are not as easily filtered.

2 Mechanical / Enclosure

2.1 sysmoRFDSATT-4-62

The sysmoRFDSATT-4-62 is available in three variants:

- PCBA only, for integration into custom projects
- 3U Component Carrier
- Desktop Enclosure

2.2 PCBA only

The PCBA-only version is provided as a 100 x 80 mm printed circuit board assembly.

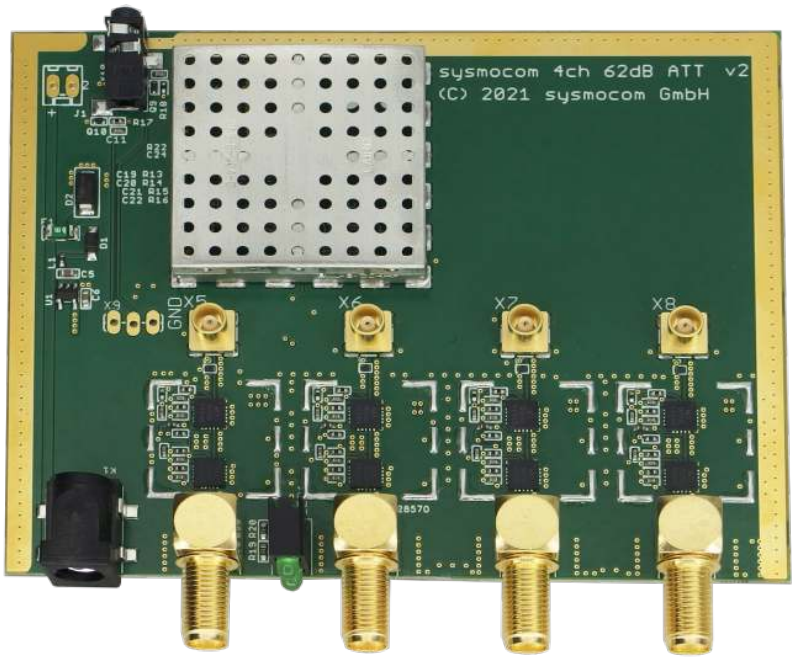

Figure 2: sysmoRFDSATT-4-62-PCBA

NOTE

Only one end of each RF channel is exposed via right-angled SMA connectors mounted to the front edge of the PCBA. The other end of each RF channel is exposed on MCX connectors in the center section of the PCBA. Your system integration must take care of including the respective RF cabling / adapters.

2.2.1 Desktop Enclosure Variant (KOH)

The desktop enclosure version is housed in an aluminium enclosure. The enclosure is roughly 105 x 105 x 44 mm, excluding the protruding connectors on the face plate.

Figure 3: sysmoRFDSATT-4-62-KOH

2.2.2 3U Component Carrier Variant (BGT)

This variant is intended to be mounted in 3U high 19" component carriers conforming to IEC 60297-3-101. Such a component carrier can house a number of sysmoRFDSATT devices or other components from sysmocom (like the 16-channel GPS RF splitter) or third parties.

Figure 4: sysmoRFDSATT-4-62-BGT

The 3U component carrier variant consists of the PCBA, a corresponding face plate and pig-tails for the RF connection as well as the UART.

The face plate has a width of 7 HP (Horizontal Pitch), equaling 35.56 mm.

Figure 5: sysmoRFDSATT-4-62-BGT mounted in 3U component carrier (leftmost module)

3 sysmoRFDSATT electronics

The sysmoRFDSATT electronics consist of a number of CMOS digital step attenuator ICs controlled by a built-in microcontroller.

As digital step attenuator ICs are only available for certain ranges of attenuation, typically up to about 30 dB, multiple stages may be required to achieve a certain attenuation range.

The arrangement of the digital step attenuators is described as follows:

- a *channel* describes one RF signal path; each has separate input and an output RF connectors.
- a *stage* describes one attenuator within a *channel*

For example, the sysmoRFDSATT-4-62 contains of four independent channels, each comprised of two stages. Each stage in turn has configurable attenuation from nominal 0..31 dB.

Principally the channels are symmetric, so input and output may be exchanged. Still insulation could be better if the edge mounted connectors are used as inputs (X1-X4). This is also noted in the block diagram.

In addition to the nominal attenuation that each stage is configured to perform, there is *insertion loss*. This is the combined loss of the sysmoRFDSATT device, caused by losses in PCB substrate, connectors, TVS diodes and inside the actual attenuator RF-ICs.

