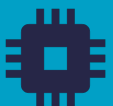




Subsystems for the
UAS integration into
the airspace

OEM TT-SC1 and TT-SC1-EXT

Data sheet - User manual



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1 Introduction

The TT-SC1 and TT-SC1-EXT are a high quality and low price OEM's **ADS-B** receivers series operating at 1090MHz.

It is based on the proven **FPGA-In-The-Loop™** technology, which is a unique combination of a single-core processor and FPGA. The patented solution allows high-speed RF data processing with significantly reduced number of electronic components. Simultaneous miniaturization of the module and its OEM nature open a wide range of possible applications.

The basic version **TT-SC1** of module offers the possibility of receiving and decoding **ADS-B** and **TT-SC1-EXT** additional with **Mode-A/C/S** in different modes. The analysis of the power/quality of the RF signal and the use of time stamps facilitates the implementation of multilaterations, and the fast UART interface and easy configuration with AT-commands allows for the simple integration of the module with the user's system. In addition, extra interfaces open the way to customize the firmware and extend the module with non-standard functions. There are several communication interfaces, protocols and special functionalities available on request.

Important:

Each firmware version becomes its own documentation. This document is relevant for firmware version v2.89.28. If your firmware version is different please find relevant documentation on our website aerobits.pl.

1.1 Available variants

Table 1: Variants of TT-SC1 modules

Variant	ADS-B	Version a/b	Mode A/C/S	UART	USB	Protocols	Timestamp
SC1	✓	✓		✓		Basic	
SC1-EXT	✓	✓	✓	✓	✓	Extended	✓

Note:

Basic protocols contains only CSV and MAVLink, extend version has all supported protocols.

Warning:

The TT-SC1 module can process up to 100 aircrafts, TT-SC1-EXT module can process up to 300 aircrafts.

1.2 Features

- Fastest ADS-B implementation on a surface of $<2cm^2$
- Receiving of ADS-B, Mode-A/C/S with RF signal strength/quality analysis
- Time stamp (raw data only) for multilateration
- Multiple supported protocols, i.a. RAW HEX, CSV, AERO, MAVLink, ASTERIX, GDL90
- High-resolution ADC with real-time signal processing; best-in-class aircraft tracking
- Simple module integration via USB or UART interface and AT commands
- Scalable OEM solution with enormous customization potential (additional functions or interfaces on request)

- **High sensitive front-end, jamming and ESD protection (only version b) with ranges over 150 km (open space, 1dBi antenna)**
- **Firmware update capability (uC and FPGA)**
- **Designed to meet MOPS defined in TSO-C199**

For more information please contact support@aerobits.pl.

2 Technical parameters

2.1 Basic technical information

Table 2: General technical parameters

Parameter	Description	Typ.	Unit
First Band	ADS-B	1090	MHz
Sensitivity (ADS-B)		-85	dBm
Antenna connector	RF-IPX125-1G-AU (version b only)		
UART	AT commands	921600	bps
USB	AT commands		
MSL	Moisture Sensitivity Level	4	
Weight	Device weight for a/b versions	1 - 1.15	g

2.2 Electrical specification

2.2.1 Absolute maximum ratings

Table 3: Absolute maximum ratings.

Parameter	Min	Max	Unit
Storage temperature	-5	+40	°C
Supply voltage (VCC)	2.7	3.6	DCV
Other pin voltage	-0.3	VCC + 0.3	DCV
RF input ADS-B	—	+10	dBm

2.2.2 Recommended operation conditions

Table 4: Recommended operation conditions.

Parameter	Min	Typ	Max	Unit
Operation temperature	-30	—	+85	°C
Supply voltage (VCC)	3.0	3.3	3.6	DCV

2.2.3 General electrical parameters

Table 5: General electrical parameters.

Parameter	Description	Min	Typ	Max	Unit
Current consumption		—	70	—	mA
Input Low Voltage	RESET, UARTs, CAN, USB, SPI, I2C	-0.3	—	0.8	DCV
Input High Voltage	RESET, UARTs, CAN, USB, SPI, I2C, GPIO	-0.3	—	0.8	DCV
Output Low Voltage	UARTs, CAN, USB, I2C, SPI, GPIO	—	—	0.4	DCV
Output High Voltage	UARTs, CAN, USB, I2C, SPI, GPIO	VCC - 0.4	—	—	DCV

2.2.4 Pin definition

Pin arrangement of OEM TT-SC1 is shown on the figure below:

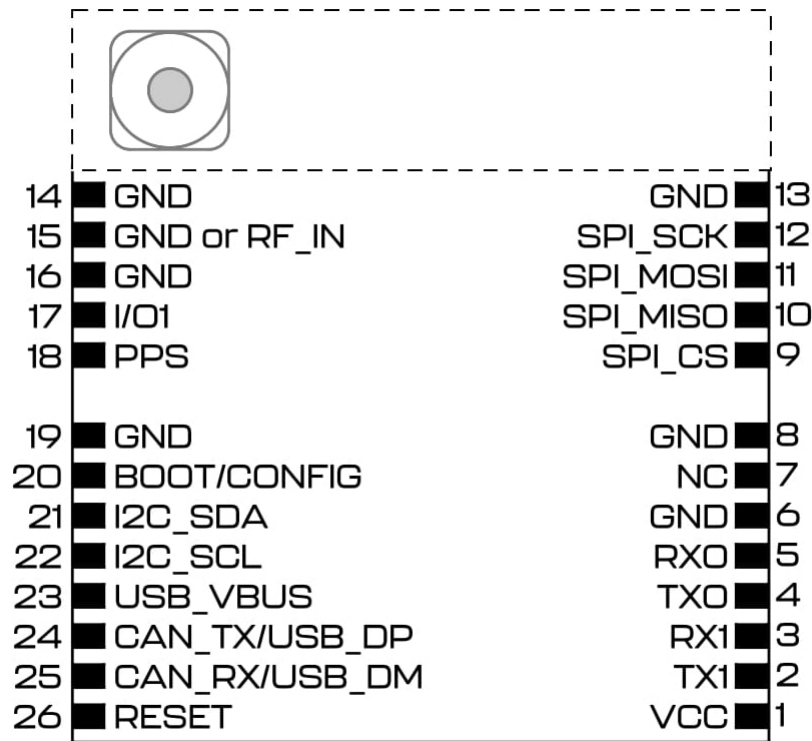


Fig. 1: Pin arrangement of OEM TT-SC1

Table 6: Pin definitions of OEM TT-SC1.

Pin number	Pin Name	Pin Type	Description
1	VCC1	IN	Power supply input
2	TX1	N/A	No commercial use (keep floating)
3	RX1	N/A	No commercial use (keep floating)
4	TX0	OUT	Main UART TX
5	RX0	IN	Main UART RX
6	GND	N/A	No commercial use (keep floating)
7	NC	N/A	No commercial use (keep floating)
8	GND	PWR	Ground
9	CS	OUT	SPI chip select (future use)
10	MISO	IN	SPI Master Input Slave Output (future use)
11	MOSI	OUT	SPI Master Output Slave Input (future use)
12	SCK	OUT	SPI Clock (future use)
13	GND	IN	SPI Master Input Slave Output (future use)
14	GND	OUT	SPI Master Output Slave Input (future use)
15 version a	RF_IN	IN	RF Input (antenna)
15 version b	GND	PWR	Ground
16	GND	PWR	Ground
17	I/O	N/A	No commercial use (keep floating)

continues on next page

Table 6 – continued from previous page

Pin number	Pin Name	Pin Type	Description
18	1PPS	IN	PPS GNSS signal
19	GND	PWR	Ground
20	B/C	IN	Bootloader/Configuration mode trigger
21	I2C_SDA	IN/OUT	I2C data (future use)
22	I2C_SCL	OUT	I2C clock (future use)
23	VBUS	IN	USB Power line
24	DP	IN/OUT	USB Data+
25	DM	IN/OUT	USB Data-
26	RESET	IN	Module reset

