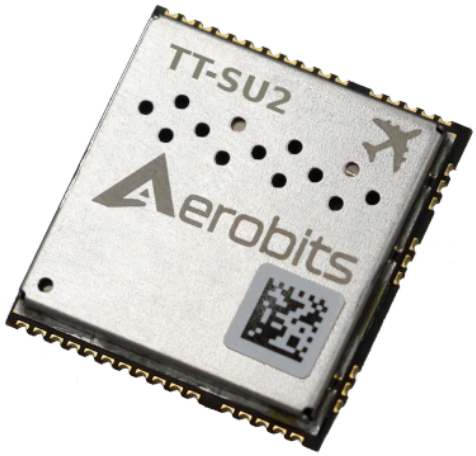
Aerobits

Subsystems for the
UAS intergration into
the airspace

OEM TT-SU2

Data sheet & User manual



Introduction

TT-SU2 is a high quality and low price OEM **ADS-B/GNSS** receiver/**UAT** receiver series operating at 1090MHz and 978MHz.

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 of module offers the possibility of receiving and decoding **ADS-B** and **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.

Applications

- SAA / DAA (Sense and Avoid / Detect and Avoid)
- UAS ground stations and high-density traffic surveillance
- UTM / U-Space construction (traffic surveillance network)
- Traffic-flow analysis and statistics
- Monitoring of 1090MHz band (signal integrity check)
- ADS-B/In/Out devices that meet the NextGen/SESAR philosophy

Main features

- Fastest ADS-B implementation on a surface of <4cm2
- 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
- Integrated high quality GNSS position source
- Receiving of UAT
- High-resolution ADC with real-time signal processing; best-in-class aircraft tracking
- High sensitive front-end, jamming and ESD protection (only version b) with ranges over 150 km (open space, 1dBi antenna)
- Simple module integration via UART interface and AT commands
- Scalable OEM solution with enormous customization potential (additional functions or interfaces on request)
- Firmware update capability (uC and FPGA)
- Designed to meet MOPS defined in TSO-C199

For more information please contact: support@aerobits.pl.

Contents

1 Technical parameters

1.1 Basic technical information

Parameter	Description	Min.	Typ.	Max.	Unit
Carrier frequency ADS-B		-	1090	-	MHz
RX sensitivity GNSS		-	approx. -167	-	dBm
RX sensitivity UAT		-	approx. -95	-	dBm
RX sensitivity ADS-B		-	approx. -85	-	dBm
UART (baud)	AT commands	115200	921600	3000000	bps

Table 1: General technical parameters.

1.2 Electrical specification

1.2.1 Absolute maximum ratings

Parameter	Min.	Max.	Unit
Storage temperature	-5	+40	°C
Supply voltage (VCC)	3.0	3.6	DCV
Other pin voltage	-0.3	VCC + 0.3	DCV
RF input GNSS	-	0	dBm
RF input UAT	-	+10	dBm
RF input ADS-B	-	+10	dBm

Table 2: Absolute maximum ratings.

1.2.2 Recommended operation conditions

Parameter	Min.	Max.	Unit
Operation temperature	-30	+85	°C
Supply voltage (VCC)	2.7	3.6	DCV

Table 3: Recommended operation conditions.

1.2.3 General electrical parameters

Parameter	Description	Min.	Typ.	Max.	Unit
Current consumption		-	130	-	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	VCC - 0.7	-	VCC + 0.3	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

Table 4: General electrical parameters.

1.2.4 Pin definition

Pin arrangement of OEM TT-SU2 is shown on the figure below (1).

Pin number	Pin Name	Pin Type	Description
1	3V3	IN	Power supply input
2	TX1	OUT	Aux UART TX
3	RX1	IN	Aux UART RX
4	TX0	OUT	Main UART TX
5	RX0	IN	Main UART RX
6	NC	N/A	No commercial use (keep floating)
7	NC	N/A	No commercial use (keep floating)
8	NC	N/A	No commercial use (keep floating)
9	NC	N/A	No commercial use (keep floating)
10	NC	N/A	No commercial use (keep floating)
11	10M	OUT	10Mhz pulse output
12	CS	OUT	SPI chip select
13	MISO	IN	SPI Master Input Slave Output
14	MOSI	OUT	SPI Master Output Slave Input
15	SCK	OUT	SPI Clock
16	GND	PWR	Ground
17	AGND	PWR	Analog ground
18	UAT	IN	UAT RF Input
19	AGND	PWR	Analog ground
20	AGND	PWR	Analog ground
21	GNSS	IN	GNSS RF Input
22	AGND	PWR	Analog ground
23	AGND	PWR	Analog ground
24	ADSB	IN	ADSB RF Input
25	AGND	PWR	Analog ground
26	FIO0	N/A	No commercial use (keep floating)
27	FIO1	N/A	No commercial use (keep floating)
28	FIO2	OUT	UAT LED
29	LED	OUT	Info LED ADS-B/Configuration mode
30	PPS	OUT	Pulse per second output from GNSS
31	GND	PWR	Ground
32	B/C	IN	Bootloader/Configuration mode trigger
33	SDA	IN/OUT	I2C data
34	SCL	OUT	I2C clock
35	C2TX	OUT	CAN logic interface TX
36	C2RX	IN	CAN logic interface RX
37	VBUS	IN	USB connection info (3.3V)
38	UDP	IN/OUT	USB Data+
39	UDM	IN/OUT	USB Data-
40	RST	IN	Module reset
41	NC	N/A	No commercial use (keep floating)