3.1 Supply Power

sysmoRFDSATT requires nominal 5V DC supply power, but can accept any voltage in the range of 3.6 .. 5.5V DC.

Supply voltage can be provided either via either of those two:

- a 5.5/2.5 mm barrel type connector on the front side of the board (K1), allowing external power supplies to be used.
- a 2.54mm pitch header on the back side of the board (J1), allowing internal supply power to be provided when the sysmoRFDSATT is integrated in larger assemblies with internal DC power supply

Only one of those two connections must be used at any time, as they are directly connected on the circuit board. They are *not* intended for fail-over/redundancy purposes!

The current consumption is quite minimal, about 30mA during typical operation.

While the voltage input features over-voltage and polarity protection, including self-resetting polyfuse, the input voltage should not exceed 5.5V to avoid risk of damage.

3.2 Microcontroller

The microcontroller used on the sysmoRFDSATT family are STM32 controllers using ARM Cortex-M0 or Cortex-M1 cores. They feature built-in RAM and Flash memories.

The Microcontroller runs *firmware*, specifically a boot-loader and main application software. For more details, see Section 5.

NOTE

The SWD programming interface of the STM32 is exposed on a TagConnect TC-2050 footprint (TC1), in case this is required for development/debugging of custom firmware builds. This is not needed during normal operation.

3.3 EEPROM

In order to be able to persist the configured attenuation values across power-cycling, there is an EEPROM memory attached to the microcontroller.

3.4 UART for remote control

The sysmoRFDSATT is software-controlled via a UART (serial port).

The UART operates at **3.3V CMOS logic level** at a speed of 115200 bits per second (bps).

It is exposed in two ways:

- via a 2.5mm *Osmocom standard* stereo jack at the back of the circuit board (X10)

Figure 6: Pinout *Osmocom standard* stereo jack

- via a 3-pos 2.54mm header in the center of the board (X9): Pin 1 is RX, Pin 2 is TX, Pin 3 is GND (named on board)

Only one of those two optional connections must be used at any time.

WARNING

The 3.3V voltage level means you **must not directly connect a RS-232 port**, which operates at much higher voltage! Only 3.3V UART cables must be used to interface, such as the sysmocom [cp2103-25] cable.

3.5 ESD protection

The semiconductors used in the sysmoRFDSATT are all sensitive to damage by electrostatic discharge (ESD). Transient voltage suppression (TVS) diodes are present on all external connectors, but the user should avoid any ESD discharge.

3.6 LEDs

There are two green LEDs vertically above each other.

- Top LED: DC power supplied
- Bottom LED: Software Controlled
  - rapid blinking: In boot loader
  - slow blinking: Application software running

3.7 Electrical Specifications

Table 1: Operating Conditions

Supply Voltage	3.6 .. 5.5 V
Supply Current (typ)	30 mA
Operating Temperature	-40 to 85 Celsius
UART Logic Voltage	3.3V CMOS
UART Bit Rate	115200
UART Bits/Word	8
UART Parity	None
UART Stop Bits	1

Table 2: RF Power Rating

Max. Input Operating Power < 100 kHz	+ 8 dBm
Max. Input Operating Power @ 1 MHz	+11 dBm
Max. Input Operating Power @ 20 MHz	+20 dBm
Max. Input Operating Power >= 50 MHz	+24 dBm
Absolute Maximum RF Input Power	+30 dBm

Maximum Input Operating Power values should not be exceeded in continuous operation.

Exceeding the Absolute Maximum RF Input Power will result in permanent damage.

4 RF performance

This section contains some typical RF performance that can be expected of the sysmoRFDSATT-4-62, based on actual measurements taken from production units.