Note:

All future use pins are available for special request in custom firmware (extra cost)

2.3 Mechanical specification

2.3.1 Dimensions

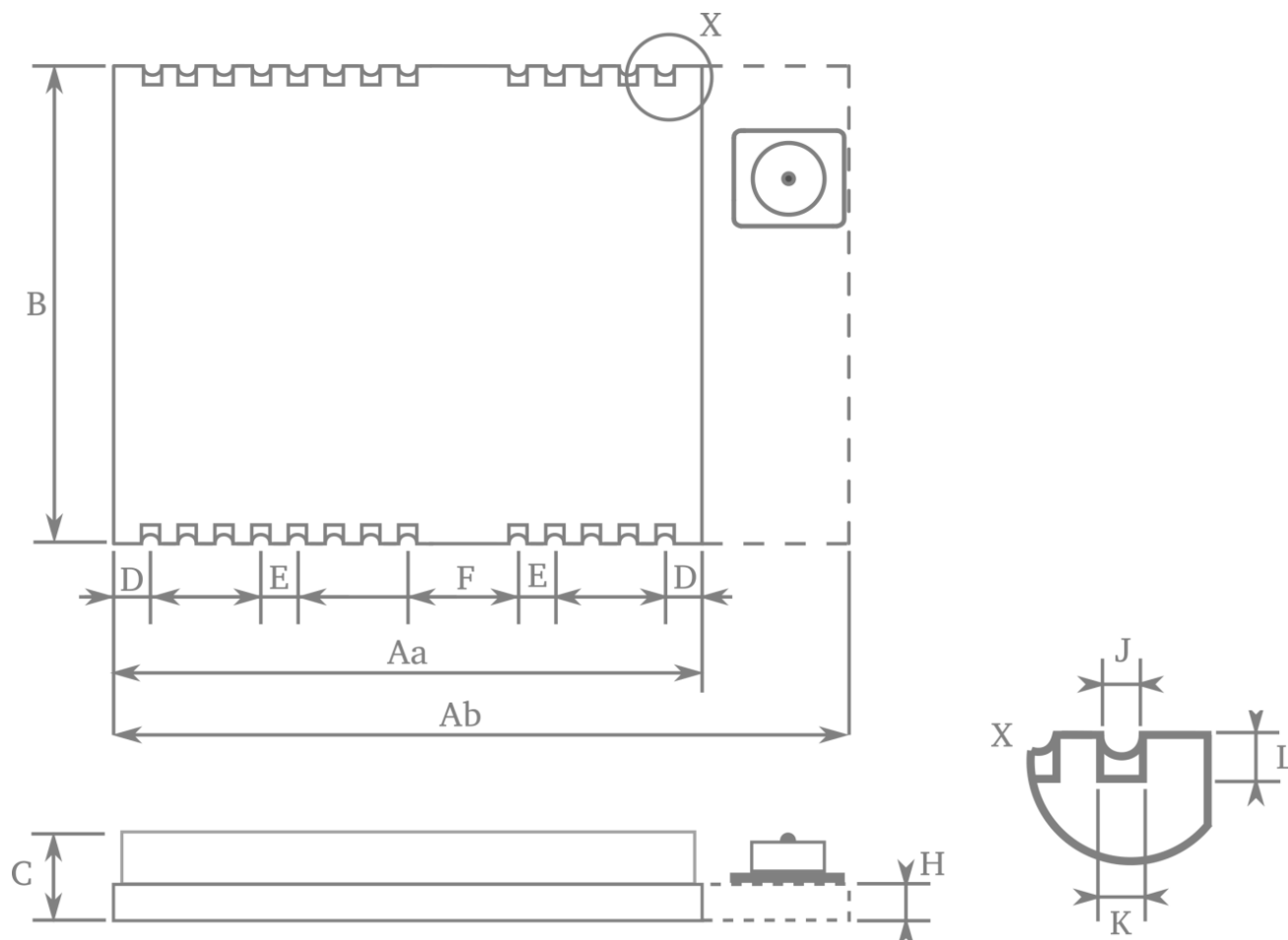


Fig. 2: Mechanical drawing of OEM TT-SC1

Table 7: Dimensions and tolerances.

Symbol	Min. (mm)	Typ. (mm)	Max. (mm)
Aa (version a)	15.9	16	16.1
Ab (version b)	19.9	20	20.1
B	12.9	13	13.1
C	2.6	2.7	2.8
D	0.9	1	1.1
E	0.9	1	1.1
F	2.9	3	3.1
H	0.6	0.7	0.8
J	0.4	0.5	0.6
K	0.6	0.7	0.8
L	0.7	0.8	0.9