Table 5: Pin definitions of OEM TT-SU2.

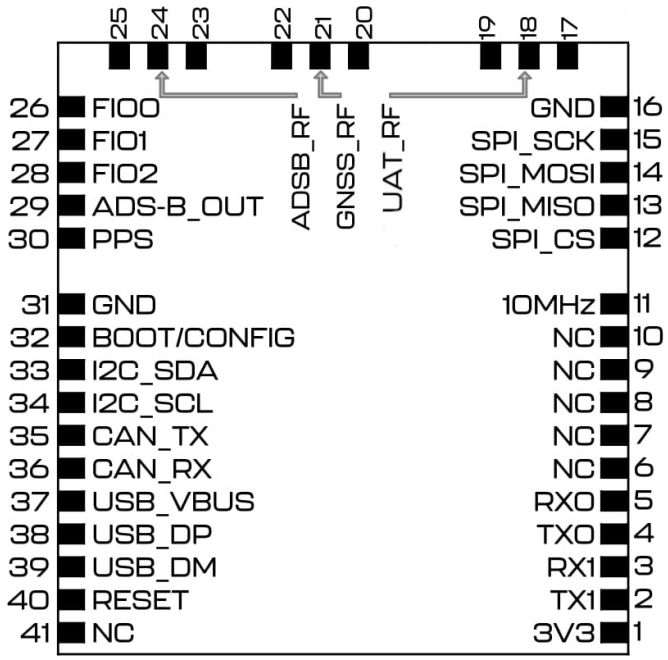


Figure 1: Pin arrangement of OEM TT-SU2.