4.1 Insertion Loss

Figure 7: Insertion Loss at nominal 0dB attenuation

4.2 Attenuation

Figure 8: Attenuation at nominal 30dB attenuation

Figure 9: Attenuation at nominal 60dB attenuation

4.3 Isolation

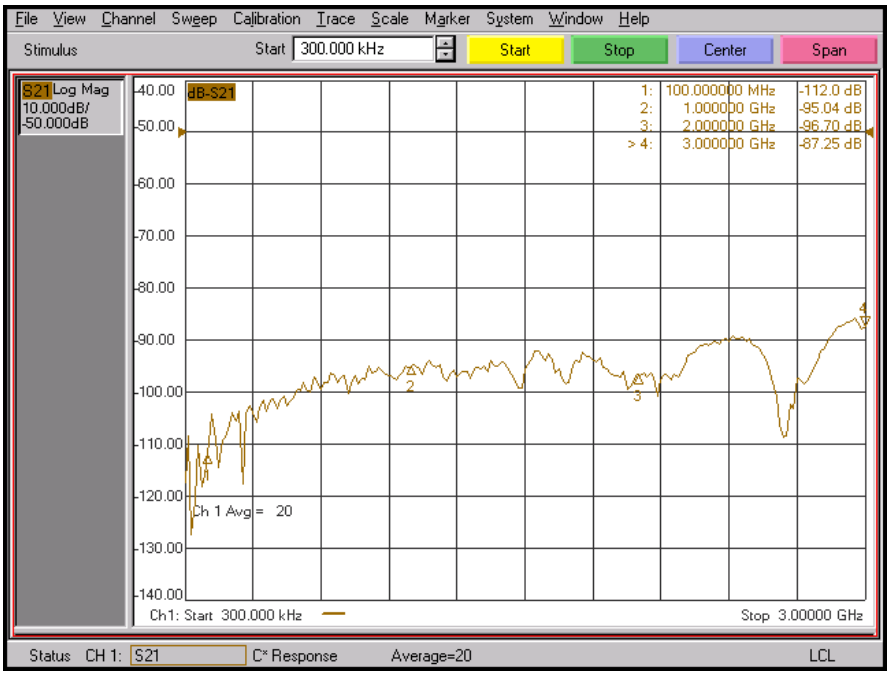

Figure 10: Isolation between SMA connectors of neighboring channels

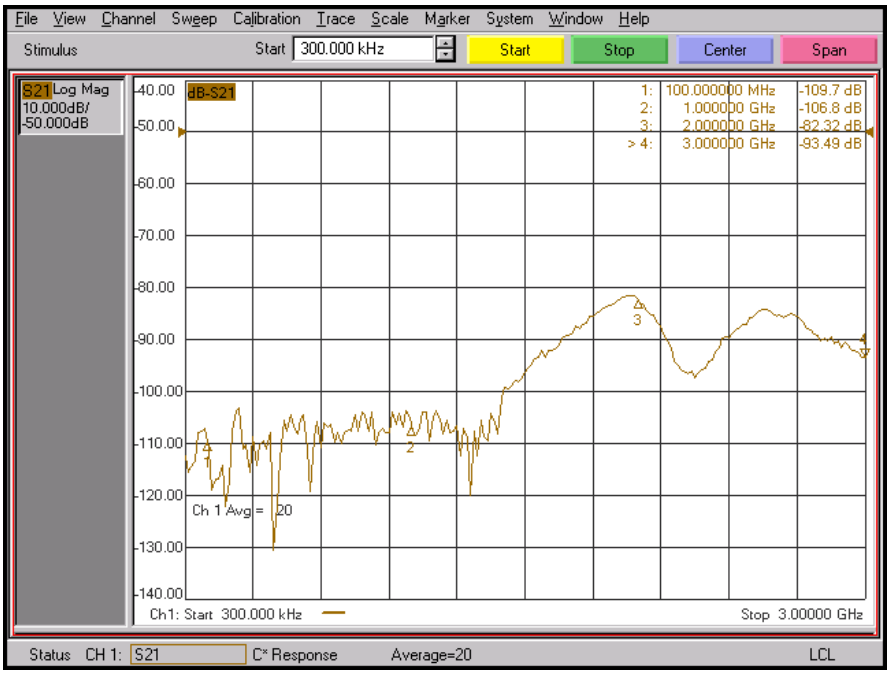

Figure 11: Isolation between MCX connectors of neighboring channels

5 sysmoRFDSATT Firmware

The sysmoRFDSATT firmware consists of two parts:

- a boot-loader
- the application firmware

5.1 Boot Loader

The first 8kByte of built-in flash are used by the serial boot-loader. Its purpose is to allow in-the-field updates of the main application firmware via the UART / serial port.

The boot-loader is OpenBLT, Licensed under GNU General Public License, Version 3.

For more information about OpenBLT, see https://github.com/feaser/openblt

The boot loader is factory-installed at sysmocom and does not normally require modification or update. Any updates can only be performed via JTAG/SWD.