2.3.2 Recommended layout

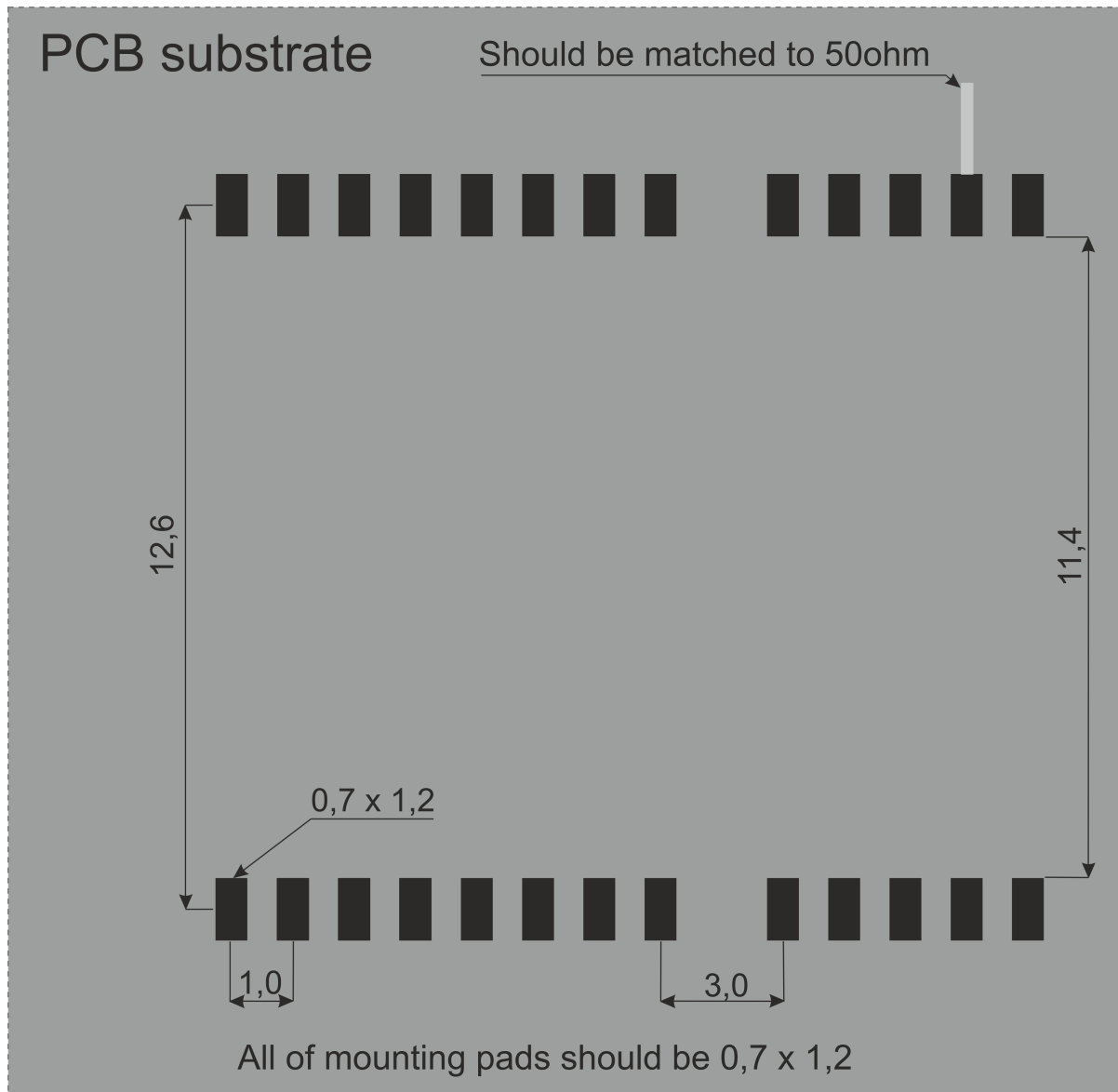


Fig. 3: Footprint of OEM TT-SC1

Important:

In case of OEM the RF inputs indicated in the [footprint](#) (page 10) should be matched to 50ohm.

2.3.3 Soldering

Reflow Soldering

It's advisable to opt for a convection-based soldering oven instead of an infrared radiation one. Convection ovens offer precise temperature control, ensuring uniform heating of all components regardless of their properties, thickness, or surface color. For more details, you can refer to the "IPC-7530 Guidelines for temperature profiling for mass soldering (reflow and wave) processes," issued in 2001.

We highly suggest take look at our soldering [profile](#) (page 11) and try to adapt it to your process. The soldering process strictly depends on the thickness of the PCB, solder paste and soldering profile, for this reason we recommend to choose the soldering method directly to the specific project.

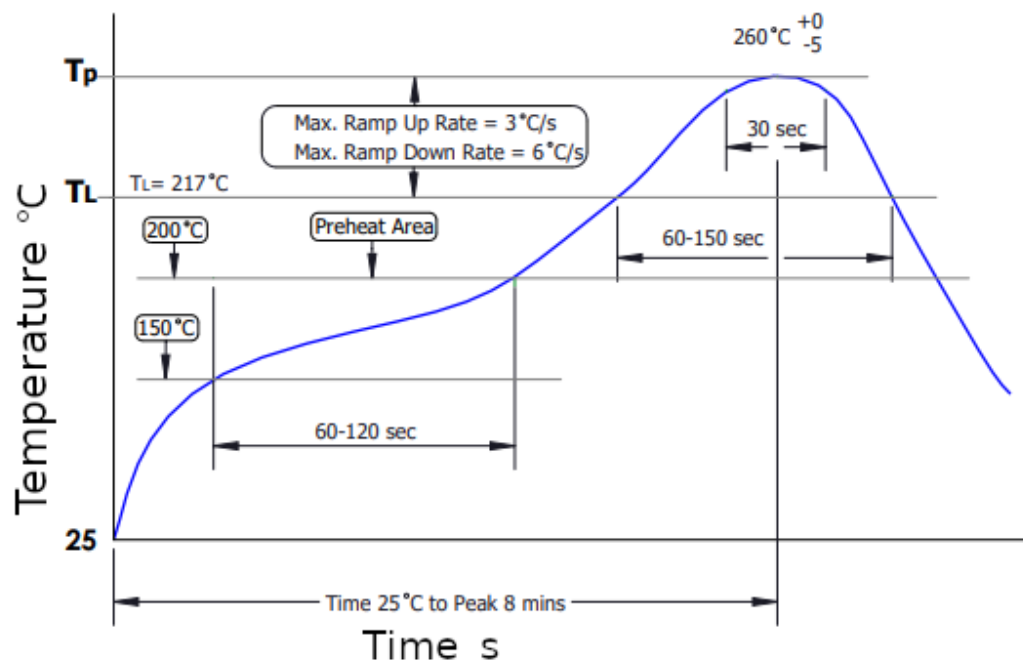


Fig. 4: Recommended soldering profile for OEM TT-SC1

3 UART configuration

Communication between module and host device is done using UART interface.

In CONFIGURATION and BOOTLOADER state transmission baud is fixed at 115200bps.

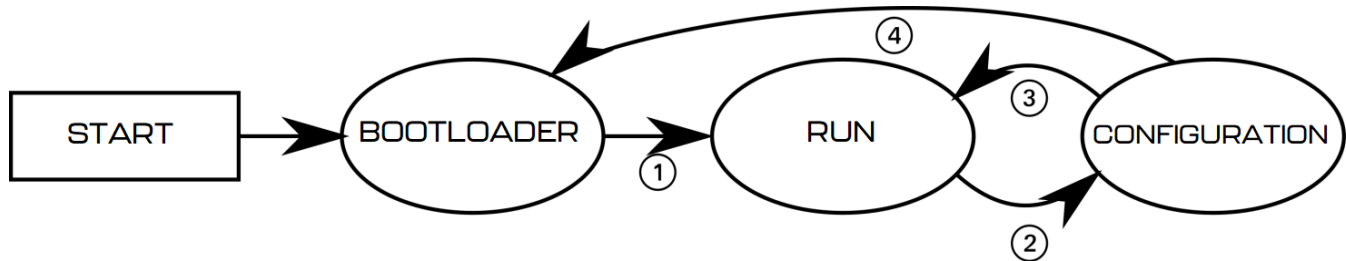
The UART interface uses settings as described in table below:

Table 8: Descriptions of UART settings.

Parameter	Min.	Typ.	Max	Unit
Baud	57600	921600	3000000	bps
Stop Bits Number	—	1	—	—
Flow Control	—	None	—	—
Parity Bit	—	None	—	—

4 Principle of operation

During work module goes through multiple states. In each state operation of the module is different. Each state and each transition is described in paragraphs below.



4.1 States of operation

4.1.1 BOOTLOADER state

This is an initial state of after restart. Firmware update is possible here. Typically module transitions automatically to RUN state. It is possible to lock module in this state (prevent transition to RUN state) using one of BOOTLOADER triggers. UART baud is constant and is set to 115200bps. After powering up module, it stays in this state for 3 seconds. If no BOOTLOADER trigger is present, module will transition to RUN state. Firmware upgrade is possible using Micro ADS-B App software. For automated firmware upgrading scenarios, aerobits_updater software is available. To acquire this program, please contact: support@aerobits.pl.

4.1.2 RUN state

In this state module is broadcasting drone identification data. In this state module is working and receiving the data from aircrafts. It uses selected protocol to transmit received and decoded data to the host system. In this state of operation module settings are loaded from non-volatile internal memory, including main UART interface's baud.

4.1.3 CONFIGURATION state

In this mode change of stored settings is possible. Operation of the module is stopped and baud is set to fixed 115200bps. Change of settings is done by using AT-commands. Changes to settings are stored in non-volatile memory on exiting this state. Additional set of commands is also available in this state, allowing to e.g. reboot module into BOOTLOADER state, check serial number and firmware version. It is possible to lock module in this state (similarly to BOOTLOADER) using suitable command.

4.2 Transitions between states

For each state transition, different conditions must be met, which are described below. Generally, the only stable state is RUN. Module always tends to transition into this state. Moving to other states requires host to take some action.

4.2.1 BOOTLOADER to RUN transition

BOOTLOADER state is semi-stable: the module requires additional action to stay in BOOTLOADER state. The transition to RUN state will occur automatically after a short period of time if no action is taken. To prevent transition from BOOTLOADER state, one of following actions must be taken:

- Send AT+LOCK=1 command while device is in BOOTLOADER state (always after power on for up to 3s)
- Send AT+REBOOT_BOOTLOADER command in CONFIGURATION state. This will move to BOOTLOADER state and will lock module in this state.