1.3 Mechanical specification

1.3.1 Dimensions

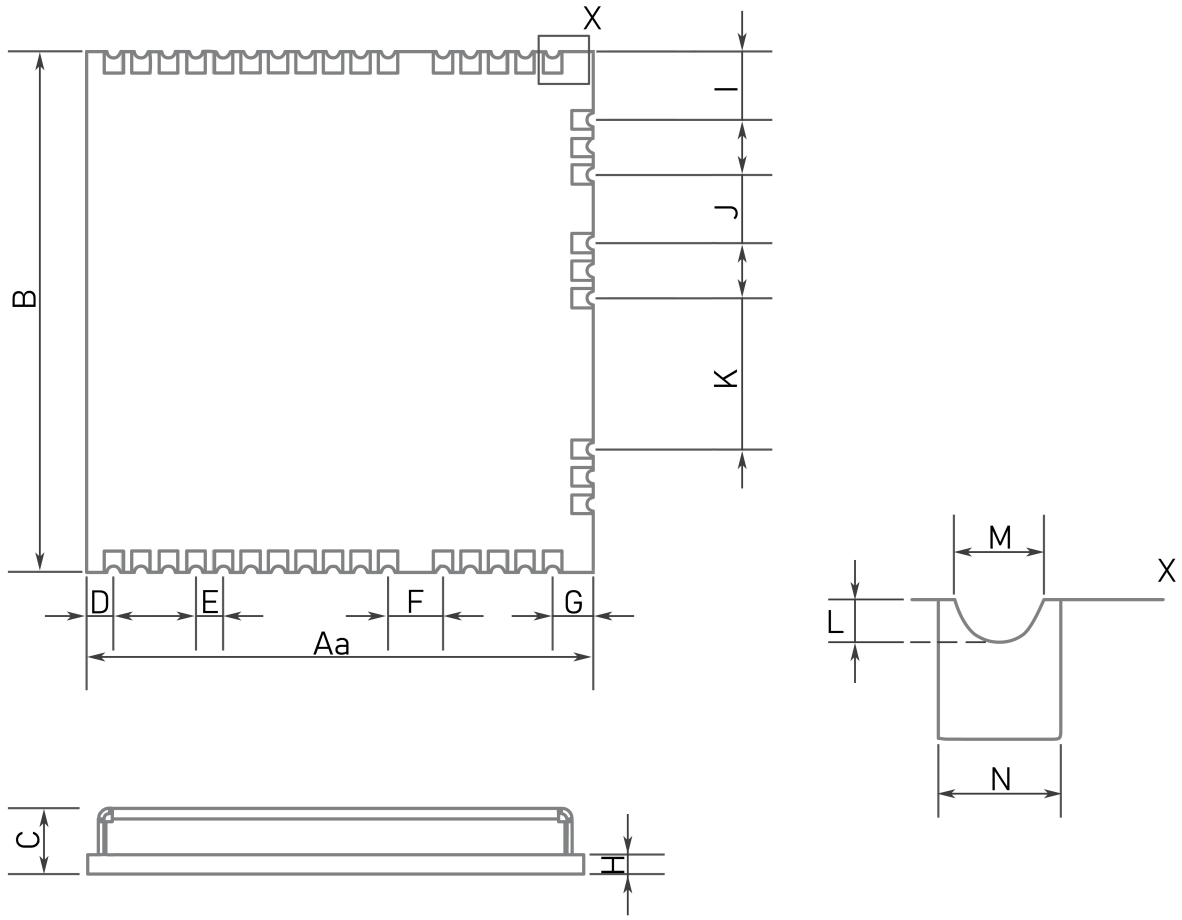


Figure 2: Mechanical drawing of OEM TT-SU2

Symbol	Min. (mm)	Typ. (mm)	Max. (mm)
A	18.4	18.5	18.6
B	18.9	19.0	19.1
C	2.3	2.4	2.5
D	0.9	1.0	1.1
E	0.9	1.0	1.1
F	1.9	2.0	2.1
G	1.4	1.5	1.6
H	0.6	0.7	0.8
I	2.45	2.55	2.65
J	2.3	2.4	2.5
K	5.4	5.5	5.6
L	0.25	0.35	0.45
M	0.4	0.5	0.6
N	0.6	0.7	0.8

Table 6: Dimensions and tolerances.