5.2 Application Firmware

The main application firmware resides at an offset of 8kByte within the internal flash of the microcontroller.

The original firmware is maintained as part of the Osmocom (Open Source Mobile Communications) project. It's source code can be found at https://git.osmocom.org/osmo-opencm3-projects/

Pre-built binaries can be obtained from https://ftp.osmocom.org/binaries/osmo-op3ncm3-projects/rfdsatt/

The application firmware is licensed under GNU General Public License, Version 3. It utilizes third-party libraries, such as libopencm3 (https://github.com/libopencm3/libopencm3) and librfn (https://github.com/daniel-thompso), both licensed under GNU Lesser General Public License, Version 3.

The complete and corresponding source code to the application firmware can be obtained from https://git.osmocom.org/osmo-opencm3-projects/ as well as upon request to support@sysmocom.de.

5.3 Updating the Firmware

In order to update the firmware from a host computer, you will need to

- download a pre-built firmware image, or build it from the source code. You will need an SREC format (file ending in `.srec`)
- install the BootCommander (command line) or MicroBoot program, which are distributed as part of the OpenBLT boot loader project.
- connect the UART of the sysmoRFDSATT to your host PC using a matching 3.3V USB UART cable

If the application software is still functional, it should auto-detect a firmware update attempt at run-time and immediately switch to boot-loader and perform it.

In case the application software is somehow broken/stuck/corrupted, you will have to power-cycle the RFDSATT *while the BootCommander / MicroBoot are already running*. They will continuously try to initialize the firmware update, and the boot-loader will detect that during the RFDSATT boot process.

A typical BootCommander session will look like this:

```
$ BootCommander -d=/dev/ttyUSB5❶ -b=115200 rfdsatt.srec❷
 ------------------------------------------------------------------------
BootCommander version 1.04.02. Performs firmware updates on a micro-
controller based system that runs the OpenBLT bootloader.

Copyright (c) 2017 by Feaser  http://www.feaser.com
 ------------------------------------------------------------------------
Processing command line parameters...[OK]
Detected firmware file: rfdsatt.srec
Detected session protocol: XCP version 1.0
Using session protocol settings:
  -> Timeout T1: 1000 ms
  -> Timeout T3: 2000 ms
  -> Timeout T4: 10000 ms
  -> Timeout T5: 1000 ms
  -> Timeout T6: 50 ms
  -> Timeout T7: 2000 ms
  -> Seed/Key file: None
  -> Connection mode: 0
Detected transport layer: XCP on RS232
Using transport layer settings:
  -> Device: /dev/ttyUSB5
  -> Baudrate: 115200 bit/sec
Loading firmware data from file...[OK]
  -> Number of segments: 1
  -> Base memory address: 0x08002000
  -> Total data size: 17756 bytes
Connecting to target bootloader...[OK] ❸
Erasing 17756 bytes starting at 0x08002000...[OK]
Programming 17756 bytes starting at 0x08002000...[OK]
Finishing programming session...[OK] ❹
```

❶ Please use the serial device of the respective UART on your system

❷ File name of the application firmware to install

❸ BootCommander trying to establish XCP connection via UART to RFDSATT

❹ Programming completed

After the programming has completed, the RFDSATT will re-boot automatically and run the newly-installed firmware.

6 Command Line Interface (CLI)

The sysmoRFDSATT application firmware features a command-line interface which is exposed via the serial port / UART at 115200 bps.

The command-line interface can be utilized both by human user as well as shell scripts.

When you connect to the serial port and power up the sysmoRFDSATT, you will be greeted by a welcome banner followed by a prompt:

```
======================================================================
sysmocom RFDSATT main (build 0.1.0)
UUID: 383309678386574855FF6706
Reset cause(s): 0x00000000
======================================================================
EEPROM Settings restored
rfdsat4ch>
```

You can type commands at that command line, for example the `help` command, listing you which commands are available.

```
rfdsat4ch> help
Help:
 Command          Help
 ---------------- ----
 help             Print command reference
 reset            Reset the board
 uuid             Get the unique ID
 version          Get the firmware version
 show             Show state of all attenuators
 set              Set an attenuator (channel, stage, dB)
 interact         Enter interactive single-key mode
 test             Enter interactive test-ramp mode
 i2c-read         Read from I2C EEPROM
 i2c-write        write to I2C EEPROM
 load             Load all settings from the EEPROM
 save             Save the current state to the EEPROM
```

6.1 Affecting Attenuation

6.1.1 `set` command

The `set` command can be used to set the attenuation value of a given channel, or of a specific stage within a channel.