If none of above conditions are met, the module will try to transition into RUN state. Firstly it will check firmware integrity. When firmware integrity is confirmed, module will transition into RUN state, if not, it will stay in BOOTLOADER state.

To transition into RUN state:

- If module is locked, send `AT+LOCK=0` command

When module enters RUN mode, it will send `AT+RUN_START` command.

4.2.2 RUN to CONFIGURATION transition

To transition from RUN into CONFIGURATION state:

- Send `AT+CONFIG=1` (using current baud).

When module leaves RUN state, it sends `AT+RUN_END` message, then `AT+CONFIG_START` message on entering CONFIGURATION state. The former is sent using baud from settings, the latter always uses 115200bps baud.

4.2.3 CONFIGURATION to RUN transition

To transition from CONFIGURATION into RUN state:

- Send `AT+CONFIG=0` command.

When module leaves CONFIGURATION state, it sends `AT+CONFIG_END` message, then `AT+RUN_START` message on entering RUN state. The former is always sent using 115200bps baud, the latter uses baud from settings.

4.2.4 CONFIGURATION to BOOTLOADER transition

To transit from CONFIGURATION into BOOTLOADER state, host should do one of the following:

- Send `AT+REBOOT_BOOTLOADER` command.
- Send `AT+REBOOT` and when module enters BOOTLOADER state, prevent transition to RUN state.

When entering the bootloader state, the module sends `AT+BOOTLOADER_START`.

5 System configuration

In RUN state, operation of the module is determined based on stored settings. Settings can be changed in CONFIGURATION state using AT-commands. Settings can be written and read.

Note:

New values of settings are saved in non-volatile memory when transitioning from CONFIGURATION to RUN state.

Settings are restored from non-volatile memory during transition from BOOT to RUN state. If settings become corrupted due to memory fault, power loss during save, or any other kind of failure, the settings restoration will fail, loading default values and displaying the AT+ERROR (Settings missing, loaded default) message as a result. This behavior will occur for each device boot until new settings are written by the user.

5.1 System settings

5.1.1 Write settings

After writing a new valid value to a setting, an AT+OK response is always sent.

AT+SETTING=VALUE

For example AT+SYSTEM_STATISTICS=1

Response: AT+OK

5.1.2 Read settings

AT+SETTING?

For example: AT+SYSTEM_STATISTICS?

Response: AT+SYSTEM_STATISTICS=1

5.1.3 Settings description

AT+SETTING=?

For example: AT+SYSTEM_STATISTICS=?

Response:

```
Setting: SYSTEM_STATISTICS
Description: System statistics protocol(0:none, 1:CSV, 2:JSON)
Access: Read Write
Type: Integer decimal
Range (min.): 0
Range (max.): 2
Preserved: 1
Requires restart: 0
```

5.1.4 Errors

Errors are reported using following structure:

```
AT+ERROR (DESCRIPTION)
```

DESCRIPTION is optional and contains information about error.

5.1.5 Command endings

Every command must be ended with one of the following character sequences: "\n", "\r" or "\r\n". Commands without suitable ending will be ignored.

5.1.6 Uppercase and lowercase

All characters (except preceding AT+) used in command can be both uppercase and lowercase, so following commands are equal:

```
AT+SYSTEM_STATISTICS?
```

```
AT+sYSTEM_staTISTICS?
```

Note:

This statement is true in configuration state, not in bootloader state. In bootloader state all letters must be uppercase.

5.1.7 Settings

Table 9: Descriptions of system settings.

Setting	Min	Max	Def	Comment
BAUDRATE	0	3	0	Baudrate in RUN state 0 - 115200bps 1 - 921600bps 2 - 3000000bps 3 - 57600bps
SYSTEM_LOG	0	1	0	System logs 0 - disable 1 - enable
SYSTEM_STATISTICS	—	—	None	System statistics protocol: None CSV

5.1.8 Example

As an example, to switch the Aerobits device to CSV protocol, one should send following commands: "<<" indicates command sent to module, ">>" is a response.

```
<< AT+CONFIG=1\r\n
>> AT+OK\r\n
<< AT+ADSB_RX_PROTOCOL_DECODED=1\r\n
>> AT+OK\r\n
<< AT+CONFIG=0\r\n
>> AT+OK\r\n
```

5.2 Commands

Apart from settings, module supports a set of additional commands. Format of these commands is similar to those used for settings, but they do not affect operation of module in RUN state.

5.2.1 Commands in BOOTLOADER and CONFIGURATION state

AT+LOCK

AT+LOCK=1 - Set lock to enforce staying in BOOTLOADER or CONFIGURATION state

AT+LOCK=0 - Remove lock

AT+LOCK? - Check if lock is set

AT+BOOT

AT+BOOT? - Check if module is in BOOTLOADER state

Response:

AT+BOOT=0 - module in CONFIGURATION state

AT+BOOT=1 - module in BOOTLOADER state

5.2.2 Commands in CONFIGURATION state

AT+CONFIG

AT+CONFIG=0 - Transition to RUN state.

AT+CONFIG? - Check if module is in CONFIGURATION state.

Response:

AT+CONFIG=0 - module in RUN state

AT+CONFIG=1 - module in CONFIGURATION state (baudrate 115200)

AT+CONFIG=2 - module in CONFIGURATION state (baudrate as set)

AT+SETTINGS?

AT+SETTINGS? - List all settings. Example output:

```
AT+BAUDRATE=0
AT+BOOT=0
AT+CONFIG=1
AT+DEVICE=TR-1F
AT+FIRMWARE_VERSION=2.72.1.0 (Jun 17 2024)
AT+LOCK=0
AT+SERIAL_NUMBER=22-0000309
AT+SYSTEM_LOG=0
AT+SYSTEM_STATISTICS=0
```

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```

AT+ADSB_RX_PROTOCOL_DECODED=1
AT+ADSB_RX_PROTOCOL_INC=0
AT+ADSB_RX_PROTOCOL_RAW=0
AT+ADSB_STATISTICS=1
AT+ADSB_TX_EMITTER_CAT=0
AT+ADSB_TX_ENABLED=1
AT+ADSB_TX_ICAO=000000
AT+ADSB_TX_IDENT=
AT+ADSB_TX_ON_BOOT=1
AT+ADSB_TX_PWR=2
AT+ADSB_TX_SQUAWK=0000
AT+ADSB_TX_SURFACE=0
AT+ADSB_TX TRANSPONDER_PRESENT=0
AT+FLARM_INFO=LIBFLARM-2.03, expires: 2025-03-01, status: OK
AT+FLARM_RX_PROTOCOL_DECODED=1
AT+FLARM_STATISTICS=0
AT+FLARM_TX=1
AT+FLARM_TX_AIRCRAFT_TYPE=13
AT+GNSS_RX_PROTOCOL_RAW=0
AT+SENSOR_PROTOCOL_DECODED=0
AT+ASTERIX_SAC=1
AT+ASTERIX_SIC=129

```

AT+HELP

AT+HELP - Show all settings and commands with descriptions. Example output:

```

SETTINGS:
SYSTEM:
  AT+BAUDRATE=0 [Baudrate of serial interface (0:115200, 1:921600, 2:3000000,
  ↪3:57600)]
  AT+BOOT=0 [Is firmware in bootloader mode]
  AT+CONFIG=1 [CONFIG mode (0:disable, 1:baudrate 115200, 2:baudrate as set)]
  AT+DEVICE=IDME-PRO [Device type's name]
  AT+LOCK=0 [Device in CONFIG mode (0:no lock, 1:lock)]
  AT+SERIAL_NUMBER=18099300000323 [Device's serial number]
  AT+SYSTEM_LOG=0 [System logs (0:disable, 1:enable)]
  AT+SYSTEM_STATISTICS=0 [System statistics protocol(0:none, 1:CSV, 2:JSON)]
  AT+FIRMWARE_VERSION=1.22.5.0 (Aug 7 2024) [Device's firmware version]
GNSS:
  AT+GNSS_RX_PROTOCOL_RAW=0 [GNSS_RX RAW protocol (0:none, 5:NMEA)]
SENSORS:
  AT+SENSORS_PROTOCOL_DECODED=0 [SENSORS decoded protocol (0:none, 1:CSV, 3:JSON)]
COMMANDS:
  AT+3RD_PARTY_LICENSES [Displays licenses of third party software]
  AT+BLUETOOTH_MAC [Bluetooth device mac address]
  AT+DRONE_ID_OPERATOR_ID [Operator message payload]
  AT+HELP [Show this help]
  AT+INFO [Display device information]
  AT+REBOOT [Reboot system]
  AT+REBOOT_BOOTLOADER [Reboot to bootloader]
  AT+SETTINGS_DEFAULT [Loads default settings]
  AT+TEST [Responds "AT+OK"]
  AT+WIFI_MAC [WiFi device mac address]

```

AT+SETTINGS_DEFAULT

AT+SETTINGS_DEFAULT - Set all settings to their default value.

AT+SERIAL_NUMBER

AT+SERIAL_NUMBER? - Read serial number of module.

Response:

AT+SERIAL_NUMBER=07-0001337

AT+FIRMWARE_VERSION

AT+FIRMWARE_VERSION? - Read firmware version of module.

Response:

AT+FIRMWARE_VERSION=2.73.1.0 (Jun 27 2024)

AT+REBOOT

AT+REBOOT - Restart module.

AT+REBOOT_BOOTLOADER

AT+REBOOT_BOOTLOADER - Restart module to BOOTLOADER state.

Note:

NOTE: This command also sets lock.

5.2.3 Commands in RUN state

AT+CONFIG=1 - transition to CONFIGURATION state (baudrate 115200). AT+CONFIG=2 - transition to CONFIGURATION state (baudrate as set).

Note:

NOTE: This command also sets lock.

6 Protocols

Each system has protocols unique to it, but protocols common to all systems such as the CSV protocol are also used. All the protocols used in our products will be presented below.

6.1 Decoded protocols

- CSV - comma separated values as plain text
- Mavlink - binary protocol used by Pixhawk and other flights controllers
- JSON - text based format represents data as structured text
- GDL90 - binary protocol for ingestion into Electronic Flight Bag applications
- ASTERIX - binary protocol used for exchanging surveillance-related information in air traffic management

6.2 RAW protocols

- HEX - hexadecimal protocol is unprocessed data sended by aircraft
- BEAST - binary protocol used by program like dump1090
- JSON - it is JSON standard format with raw HEX frames inside structures
- HEXd - it is HEX protocol without extra fields, special prepared for dump1090

6.3 Statistics protocol

- CSV - comma separated values as plain text

6.4 CSV protocol (AERO)

CSV protocol is simple text protocol, that allows fast integration and analysis of tracked aircrafts. CSV messages start with '#' character and ends with "\r\n" characters. There are following types of messages:

1. ADS-B Aircraft message,
2. FLARM Aircraft message,
3. UAT Aircraft message,
4. RID Aircraft message,
5. Systems statistics messages,
6. Sensors messages.

Note:

In future versions, additional comma-separated fields may be introduced to any CSV protocol message, just before CRC field, which is guaranteed to be at the end of message. All prior fields are guaranteed to remain in same order.

6.4.1 CRC

Each CSV message includes CRC value for consistency check. CRC value is calculated using standard CRC16 algorithm and its value is based on every character in frame starting from '#' to last comma ',' (excluding last comma). After calculation, value is appended to frame using hexadecimal coding. Example function for calculating CRC is shown below.

```
uint16_t crc16(const uint8_t* data_p, uint32_t length) {
    uint8_t x;
    uint16_t crc = 0xFFFF;
    while (length--){
        x = crc>>8 ^ *data_p++;
        x ^= x>>4;
        crc = (crc<<8) ^ ((uint16_t) (x<<12)) ^ ((uint16_t) (x<<5)) ^ ((uint16_t) x);
    }
    return swap16(crc);
}
```

6.5 MAVLink protocol

MAVLink (Micro Air Vehicle Link) is a lightweight, efficient communication protocol designed primarily for unmanned aerial vehicles (UAVs), but it is also used in other robotic systems, including ground and marine vehicles. MAVLink facilitates communication between a ground control station (GCS) and an onboard autopilot, as well as between onboard components such as sensors, cameras, and controllers.[\(here\)](#).

6.5.1 Common Use Cases

- Flight Control: Communicating flight commands and receiving telemetry from UAVs.
- Sensor Integration: Transmitting data from onboard sensors to the ground station or other components.
- Mission Planning: Sending waypoints and mission plans to the UAV from the ground station.
- Remote Monitoring: Monitoring the health and status of the UAV during flight.

Overall, MAVLink is a versatile and robust protocol that has become the standard for UAV communication, particularly in the open-source community.

6.6 JSON protocols

JSON (JavaScript Object Notation) is a lightweight, text-based data interchange format that is easy for humans to read and write and easy for machines to parse and generate. JSON is widely used for transmitting data between a server and a web application, as well as for configuration files, data storage, and APIs.

Each message is encoded as separate JSON object, without any excess whitespace, consisting of fields described in table below:

```
{
  "src": "ID-0000001",
  "ts": 69061337,
  "ver": 1,
  "gnss": {
  }
}
```

Table 10: Description of main JSON fields.

JSON Field	Unit	Example	Description
src	—	ID-0000001	OEM TT serial number.
ts	milliseconds	69061337	Timestamp in milliseconds, relative to last UTC mid-night. Value 69061337 encodes 19:11:01.337. Omitted if unknown.
ver	—	1	JSON protocol version. See details below.
gnss	—	{...}	One or more of the data fields, described in subchapters below.

Note:

The order of JSON object fields in any part of message may vary between firmware revisions and messages.

Some JSON objects have fields, of which values may sometimes be unknown. In this case, they are skipped in JSON output. In following chapters, each of those fields are explicitly marked as omissible.

Note:

In case of JSON objects consisting of only omissible fields, if none of them are set, the whole object may be omitted.

The *ver* field indicates JSON protocol version. Future ICD versions may introduce additional fields without changing the version number. If a breaking change occurs in Ground Station with Linux JSON specification, the version number is guaranteed to be incremented.

Note:

The version number of JSON protocol described in this document is 1.

6.6.1 Status section

The “status” section contains status information related to OEM TT-Multi-RF itself. The example JSON message with this section fields described:

```
{
  "src": "ID-0000001",
  "ts": 69061337,
  "ver": 1,
  "status": {
    "fw": "30903679 (Jan 15 2021) ",
  }
}
```

Table 11: Description of status JSON fields.

JSON Field	Unit	Example	Description
src	—	ID-0000001	See table Description of main JSON fields. (page 22).
ts	milliseconds	69061337	See table Description of main JSON fields. (page 22).
ver	—	1	See table Description of main JSON fields. (page 22).
status	—	type of message	
fw	—	30903679(Jan 15 2021)	Firmware version, with same syntax as AT+FIRMWARE_VERSION command. Value 30903679 is version 3.9.3.679.

6.7 Statistics protocol

Statistic protocols contains system information. These information can be used to diagnose system health.

6.7.1 CSV statistic protocol

Format of that frame is shown below:

#S:CPL,UPT,CRC\r\n

CPL - CPU load in %

UPT - Time since statistic was enabled

CRC - Value is calculated using standard CRC16 algorithm

7 ADS-B receiver or transceiver subsystem

7.1 Settings

Important:

This part of documentation is relevant only for devices which have **ADS-B IN** functionality

Table 12: Descriptions of ADS-B settings.

Setting	Min	Max	Def	Comment
ADSB_RX_PROTOCOL_DECODED	—	—	CSV	ADS-B decoded protocol: None CSV Mavlink JSON GDL90 ASTERIX
ADSB_RX_PROTOCOL_INC	0	2	0	Reporting mode of decoded ADS-B targets: 0 - once per second, always 1 - once per second, if data updated 2 - immediately, only after position update
ADSB_RX_PROTOCOL_RAW	—	—	None	ADS-B raw protocol: None HEX BEAST JSON HEXd – dump1090
ADSB_STATISTICS	—	—	CSV	ADS-B statistics protocol: None CSV JSON

7.1.1 ADS-B SURFACE MODE

Typically, in bigger aircraft, there are 2 methods.

Preferred one is to use a load sensor on the wheels. When load is detected, the transceiver will switch to surface.

Second one is velocity. When aircraft travel over 70 knots, transceiver switches to airborne.

None of the methods above apply to drones, so we have to rely on injecting this information from outside. To switch, some parent system has to send a command to our transceiver to switch.

7.1.2 ADS-B reports

ADS-B reports update received data per aircraft, not per all received airplanes.

For example:

If we have $ADSB_RX_PROTOCOL_INC = 1$, then all received ADS-B airplanes will be updated once per second, one by one, rather than all at the same time.

Another example:

If we have $ADSB_RX_PROTOCOL_INC = 2$, then all received ADS-B airplanes will be updated ASAP, but only if the position data has been changed.

7.1.3 ASTERIX settings

Note:

Works only if $ADSB_RX_PROTOCOL_DECODED=ASTERIX$ is selected

Table 13: Descriptions of Asterix settings.

Setting	Min	Max	Def	Comment
ASTERIX_SAC	0	255	1	Setting SAC for ASTERIX protocol (Visible when $ADSB_DECODED_PROTOCOL=5$)
ASTERIX_SIC	0	255	129	Setting SIC for ASTERIX protocol (Visible when $ADSB_DECODED_PROTOCOL=5$)

7.2 Protocols

7.2.1 ADS-B decoded protocols

ADS-B CSV protocol

This message describes state vector of aircraft determined from ADS-B messages and is sent once per second. The message format is as follows:

#A: ICAO, FLAGS, CALL, SQ, LAT, LON, ALT_BARO, TRACK, VELH, VELV, SIGS, SIGQ, FPS, NICNAC, ALT_GEO, ECAT, CRC\r\n

Table 14: Descriptions of ADS-B fields.

#A	Aircraft message start indicator	Example value
ICAO	ICAO number of aircraft (3 bytes)	3C65AC
FLAGS	Flags bitfield, see table below <i>Descriptions of ADS-B FLAGS field.</i> (page 26)	1
CALL	Callsign of aircraft	N61ZP
SQ	SQUAWK of aircraft	7232
LAT	Latitude, in degrees	57.57634
LON	Longitude, in degrees	17.59554

continues on next page

Table 14 – continued from previous page

#A	Aircraft message start indicator	Example value
ALT_BARO	Barometric altitude, in feet	5000
TRACK	Track of aircraft, in degrees [0,360)	35
VELH	Horizontal velocity of aircraft, in knots	464
VELV	Vertical velocity of aircraft, in ft/min	-1344
SIGS	Signal strength, in dBm	-92
SIGQ	Signal quality, in dB	2
FPS	Number of raw MODE-S frames received from aircraft during last second	5
NICNAC	NIC/NAC bitfield, see table 11 (v2.6.0+)	31B
ALT_GEO	Geometric altitude, in feet (v2.6.0+)	5000
ECAT	Emitter category, <i>ADS-B emitter category values in CSV protocol.</i> (page 26) (v2.7.0+)	14
CRC	CRC16 (described in CRC section)	2D3E

Table 15: Descriptions of ADS-B FLAGS field.

Value	Flag name	Description
0x0001	PLANE_ON_THE_GROUND	The aircraft is on the ground
0x0002	PLANE_IS_MILITARY	The aircraft is military object
0x0100	PLANE_UPDATE_ALTITUDE_BARO	During last second, barometric altitude of this aircraft was updated
0x0200	PLANE_UPDATE_POSITION	During last second, position (LAT & LON) of this aircraft was updated
0x0400	PLANE_UPDATE_TRACK	During last second, track of this aircraft was updated
0x0800	PLANE_UPDATE_VELO_H	During last second, horizontal velocity of this aircraft was updated
0x1000	PLANE_UPDATE_VELO_V	During last second, vertical velocity of this aircraft was updated
0x2000	PLANE_UPDATE_ALTITUDE_GEO	During last second, geometric altitude of this aircraft was updated

The NIC/NAC bitfield is transmitted in big endian hexadecimal format without leading zeros. Table 11 describes its bitfield layout. The meaning of NIC/NAC indicators is exactly the same as described in ED-102A.

Table 16: Structure of NIC/NAC bitfield in CSV protocol.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved				NAC _p				NAC _v			NIC _{baro}	NIC			

The emitter category values returned in ecat field is shown in table below:

Table 17: ADS-B emitter category values in CSV protocol.

“ecat” value	Description
0	Unknown.
1	Light (below 15500 lbs.).
2	Small (15500 - 75000 lbs.).
3	Large (75000 - 300000 lbs.).
4	High-Vortex Large (aircraft such as B-757).
5	Heavy (above 300000 lbs.).
6	High performance (above 5g acceleration and above 400 knots).
7	Rotorcraft.
8	Reserved.
9	Glider, Sailplane.

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Table 17 – continued from previous page

“ecat” value	Description
10	Lighter-Than-Air.
11	Parachutist, Skydiver.
12	Ultralight, hang-glider, paraglider.
13	Reserved.
14	Unmanned Aerial Vehicle.
15	Space, Trans-atmospheric Vehicle.
16	Reserved.
17	Surface Vehicle - Emergency Vehicle.
18	Surface Vehicle - Service Vehicle.
19	Point Obstacle (includes Tethered Balloons).
20	Cluster obstacle.
21	Line obstacle.

If data of any field of frame is not available, then it is transmitted as empty. For example:

```
#A:4D240E,3F00,,7273,53.47939,14.55892,28550,23,510,1408,-71,5,9,938,28850,,A9FE\r\n
```