1.3.2 Recommended layout

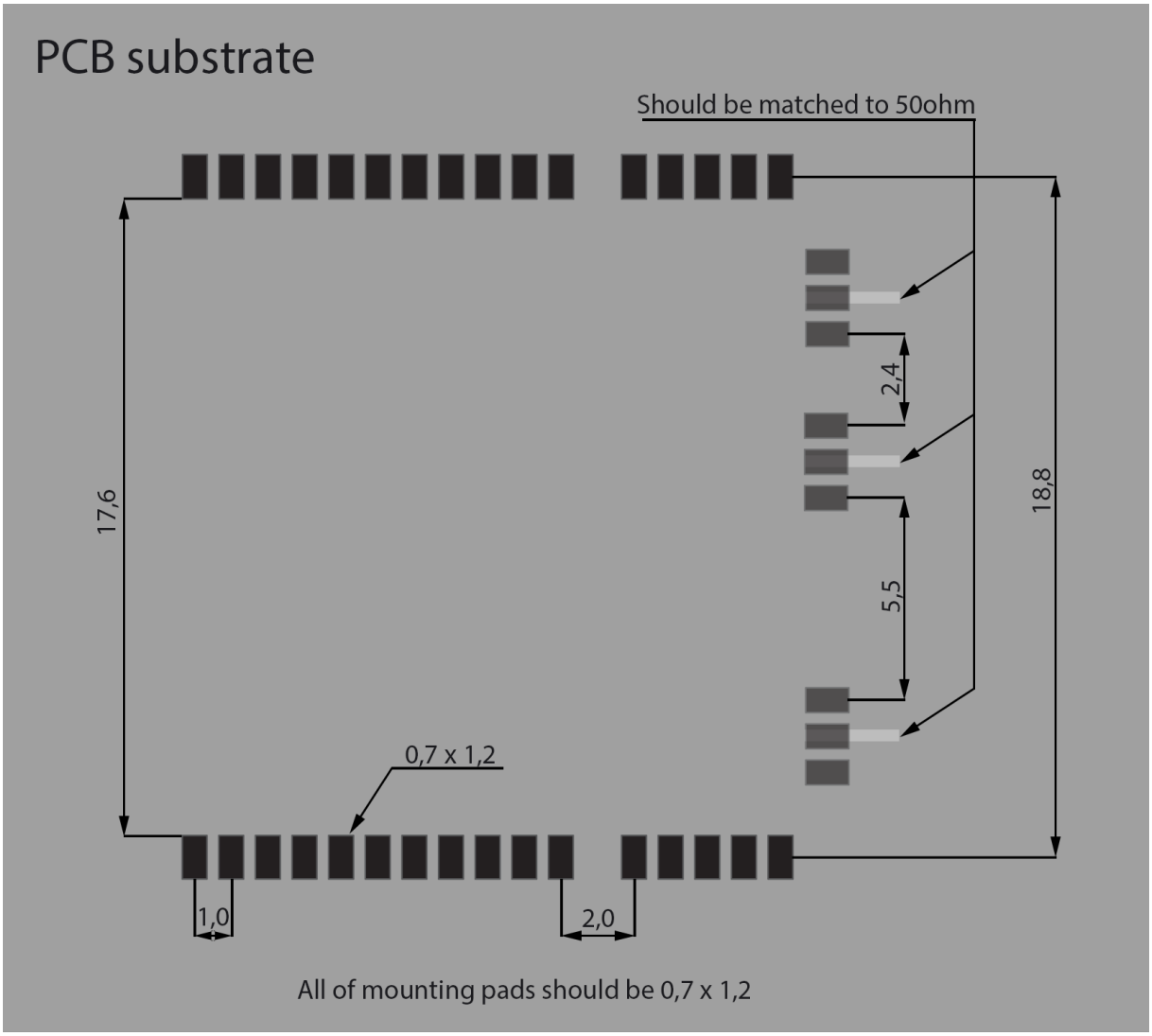


Figure 3: Footprint of OEM TT-SU2

NOTE: In case of OEM the RF inputs indicated in the footprint(3) should be matched to 50ohm.

2 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.

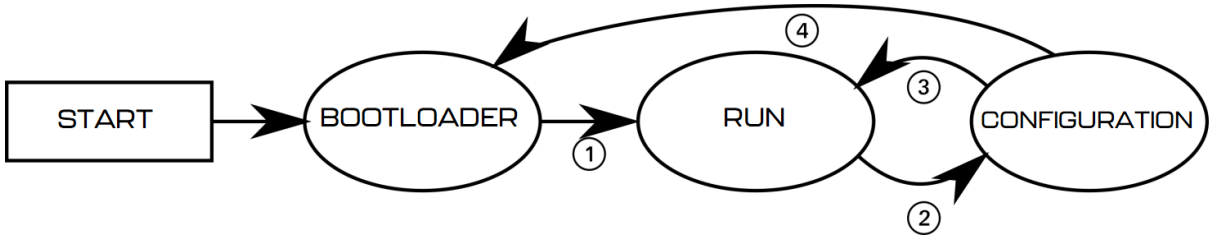


Figure 4: State machine of OEM TT-SU2

2.1 States of operation

2.1.1 BOOTLOADER state

This is an initial state of OEM TT-SU2 after restart. Firmware update is possible here. Typically module transits 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 up to 3 seconds. If no BOOTLOADER trigger is present, module will transit 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.

2.1.2 RUN state

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.

2.1.3 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.

2.2 Transitions between states

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

2.2.1 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 short period of time if no action will be taken. To prevent transition from BOOTLOADER state, one of following actions must be processed:

- Pull BOOT/CONFIG pin low during start of module
- 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 transit into RUN state. Firstly it will check firmware integrity. When firmware integrity is confirmed, module will transit into RUN state, if not, it will stay in BOOTLOADER state.

To transit into RUN state:

- Release or pull high BOOT/CONFIG pin
- If module is locked, send `AT+LOCK=0` command

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

2.2.2 RUN to CONFIGURATION transition

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

- Pull BOOT/CONFIG pin low
- Send `AT+CONFIG=1` (using current baud). This method is not recommended, because module will support multiple protocols in future and Aerobits Sp. z o.o. cannot ensure that this command will be present in all protocols.

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.

2.2.3 CONFIGURATION to RUN transition

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

- Release or pull high BOOT/CONFIG pin
- 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.

2.2.4 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` .

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 7.

UART Settings				
Parameter	Min.	Typ.	Max	Unit
Baud	115200	921600	3000000	bps
Stop Bits Number	-	1	-	-
Flow Control	-	None	-	-
Parity Bit	-	None	-	-

Table 7: UART settings.

4 Settings

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 do 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.

4.1 Write settings

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

`AT+SETTING=VALUE`
For example `AT+PROTOCOL=1`
Response: `AT+OK`

4.2 Read settings

`AT+SETTING?`
For example: `AT+PROTOCOL?`
Response: `AT+PROTOCOL=1`

4.3 Settings description

`AT+SETTING=?`
For example: `AT+PROTOCOL=?`
Response:

```
Setting: PROTOCOL
       Description: Selected protocol (0: NONE, 2: CSV, 3: MAVLINK)
       Type: Integer decimal
       Range (min.): 0
       Range (max.): 5
       Is preserved: 1
       Is restart needed: 0
```

4.4 Errors

Errors are reported using following structure:
`AT+ERROR (DESCRIPTION)`
DESCRIPTION is optional and contains information about error.

4.5 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.