If you use the two-argument version of `set`, you simply specify the overall attenuation and the firmware will split it up among the stages of the channel.

Two-Argument set command

```
rfdsat4ch> set 1❶ 45❷
Setting CH1 to 22 + 22 = 045 dB
```

❶ selecting channel 1, the first channel

❷ specifying the attenuation value in dB

In some situations you may want to control the attenuation of a specific stage. To do so, use the three-argument version of `set`:

Three-Argument set command

```
rfdsat4ch> set 3❶ 2❷ 30❸
Setting CH3-ST2 to 30 dB
```

❶ selecting channel 3, the third channel

❷ selecting stage 2, the second stage

❸ specifying the attenuation value in dB

6.1.2 `show` command

The `show` command dumps the current attenuation settings of all stages in all channels:

```
rfdsat4ch> show
Channel 01: Stage1 22 dB, Stage2 22 dB, Sum 45 dB
Channel 02: Stage1 00 dB, Stage2 00 dB, Sum 00 dB
Channel 03: Stage1 12 dB, Stage2 30 dB, Sum 42 dB
Channel 04: Stage1 00 dB, Stage2 00 dB, Sum 00 dB
```

6.2 Making settings persistent

6.2.1 `save` command

The `save` command will store the current attenuation settings in the built-in EEPROM.

Those settings will be automatically applied on power-up.

```
rfdsat4ch> save
Saved current settings to EEPROM
```

Note
Writing to the EEPROM will take a few seconds, don't be surprised by a relatively high command processing time.

6.2.2 `load` command

The `load` command can be used to restore all attenuation settings from the non-volatile EEPROM storage.

```
rfdsat4ch> load
Setting CH1-ST1 to 22 dB
Setting CH1-ST2 to 22 dB
Setting CH2-ST1 to 0 dB
Setting CH2-ST2 to 0 dB
Setting CH3-ST1 to 12 dB
Setting CH3-ST2 to 30 dB
Setting CH4-ST1 to 0 dB
Setting CH4-ST2 to 0 dB
EEPROM settings restored
```

6.3 Interactive mode

If you want to make very quick, interactive changes, typing lengthy commands for each change can be tiresome.

This is what the *interactive mode* is meant for. It allows very quick interactive modification of attenuation values with single key-presses.

The *interactive mode* is entered by the `interact` command on the CLI. You can use the upper-case `X` character to return back to the CLI.

Example interact session

```
rfdsat4ch> interact
Entering interactive single-key mode. Press 'X' for exit, '?' for help
❶
'1'..'4': Select channel
'0'     : Set attenuation of current channel+stage to 0 dB
'f'     : Set attenuation of current channel+stage to 31 dB
'+'/'-' : Increment/decrement attenuation in dB
'a'/'b' : Select stage 1/2 within channel
'X'     : Exit interactive mode
❷
Setting CH2-ST1 to 0 dB
❸
Setting CH2-ST1 to 1 dB
Setting CH2-ST1 to 2 dB
Setting CH2-ST1 to 3 dB
Setting CH2-ST1 to 4 dB
Setting CH2-ST1 to 5 dB
❹
Setting CH2-ST1 to 4 dB
❺
Setting CH2-ST2 to 0 dB
Setting CH2-ST2 to 1 dB
Setting CH2-ST2 to 2 dB
Setting CH2-ST2 to 3 dB
Setting CH2-ST2 to 4 dB
Setting CH2-ST2 to 5 dB
Setting CH2-ST2 to 6 dB
Setting CH2-ST2 to 7 dB
Setting CH2-ST2 to 8 dB
❻
Setting CH2-ST2 to 0 dB
❼
rfdsat4ch>
```

❶ `?` key is entered to get the help

❷ `2` key is entered to select channel 2

❸ `+` key is pressed several consecutive times, each time incrementing the attenuation of the selected attenuator stage/channel by 1 dB

❹ `-` key is pressed to reduce the attenuation by 1 dB

❺ `b` key is pressed to switch to stage 2 within the channel

❻ `0` key is pressed to set the attenuation of the selected stage to 0 dB

❼ `X` key is pressed to return to the CLI prompt

6.4 Test mode

This mode is mainly meant for factory testing, but can also be used in order to validate the correct function of the sysmoRFDSATT device

In this mode, the attenuation value of the selected channel will continuously cycle in steps between 0, 10, 20, 30, 40, 50, 60 and then re-start again from 0 dB. The step duration is 500ms.