```
#A:4D240E,3F00,,7273,53.52026,14.58906,29075,23,506,1600,,,,,,,,C1EC\r\n
```

Note:

SIGS and **SIGQ** fields are updated based on raw MODE-S frames. They are calculated from frames received in last second. If there were no receiver frames (FPS=0), those fields will not be updated.

Note:

LAT and **LON** are transmitted differently for aircraft on the surface and in airborne. ADSB messages send from airborne aircrafts are unambiguous. Surface messages needs reference position which is used to determine final position of the aircraft. Aerobits devices if it is possible use their own position as reference. For devices without GNSS functionality reference position is set using last received airborne aircraft.

ADS-B MAVLink protocol

The device can be switched to use MAVLink protocol. This can be achieved by altering ADSB_RX_PROTO-COL_DECODED setting. When MAVLink protocol is used, module is sending list of aircraft's every second. MAVLink messages have standardized format, which is well described on official protocol webpage ([here](#)).

ADS-B Aircraft message

Aircrafts are encoded using ADSB_VEHICLE message ([ADSB_VEHICLE](#)). MAVLink message contains several data fields which are described below.

Table 18: MAVLink ADSB_VEHICLE message description.

Field Name	Type	Description
ICAO_address	uint32_t	ICAO address
lat	int32_t	Latitude, expressed as degrees * 1E7
lon	int32_t	Longitude, expressed as degrees * 1E7
altitude	int32_t	Barometric/Geometric Altitude (ASL), in millimeters
heading	uint16_t	Course over ground in centidegrees
hor_velocity	uint16_t	The horizontal velocity in centimeters/second
ver_velocity	uint16_t	The vertical velocity in centimeters/second, positive is up
flags	uint16_t	Flags to indicate various statuses including valid data fields
squawk	uint16_t	Squawk code
altitude_type	uint8_t	Type from ADSB_ALTITUDE_TYPE enum
callsign	char[9]	The callsign, 8 chars + NULL
emitter_type	uint8_t	Type from ADSB_EMITTER_TYPE enum
tslc	uint8_t	Time since last communication in seconds

ADS-B ASTERIX protocol

The device can be switched to use ASTERIX binary protocol. This can be achieved by altering ADSB_RX_PROTOCOL_DECODED setting. When ASTERIX protocol is used, module is sending list of aircrafts every second. Aircrafts are encoded using I021 ver. 2.1 message. Also, once per second the device sends a heartbeat message using I023 ver. 1.2 format in Ground Station Status variant. When running Transceiver TR-1F with ASTERIX, ASTERIX_SIC and ASTERIX_SAC settings are available.

For further reference of parsing ASTERIX frames, please see relevant official documentation:

- I021 messages: [CAT021 - EUROCONTROL Specification for Surveillance Data Exchange Part 12: Category 21](#)
- I023 messages: [CAT023 - EUROCONTROL Specification for Surveillance Data Exchange Part 16: Category 23](#)

ADS-B GDL90 protocol

The device can be configured to use GDL90 binary protocol. This can be achieved by altering ADSB_RX_PROTOCOL_DECODED setting. When GDL90 protocol is used, module is sending list of aircrafts every second. Aircrafts are encoded using Traffic Report (#20) message. Also, once per second device sends Heartbeat (#0), Ownship Report (#10) and Ownship Geometric Altitude (#11) messages.

For further reference of parsing GDL90 frames see relevant documentation: [GDL90 Data Interface Specification](#)

The ADS-B vehicle may transmit barometric, as well as geometric altitude. The ADSB_RX_PROTOCOL setting allows for toggling Traffic Report altitude transmit priority:

- When set to 0, altitude field will be filled with geometric altitude first. If not available, barometric altitude will be used.
- When set to 1, barometric altitude will be preferred.

Note:

Currently, only ADS-B aircrafts are reported via this protocol. To obtain information about aircrafts reported from FLARM hardware, please use any other supported protocol.

ADS-B Decoded JSON protocol

The “adsb” section contains aircraft information determined by OEM TT-Multi-RF internal ADS-B processing engine. The messages are encoded as JSON array with at least one entry. Each entry is an object consisting of fields denoted in table [adsb](#) (page 30).. Reports for each ADS-B aircraft are updated once every second.

```
{
  "src": "33-0000683",
  "ts": 69061337,
  "ver": 1,
  "adsb": [
    {
      "icao": "780A3F",
      "flags": {
        "groundState": false,
        "updAltBaro": true,
        "updAltGeo": true,
        "updPosition": true,
        "updTrack": true,
        "updVeloH": true,
        "updVeloV": true
      },
      "sigStr": -67,
      "sigQ": 9,
      "lat": 34.39696,
      "lon": -85.1055,
      "altBaro": 35000,
      "geoAlt": 36975,
      "track": 143.78,
      "velH": 528,
      "velV": 0,
      "mag_heading": 123.1,
      "true_heading": 125.5,
      "ias": 100,
      "tas": 100,
      "roll": 2.1,
      "nav_qnh": 1013.59,
      "nav_altitude_mcp": 35008,
      "nav_altitude_fms": 35008,
      "nav_modes": {
        "althold": false,
        "approach": false,
        "autopilot": false,
        "lnav": false,
        "tcas": true,
        "vnav": false
      },
      "nav_heading": 151.17,
      "call": "CPA3174",
      "ecat": 5,
      "squawk": "5730",
      "nacp": 9,
      "nacv": 1,
      "nicBaro": 1,
      "nic": 8,
      "gva": 2,
    }
  ]
}
```

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(continued from previous page)

```

    "ts1s": 1157704704,
  }
]
}

```

Table 19: Descriptions of JSON ADS-B section fields.

JSON Field	Unit	Example	Description
src	—	ID-0000001	See table <i>Description of main JSON fields.</i> (page 22).
ts	milliseconds	69061337	See table <i>Description of main JSON fields.</i> (page 22).
ver	—	1	See table <i>Description of main JSON fields.</i> (page 22).
adsb	—	type of message	
icao	—	DABABE	ICAO address, 24-bit value encoded in uppercase hexadecimal, with leading zeros.
flags	—	type of message	
ground-State	bool	True	
updPosition	bool	True	
updTrack	bool	True	
updVeloH	bool	True	
updVeloV	bool	True	
updAlt-Geo	bool	True	
sigStr	dBm	-95	Signal strength, in dBm.
sigQ	dB	2	Signal quality, in dB.
lat	—	53.42854	Latitude. Omitted if position is unknown.
lon	—	14.55281	Longitude. Omitted if position is unknown.
altBaro	ft	1725	Barometric altitude, in feet. Omitted if unknown.
geoAlt	ft	1712	Geometric altitude, in feet. Omitted if unknown.
track	degree °	72.18	Track angle, 0°..360°. Omitted if unknown.
velH	knots	10.5	Horizontal velocity, in knots. Omitted if unknown.
velV	ft/min	50	Vertical velocity, in ft/min, positive value is upwards. Omitted if unknown.
mag_heading	degree °	123.1	Magnetic Heading.
true_heading	degree °	125.5	True Heading.
ias	knots	100	Indicated airspeed.
tas	knots	100	True airspeed.
roll	degree °	2.1	Aircraft roll angle.
nav_qnh	hPa	1013.59	Aviation “Q” Code for “Nautical Height”
nav_altitude_mcp	ft	35008	Refence altitude manually entered into the MCP/FCU
nav_altitude_fms	ft	35008	Altitude selected by the Flight Management System
nav_modes	—	type of message	
althold	bool	False	
approach	bool	False	
autopilot	bool	False	
lnav	bool	False	

continues on next page

Table 19 – continued from previous page

JSON Field	Unit	Example	Description
tcas	bool	False	
vnav	bool	False	
nav_heading	degree °	43.1	Heading selected by the Flight Management System
call	—	TEST8	Callsign, up to 8 chars. Omitted if unknown.
ecat	—	13	Emitter category code, see table ecat (page 31).. Omitted if unknown.
squawk	—	7232	Squawk, 4 octal digits. Omitted if unknown.
nacp	—	3	NAC_P value, as described in ED-102A. Omitted if value is 0 (unknown).
nacv	—	1	NAC_V value, as described in ED-102A. Omitted if value is 0 (unknown).
nicBaro	—	1	NIC_{BARO} value, as described in ED-102A. Omitted if value is 0 (unknown).
nic	—	2	NIC value, as described in ED-102A. Omitted if value is 0 (unknown).
gva	—	2	GVA value, as described in ED-102A. Omitted if value is 0 (unknown).
ts1s	—	1157704704	MLAT TS value: number of nanoseconds elapsed from the last PPS pulse
ts24h	—	1157704704	MLAT TS value: number of nanoseconds elapsed from midnight

The emitter category values returned in *ecat* field is shown in table below:

Table 20: ADS-B emitter category values in JSON protocol.

“ecat” value	Description
0	Unknown.
1	Light (below 15500 lbs.).
2	Small (15500 - 75000 lbs.).
3	Large (75000 - 300000 lbs.).
4	High-Vortex Large (aircraft such as B-757).
5	Heavy (above 300000 lbs.).
6	High performance (above 5g acceleration and above 400 knots).
7	Rotorcraft.
8	Reserved.
9	Glider, Sailplane.
10	Lighter-Than-Air.
11	Parachutist, Skydiver.
12	Ultralight, hang-glider, paraglider.
13	Reserved.
14	Unmanned Aerial Vehicle.
15	Space, Trans-atmospheric Vehicle.
16	Reserved.
17	Surface Vehicle - Emergency Vehicle.
18	Surface Vehicle - Service Vehicle.
19	Point Obstacle (includes Tethered Balloons).
20	Cluster obstacle.
21	Line obstacle.

7.2.2 ADS-B raw protocols

ADS-B HEX protocol

This protocol is dedicated for raw Mode-A/C/S frames acquisition. In this special mode of operation, output frames are not processed, nor validated in any way. All processing, checksum validation, etc. must be done on user's side. All raw frames, regardless of type, start with '*' and end with ';', ASCII characters, whereas their content is encoded in hexadecimal format, MSB first. At the end, extended fields are appended to frame.