4.6 Uppercase and lowercase

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

```
AT+PROTOCOL?
AT+pRoToCoL?
```

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

4.7 Available settings

Setting	Min	Max	Def	Comment
BAUDRATE	0	2	0	Baudrate in RUN state 0 - 115200bps 1 - 921600bps 2 - 3000000bps
GNSS_LOG	0	2	0	GNSS NMEA forwarding 0 - No forwarding 1 - RMC Messages only 2 - All
UAT_LOG	0	2	0	Selected UAT protocol. 0 - None 1 - RAW HEX 2 - CSV
ASTERIX_SIC	0	255	129	Setting SIC for ASTERIX protocol (Visible when PROTOCOL=4)
ASTERIX_SAC	0	255	1	Setting SAC for ASTERIX protocol (Visible when PROTOCOL=4)
PROTOCOL	0	8	2	Selected protocol. Not all values are valid for all devices. 0 - None 1 - RAW HEX 2 - CSV (AERO) 3 - MAVLink 4 - ASTERIX 5 - GDL90 7 - BEAST 8 - JSON
SUBPROTOCOL	0	0	0	Reserved for future use
AERO_JSON_BITMASK	0	3F	3B	Determine, what data will be sent over Json protocol. Value is the sum in hexadecimal of required data according to value below. 0x01 - ADSB 0x02 - FLARM 0x04 - RAW 0x08 - STATUS 0x10 - GNSS 0x20 - SENSOR e.g ADSB, FLARM, STATUS, GNSS, SENSOR 0x01 + 0x02 + 0x08 + 0x10 + 0x20 = 0x3B e.g ADSB, FLARM 0x01 + 0x02 = 0x03

Table 8: Settings

4.8 Example

As an example, to switch OEM TT-SU2 module 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+PROTOCOL=2\r\n
>> AT+OK\r\n
>> AT+OK\r\n
<< AT+CONFIG=0\r\n
```

5 Commands

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

5.1 Commands in BOOTLOADER and CONFIGURATION state

5.1.1 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

5.1.2 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 Commands in CONFIGURATION state

5.2.1 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)

5.2.2 AT+SETTINGS?

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

```
AT+PROTOCOL=2
AT+SUBPROTOCOL=0
AT+BAUDRATE=0
```

5.2.3 AT+HELP

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

```
SETTINGS:
AT+PROTOCOL=2         [Selected protocol (0: NONE, 2: CSV, 3: MAVLINK)]
AT+SUBPROTOCOL=0      [Subprotocol of selected protocol]
COMMANDS:
AT+HELP               [Show this help]
AT+TEST               [Responds "AT+OK"]
AT+SETTINGS_DEFAULT   [Load default settings]
AT+REBOOT             [Reboot system]
```

5.2.4 AT+SETTINGS_DEFAULT

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

5.2.5 AT+SERIAL_NUMBER

`AT+SERIAL_NUMBER?` - Read serial number of module.

Response:

```
AT+SERIAL_NUMBER=07-0001337
```

5.2.6 AT+FIRMWARE_VERSION

`AT+FIRMWARE_VERSION?` - Read firmware version of module.

Response:

```
AT+FIRMWARE_VERSION=10101017(May 11 2018)
```

5.2.7 AT+REBOOT

`AT+REBOOT` - Restart module.

5.2.8 AT+REBOOT_BOOTLOADER

`AT+REBOOT_BOOTLOADER` - Restart module to BOOTLOADER state.

NOTE: This command also sets lock.

5.3 Commands in RUN state

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

NOTE: This command also sets lock.

6 Protocols

6.1 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. UAT Aircraft message,
3. Statistics message.

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.

6.1.1 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);
}
```