This allows a very quick validation of a channel with a VNA or RF power meter

Example test session

```
rfdsat4ch> test
Interactive test-ramp mode. Press 'X' for exit, '?' for help
Setting CH1 to 10 + 00 = 010 dB
Setting CH1 to 20 + 00 = 020 dB
Setting CH1 to 30 + 00 = 030 dB
Setting CH1 to 31 + 09 = 040 dB
Setting CH1 to 31 + 19 = 050 dB
Setting CH1 to 31 + 29 = 060 dB
Setting CH1 to 00 + 00 = 000 dB
Setting CH1 to 10 + 00 = 010 dB
Setting CH1 to 20 + 00 = 020 dB
Setting CH1 to 30 + 00 = 030 dB
❶
rfdsat4ch>
```

❶ `X` key is pressed to return to CLI prompt

The following single-key commands can be used during test mode:

```
'1'..'4': Select channel
'0'     : Set attenuation of current channel to 0 dB
'X'     : Exit interactive test-ramp mode
```

6.5 Miscellaneous commands

6.5.1 `reset` command

The `reset` command is used to reset the microcontroller of the sysmoRFDSATT:

```
rfdsat4ch> reset&#xfffd;
======================================================================
sysmocom RFDSATT main (build 0.1.0)
UUID: 383309678386574855FF6706
Reset cause(s): 0x00000000
======================================================================

Setting CH1-ST1 to 22 dB
Setting CH1-ST2 to 22 dB
Setting CH2-ST1 to 0 dB
Setting CH2-ST2 to 0 dB
Setting CH3-ST1 to 12 dB
Setting CH3-ST2 to 30 dB
Setting CH4-ST1 to 0 dB
Setting CH4-ST2 to 0 dB
EEPROM settings restored
rfdsat4ch>
```

6.5.2 `uuid` command

The `uuid` command can be used to obtain the device-unique serial number.

This is useful if you have a large number of sysmoRFDSATT devices attached to one controlling computer, and you are not certain the wiring / ttyUSB devices are persistent.

```
rfdsat4ch> uuid
UUID: 383309678386574855FF6706
```

6.5.3 `version` command

The `version` command will show you the firmware build version you're running.

```
rfdsat4ch> version
Firmware Version: 0.1.0
```

7 GNU General Public License, Version 3

The OpenBLT boot loader as well as the main application firmware are licensed under the terms of the GNU General Public License, Version 3.

The complete and corresponding source code can be obtained from the URLs stated in Section 5, and alternatively requested from sysmocom at support@sysmocom.de.

```
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  A "covered work" means either the unmodified Program or a work based
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  To "propagate" a work means to do anything with it that, without
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```
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  To "convey" a work means any kind of propagation that enables other
parties to make or receive copies.  Mere interaction with a user through
a computer network, with no transfer of a copy, is not conveying.

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feature that (1) displays an appropriate copyright notice, and (2)
tells the user that there is no warranty for the work (except to the
extent that warranties are provided), that licensees may convey the
work under this License, and how to view a copy of this License.  If
the interface presents a list of user commands or options, such as a
menu, a prominent item in the list meets this criterion.

  1. Source Code.

  The "source code" for a work means the preferred form of the work
for making modifications to it.  "Object code" means any non-source
form of a work.

  A "Standard Interface" means an interface that either is an official
standard defined by a recognized standards body, or, in the case of
interfaces specified for a particular programming language, one that
is widely used among developers working in that language.

  The "System Libraries" of an executable work include anything, other
than the work as a whole, that (a) is included in the normal form of
packaging a Major Component, but which is not part of that Major
Component, and (b) serves only to enable use of the work with that
Major Component, or to implement a Standard Interface for which an
implementation is available to the public in source code form.  A
"Major Component", in this context, means a major essential component
(kernel, window system, and so on) of the specific operating system
(if any) on which the executable work runs, or a compiler used to
produce the work, or an object code interpreter used to run it.

  The "Corresponding Source" for a work in object code form means all
the source code needed to generate, install, and (for an executable
work) run the object code and to modify the work, including scripts to
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    may be on a different server (operated by you or a third party)
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