```
*RAW_FRAME; (SIGS, SIGQ, TS1s, TS24h) \r\n
```

Table 21: Descriptions of RAW extended messages.

Var.	Description	Example
SIGS	Signal strength in dBm	-95
SIGQ	Signal quality in dB	2
TS1s	Timestamp for multilateration. Time from last PPS pulse, hex format, in nanoseconds.	75BCD15 (0.123456789s)
TS24h	Timestamp for multilateration. Time from midnight, hex format, in nanoseconds.	2B5792B49315 (47655.123456789s = 13:14:15.123456789)

Note:

To use multilateration, TS value must be calibrated using calibration value from statistics message.

Note:

TS field is available when precise PPS signal from GNSS source is applied to module to 1PPS pin.

Mode-S raw frames

Short and long frames consist accordingly of 7 or 14 data bytes. Examples of raw MODE-S frames:

- Short frame: *5D4B18FFFC710B; (-70, 3, 75BCD15, 2B5792B49315) \r\n
- Long frame: *8D4CA7E858B9838206BA422BBD7B; (-71, 4, 75BCD15, 2B5792B49315) \r\n

Mode-AC raw frames

Note:

It is impossible to reliably distinguish between MODE-A and MODE-C frames based only on received signal on 1090MHz.

Starting with firmware 2.7.0, each frame is interpreted as squawk and formatted as 4 octal digits. They can also be read as binary frame with 4 hexadecimal digits, with bits being set as shown in table below.

Table 22: Description of bits in raw Mode-A/C frames in new protocol version.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	A4	A2	A1		B4	B2	B1		C4	C2	C1		D4	D2	D1

Examples of raw MODE-A/C frames using this format are as follows:

- `*0363;(979,151,75BCD15, 2B5792B49315)\r\n`
- `*7700;(995,167,75BCD15, 2B5792B49315)\r\n`

ADS-B HEXd protocol

Important:

This is RAW HEX protocol standardized for dump1090, without additional fields after ;.

ADS-B Beast protocol

Original specification: [documentation](#)

Format

All data is escaped: real byte `0x1a` becomes `0x1a 0x1a` in a message. Note that synchronization is still complex, since `0x1a 0x31` may be the start of a frame or mid-data, depending on what preceded it. To synchronize, you must see, in order:

- anything else but `0x1a`
- `0x1a`
- `0x31` or `0x32` or `0x33`

Escaping makes frame length for a given type variable, up to $2 + (2 * \text{data_length_sum})$

Frame structure

- `0x1a`
- 1 byte frame type (see types below)
- 6 byte MLAT timestamp (see below)

Frame types

- 0x31: Mode-AC frame
 - 1 byte RSSI
 - 2 byte Mode-AC data
- 0x32: Mode-S short frame
 - 1 byte RSSI
 - 7 byte Mode-S short data
- 0x33: Mode-S long frame
 - 1 byte RSSI
 - 14 byte Mode-S long data

MLAT timestamp

The MLAT timestamp included in each frame is the big-endian value of a 12 MHz counter at the time of packet reception. This counter isn't calibrated to external time, but receiving software can calculate its offset from other receiving stations across multiple packets, and then use the differences between station receive timing to calculate signal source position.

FlightAware's dump1090 fork sends 0x00 0x00 0x00 0x00 0x00 0x00 when it has no MLAT data.

RSSI

FlightAware's dump1090 fork sends 0xff when it has no RSSI data.

Examples

- 0x1a 0x32 0x08 0x3e 0x27 0xb6 0xcb 0x6a 0x1a 0x1a 0x00 0xa1 0x84 0x1a 0x1a 0xc3 0xb3 0x1d
 - 0x1a: Frame start
 - 0x32: Mode-S short frame
 - 0x08 0x3e 0x27 0xb6 0xcb 0x6a: MLAT counter value
 - * Decimal: 9063047285610
 - 0x1a 0x1a: Signal level
 - * Unescaped: 0x1a
 - * Decimal: 26
 - * $26 / 255 * 100\% = 10\%$
 - 0x00 0xa1 0x84 0x1a 0x1a 0xc3 0xb3 0x1d: Mode-S short data

* Unescaped: 0x00 0xa1 0x84 0x1a 0xc3 0xb3 0x1d

ADS-B raw JSON protocol

The “raw” section contains raw, unprocessed and unfiltered ADS-B frames gathered by OEM TT-Multi-RF , which can be used e.g. for multilateration and other low-level analysis. Raw messages are encoded as JSON array with at least one entry. Each array entry is a separate array containing values as described below

```
{
  "src": "ID-0000001",
  "ts": 69061337,
  "ver": 1,
  "raw": [
    [
      "18A9725A4C842D",
      -78,
      2,
      "295CAB573A77"
    ]
  ]
}
```

Table 23: Descriptions of JSON ADS-B Raw section fields.

JSON Field	Unit	Example	Description
src	—	ID-0000001	See table <i>Description of main JSON fields.</i> (page 22).
ts	milliseconds	69061337	See table <i>Description of main JSON fields.</i> (page 22).
ver	—	1	See table <i>Description of main JSON fields.</i> (page 22).
raw	—	type of message	
	hexadecimal	18A9725A4C842D	Raw frame bytes, formatted as uppercase hexadecimal. Short Mode-S frames encode 7 bytes, long frames contain 14 bytes.
	dBm	-78	Signal strength, in dBm.
	dB	2	Signal quality, in dB.
	nanoseconds	295CAB573A77	UTC-calibrated time of reception, formatted as uppercase hexadecimal, in nanoseconds. Example translates to 12:37:57.988350583

Warning:

Due to constrained throughput of device communication, transmission of some raw frames may be skipped in heavy aircraft traffic situations.

7.2.3 ADS-B statistics protocols

ADS-B CSV statistic protocol

This message contains some useful statistics about operation of module. Format of that frame is shown below:

#AS:FPSS,FPSAC,CALIB,CRC\r\n

FPSS - All received mode S frames per second

FPSAC - All received mode A/C frames per second

CALIB - Real uC frequency based on GNSS module (PPS)

CRC - Value is calculated using standard CRC16 algorithm

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