6.1.2 ADS-B Aircraft message

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
```

#A	Aircraft message start indicator	Example value
ICAO	ICAO number of aircraft (3 bytes)	3C65AC
FLAGS	Flags bitfield, see table 10	1
CALL	Callsign of aircraft	N61ZP
SQ	SQUAWK of aircraft	7232
LAT	Latitude, in degrees	57.57634
LON	Longitude, in degrees	17.59554
ALT_BARO	Barometric altitude, in feets	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 feets (v2.6.0+)	5000
ECAT	Emitter category, see table 12 (v2.7.0+)	14
CRC	CRC16 (described in CRC section)	2D3E

Table 9: Descriptions of ADS-B message fields.

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

Table 10: ADS-B message Flags description.

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.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved				NAC_p				NAC_v			NIC_{baro}	NIC			

Table 11: Structure of NIC/NAC bitfield in CSV protocol.

Below is a list of emitter category values returned in ECAT field.

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 Ballons).
20	Cluster obstacle.
21	Line obstacle.

Table 12: ADS-B emitter category values in CSV protocol.

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: SIGS is measured based on analog RF signal. This signal has DC offset of about 700mV.

6.1.3 UAT Aircraft message CSV

This protocol can be selected for UAT. Received messages are sent using CSV. In this configuration uplink messages are not shown. The message format is as follows:

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

#U	Description	Example value
ICAO	ICAO number of aircraft (3 bytes)	3C65AC
FLAGS	Flags bitfield, see table 10 and table 14	1
CALL	Callsign of aircraft	N61ZP
SQ	SQUAWK of aircraft (available when there is no Callsign)	7232
LAT	Latitude, in degrees	57.57634
LON	Longitude, in degrees	17.59554
ALT_BARO	Barometric altitude, in feet, see table 14	5000
TRACK	Track of aircraft, in degrees	355
VELH	Horizontal velocity of aircraft, in knots	464
VELV	Vertical velocity of aircraft, in ft/min	1344
SIGS	Signal strength, in dBm, see table 14	-70
SIGQ	Signal quality, number of errors corrected, 0(best)...6(worst), see table 14	1
FPS	Number of raw frames received from aircrafts during last second	5
NICNAC	NIC/NAC bitfield, see table 11	31B
ALT_GEO	Geometric altitude, in feet, see table 14	5000
ECAT	Emitter category, see table 12	14
U_EMERG	UAT emergency status, see table 15	3
U_FLAGS	UAT special status flags, see table 16	1F
CRC	CRC16 (described in CRC section)	2D3E

Table 13: Description of UAT message fields.

Field	Difference in meaning
PLANE_ON_THE_GROUND	Gliders, UAVs and others always declare airborne.
PLANE_IS_MILITARY	Will be always 0 as UAT does not have this information.
ALT_BARO and ALT_GEO	UAT has ”main” altitude and ”second” altitude. If plane has barometric selected as main, then geometric will be automatically second. Make sure to check both ALT_BARO and ALT_GEO fields, as plane can have one set as main source and not have the other one.
SIGS	in dBm
SIGQ	in number of errors corrected

Table 14: Differences in UAT.

Value	Description
0	No emergency/Not reported
1	General emergency
2	Lifeguard/medical emergency
3	Minimum fuel
4	No communications
5	Unlawful interference
6	Downed Aircraft
7	(Reserved)

Table 15: Emergency status values.

Value	Description
0x0001	UTC coupling
0x0002	CDTI Traffic Display Capability
0x0004	TCAS/ACAS Installed and Operational
0x0008	TCAS/ACAS Resolution Advisory Active
0x0010	IDENT Switch Active (equal or less than 20 seconds since activated by pilot)
0x0020	Receiving ATC Services
0x0040	Heading according to: 0 = true north (default), 1 = magnetic north
0x0080	
0x0100	
0x0200	
0x0400	
0x0800	Reserved for air quality
0x1000	Reserved for air quality
0x2000	
0x4000	
0x8000	

Table 16: Other flags values.

6.1.4 Statistics message

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

```
#S:CPU,RES,RES,FPSS,FPSAC,TSCAL,CRC
```

#S	Statistics message start indicator	Example
CPU	CPU load in %	12.1
RES	Reserved for future use	-
RES	Reserved for future use	-
FPSS	Number of MODE-S frames received in last second	3
FPSAC	Number of MODE-A or MODE-C frames received in last second	35
TSCAL	Calibration value for TS field in raw frames	13999415
CRC	CRC16 (described in CRC section)	2D3E

Table 17: Statistics message fields.

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

6.1.5 Calibration of raw frames

To get precise time, TS field from raw frames must be calibrated using TSCAL field from statistics message. This allow obtaining precise time which have passed between most recent PPS pulse and reception of that particular frame.

$$TS_{CALIB}[ns] = \frac{TS}{TSCAL}\frac{1s}{10^9}$$

6.2 RAW 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
```

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 nano secounds.	75BCD15 (0.123456789s)
TS24h	Timestamp for multilateration. Time from midnight hex format hex format in nano secounds.	2B5792B49315 (47655.123456789s = 13:14:15.123456789)

Table 18: Extended messages description.

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.

6.2.1 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`

6.2.2 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.

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

Table 19: Description of bits in raw Mode-A/C frames in new protocol version.

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`

6.2.3 UAT raw frames

This protocol can be selected for UAT. Received UAT frames (including uplink frames) are sent using HEX format. Uplink frames have close to 600 bytes, giving approximately 1200 characters in one line, so serial buffers need to handle this. For example long frame has 48 bytes and will be sent as RAW frame like this:

```
*0D003039160B600C5F9203618A6FC02C0070AB13FCE6C4A50413F8A0000481000
        0006F8D311FB08B51C43371A6037CD6;(500,20,7F0A)\r\n
```

Var.	Description	Example
SIGS	Signal strength in dBm	-70
SIGQ	Signal quality, number of errors corrected, 0(best)...6(worst)	1
TS1s	Timestamp for multilateration. Time from last PPS pulse hex format in nano secounds.	75BCD15

Table 20: Extended UAT messages description.

6.3 MAVLink protocol

OEM TT-SU2 can be switched to use MAVLink protocol. This can be achieved by altering PROTOCOL setting. When MAVLink protocol is used, module is sending list of aircrafts every second. MAVLink messages have standarized format, which is well described on official protocol webpage (mavlink.io/en/messages).

6.3.1 ADS-B Aircraft message

Aircrafts are encoded using ADSB_VEHICLE message (mavlink.io/en/messages/common.html#ADSB_VEHICLE). MAVLink message contains several data fields which are described below.

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

Table 21: MAVLink ADSB_VEHICLE message description

6.4 ASTERIX protocol

OEM TT-SU2 can be switched to use ASTERIX binary protocol. This can be achieved by altering PROTOCOL 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 OEM TT-SU2 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

6.5 GDL90 protocol

OEM TT-SU2 can be configured to use GDL90 binary protocol. This can be achieved by altering PROTOCOL 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 SUBPROTOCOL 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 wil be preferred.

6.6 Beast protocol

Original specification: https://github.com/firestuff/adsb-tools/blob/master/protocols/beast.md.

6.6.1 Format

All data is escaped: 0x1a -> 0x1a 0x1a. 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:

- != 0x1a
- 0x1a
- 0x31, 0x32, 0x33

Escaping makes frame length for a given type variable, up to 2 + (2 * data_length_sum)

6.6.2 Frame structure

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

6.6.3 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

6.6.4 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.

6.6.5 RSSI

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

6.6.6 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
  - 0x00 0xa1 0x84 0x1a 0x1a 0xc3 0xb3 0x1d: Mode-S short data
    - Unescaped: 0x00 0xa1 0x84 0x1a 0xc3 0xb3 0x1d

6.7 JSON Protocol

Each message is encoded as separate JSON object, without any excess whitespace, consisting of fields described in table 22.

Name	Description	Value type
`{`		
`"src": "ID-0000001",`	OEM TT-SU2 serial number.	String
`"ts": 69061337,`	Timestamp in milliseconds, relative to last UTC midnight. Value `69061337` encodes 19:11:01.337. Omitted if unknown.	Unsigned integer
`"ver": 1,`	JSON protocol version. See details below.	Unsigned integer
`"gnss": {...}`	One or more of the data fields, described in subchapters below.	Object or array
`}`		

Table 22: Description of main JSON fields.

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 ommitable.

NOTE: In case of JSON objects consisting of only ommitable 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 OEM TT-SU2 JSON specification, the version number is guaranteed to be incremented.

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

6.7.1 Status section

The "status" section contains status information related to OEM TT-SU2 itself. The example JSON message with this section fields described, is shown in table 23.

JSON field	Description	Value type
{		
"src": "ID-0000001",	see table 22.	
"ts": 69061337,		
"ver": 1,		
"status": {		
"fw": "30903679(Jan 15 2021)",	Firmware version, with same syntax as AT+FIRMWARE_VERSION command. Value 30903679 is version 3.9.3.679.	String
}		
}		

Table 23: Descriptions of JSON sensor section fields.

6.7.2 GNSS section

The `"gnss"` section contains basic GNSS information. This message is sent once per second. The example JSON message with `"gnss"` section fields described, is shown in table 24.

JSON field	Description	Value type
`{`		
`"src": "ID-0000001",`	see table 22.	
`"ts": 69061337,`		
`"ver": 1,`		
`"gnss": {`		
`"fix": 1,`	Set to 1 if onboard GNSS currently has fix, otherwise 0.	Unsigned integer
`"lat": 53.42854,`	Last known latitude. Omitted if there was no GNSS fix since device boot.	Floating point
`"lon": 14.55281,`	Last known longitude. Omitted if there was no GNSS fix since device boot.	Floating point
`"altWgs84": 499.6,`	Last known WGS-84 Altitude, in meters. Omitted if there was no GNSS fix since device boot.	Floating point
`"altMsl": 508.6,`	Last known MSL Altitude, in meters. Omitted if there was no GNSS fix since device boot.	Floating point
`"track": 127.3,`	Track angle, 0°..360°, relative to true north. Omitted if unknown.	Floating point
`"hVelo": 10.5,`	Horizontal velocity, in knots. Omitted if unknown.	Floating point
`"vVelo": 25.00,`	Vertical velocity, in m/s. Positive value is upwards. Omitted if unknown.	Floating point
`"gndSpeed": [`		
`5.2, 2.1`	Ground speed in east-west and north-south axes respectively, in knots. Positive value is East and North. Derived from `track` / `hVelo` values. Omitted if unknown.	Floating point
`],`		
`"acc": {`		
`"lat": 5.2,`	Accuracy of latitude, in meters. Omitted if unknown.	Floating point
`"lon": 2.1,`	Accuracy of longitude, in meters. Omitted if unknown.	Floating point
`"alt": 3.6`	Accuracy of altitude, in meters. Omitted if unknown.	Floating point
`},`		
`"nacp": 12`	Navigational Accuracy Category for Position value, as defined in ED-282. Omitted if unknown.	Unsigned integer
`"nacv": 2`	Navigational Accuracy Category for Velocity value, as defined in ED-282. Omitted if unknown.	Unsigned integer
`"nic": 12`	Navigation Integrity Category as defined in ED-282. Omitted if unknown.	Unsigned integer
`}`		
`}`		

Table 24: Descriptions of JSON GNSS section fields.

NOTE: The `nacp`, `nacv` and `nic` values are not available in regular HOD hardware.

6.7.3 Raw ADS-B section

The "raw" section contains raw, unprocessed and unfiltered ADS-B frames gathered by OEM TT-SU2 , 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 in table 25

JSON field	Description	Value type
{		
"src": "ID-0000001",	see table 22.	
"ts": 69061337,		
"ver": 1,		
"raw": [		
[		
"18A9725A4C842D",	Raw frame bytes, formatted as uppercase hexadecimal. Short Mode-S frames encode 7 bytes, long frames contain 14 bytes.	String
696,	Signal strength, in mV.	Unsigned integer
68,	Signal quality, in mV.	Unsigned integer
"295CAB573A77"	UTC-calibrated time of reception, formatted as uppercase hexadecimal, in nanoseconds. Example translates to 12:37:57.988350583	String
]		
]		
}		

Table 25: Descriptions of JSON raw ADS-B section fields.

NOTE: Due to constrained throughput of OEM TT-SU2 communication, transmission of some raw frames may be skipped in heavy aircraft traffic situations.

6.7.4 Processed ADS-B reports

The `"adsb"` section contains aircraft information determined by OEM TT-SU2 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 26. Reports for each ADS-B aircraft are updated once every second.

JSON field	Description	Value type
`{`		
`"src": "ID-0000001",`	see table 22.	
`"ts": 69061337,`		
`"ver": 1,`		
`"adsb": [`		
`{`		
`"icao": "DABABE",`	ICAO address, 24-bit value encoded in uppercase hexadecimal, with leading zeros.	String
`"sigStr": -95,`	Signal strength.	Signed integer
`"sigQ": 2,`	Signal quality.	Unsigned integer
`"fps": 5,`	Number of raw Mode-S frames received from aircraft during last second.	Unsigned integer
`"lat": 53.42854,`	Latitude. Omitted if position is unknown.	Floating point
`"lon": 14.55281,`	Longitude. Omitted if position is unknown.	Floating point
`"baroAlt": 1725,`	Barometric altitude, in feet. Omitted if unknown.	Signed integer
`"geoAlt": 1712,`	Geometric altitude, in feet. Omitted if unknown.	Signed integer
`"track": 72.18,`	Track angle, -180°..180°. Omitted if unknown.	Floating point
`"hVelo": 10.5,`	Horizontal velocity, in knots. Omitted if unknown.	Floating point
`"vVelo": 50,`	Vertical velocity, in ft/min, positive value is upwards. Omitted if unknown.	Signed integer
`"ident": "TEST8",`	Callsign, up to 8 chars. Omitted if unknown.	String
`"squawk": "7232",`	Squawk, 8 octal digits. Omitted if unknown.	String
`"ecat": 13,`	Emitter category code, see table 27. Omitted if unknown.	Unsigned integer
`"nacp": 3,`	NAC_P value, as described in ED-102A. Omitted if value is 0 (unknown).	Unsigned integer
`"nacv": 1,`	NAC_V value, as described in ED-102A. Omitted if value is 0 (unknown).	Unsigned integer
`"nicBaro": 1,`	NIC_{BARO} value, as described in ED-102A. Omitted if value is 0.	Unsigned integer
`"nic": 2,`	NIC value, as described in ED-102A. Omitted if value is 0 (unknown).	Unsigned integer
`"surf": 1`	Set to 1 if plane is on earth surface. Omitted if plane is in air or unknown.	Unsigned integer
`}`		
`]`		
`}`		

Table 26: Descriptions of JSON ADS-B section fields.

The emitter category values returned in `"ecat"` field is shown in table 27.

"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.

Table 27: ADS-B emitter category values in JSON protocol.

Please read carefully

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