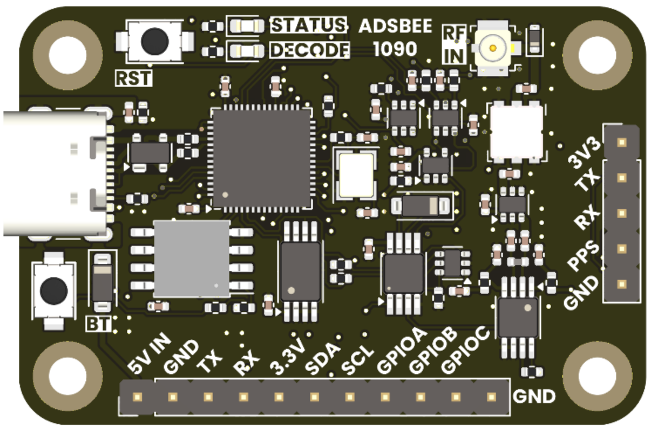
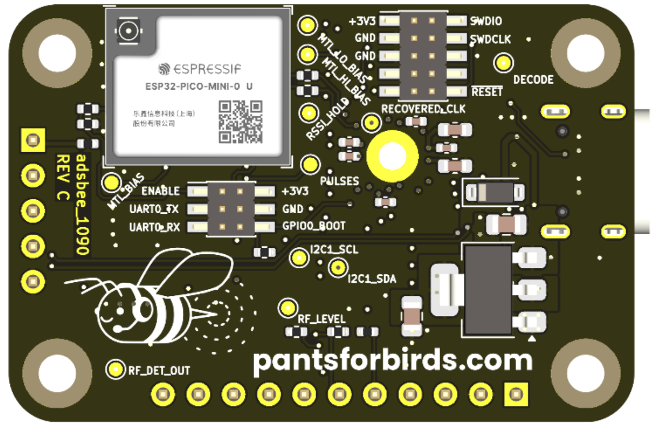
ADSBee 1090

Open Source Embedded ADS-B Receiver





Features

- 1090MHz Mode S and ADS-B packet decoding.
- Adjustable receive gain and trigger levels for customized tuning in diverse RF environments.
- Multiple output formats over UART or USB:
  - ADSBee CSV
  - MAVLink
  - GDL90 (not yet implemented)
  - More to come!
- Built-in EEPROM for storing configuration parameters in non-volatile memory.
- GNSS module input (UART + PPS) for MLAT or Remote ID applications.
- 2.4GHz 802.11 module for connecting directly to ADS-B databases via WiFi or broadcasting Remote ID beacon frames in UAS applications (not yet implemented).
- Integrated M2.5 mounting holes.
- Firmware updates over USB.

Applications

- Standalone feeder device for online ADS-B databases. No external compute required, just add power and WiFi!
- Aircraft detection for robotics and embedded projects.

Quick Specs

Supply Voltage	5V (Via USB or 5V pin)
Supply Current	75mA (WiFi disabled) ~400mA (WiFi enabled)
Minimum RF Input Power Level	-70dBm (not yet tested)
Simultaneous Aircraft Tracks Supported	≤100
Connectors	1090MHz RF In: U.FL / MHF1 802.11 RF Out: W.FL / MHF3 Power / Data: USB C GPIO / UART: 0.1” Pin Headers

Open Source Hardware + Software

Github Repository: https://github.com/coolnamesalltaken/ads-bee

All hardware schematics and source code files required to build ADSBee 1090 are available under a GNU GPL v3 license. This means that they can be freely incorporated into other open-source projects that utilize a compatible license. The hope is that by opening the design to contributions and feedback from a community of users, the functionality of the ADSBee 1090 will be enhanced over time.

Note that the GPL v3 license applies to design and source code files, and not devices. ADSBee 1090 units purchased from Pants for Birds may be used in commercial applications without any licensing restrictions.

For commercial licensing requests of ADSBee hardware or software design files, please contact john@pantsforbirds.com.

Contents

1 Background

ADSBee 1090 was created as an attempt to build a low-cost ADS-B receiver without the use of an FPGA (found in most embedded ADS-B receivers on the market) and without the need for external compute (a requirement of most SDR-based ADS-B receivers). ADSBee 1090 accomplishes this through the use of a low-cost dual core microcontroller (RP2040) with flexible IO peripherals (PIO) that run a set of custom-written programs for preamble detection and packet decoding. By dedicating the RP2040's PIO peripherals to the tasks required to find and decode ADS-B packets, ADSBee 1090 frees up its remaining cores to perform the logical functions required to validate checksums on decoded packets and decipher aircraft information (position, altitude, callsign, etc).

The ADSBee 1090 reports decoded aircraft information over UART and USB interfaces in a variety of protocols, and can utilize its attached ESP32 S3 module to host WiFi networks for data streaming to other devices, or connect to existing WiFi networks in order to upload data to the internet or other devices on the network.

Provisions are included for connecting an external GNSS module and UAT radio receiver to the ADSBee 1090. These features will enter development in the near future.

2 Communication Interfaces

2.1 Console Interface

The CONSOLE interface (USB-C connector) on the ADSBee 1090 can be used to supply the device with power, configure the device's internal parameters via AT commands, and receive data from the device.

No baud rate configuration is necessary for the CONSOLE interface. Note that AT commands must be suffixed with CR+LF ("\r\n") in order to be processed by the AT command parser.

2.2 COMMS_UART Interface

The COMMS_UART interface is used for data output, and can support a number of different protocols. Data can be streamed out of the CONSOLE and COMMS_UART interfaces simultaneously. The baud rate of the COMMS_UART interface can be adjusted via AT commands.

COMMS_UART Parameters

Parameter	Value
Baud Rate	115200 baud (default)
Data Bits	8
Stop Bits	0 (N)
Parity Bits	1
Logic Level	3.3V

2.3 GNSS_UART Interface

The ADSBee 1090's GNSS module connector includes a UART interface which can be used to receive NMEA sentences from a GNSS module. The baud rate of the GNSS_UART interface can be adjusted via AT commands.

GNSS_UART Parameters

Parameter	Value
Baud Rate	9600 baud (default)
Data Bits	8
Stop Bits	0 (N)
Parity Bits	1
Logic Level	3.3V

3 AT Commands

AT Commands are used to configure the ADSBee 1090 receiver's internal parameters via the CONSOLE interface. AT commands can be used to set values (with the '=' operator, e.g. "AT+BAUDRATE=COMMS_UART,115200") or query values (with the '?' operator, e.g. "AT+BAUDRATE?").

AT commands and parameters must be all-caps. Whitespace is not ignored and should only be used intentionally (e.g. as part of a WiFi network SSID which contains spaces). Arguments are separated by a single comma and no spaces.

All AT command arguments are optional. Arguments will be ignored if left as blank.For instance, to set the second parameter of AT+TL_SET to 3000 without changing the value of the first parameter, the command "AT+TL_SET=,3000" can be sent. Likewise, to change the first parameter to 2000 without changing the value of the second, the command "AT+TL_SET=2000," can be sent.

Commands from the user to the ADSBee 1090 are prefixed with "AT+" (e.g. "AT+BAUDRATE…"). Replies may be prefixed with the relevant command (e.g. "+BAUDRATE=…") or nothing (e.g. "OK"). Replies to AT command queries may include text enclosed by parentheses (e.g. "AT+BAUDRATE=115200(COMMS),9600(GNSS). These text blobs are annotations to improve human readability of the reply.

3.1 AT+BAUDRATE

3.1.1 Set Baudrate

AT+BAUDRATE=<iface>,<baudrate>

Set the baudrate for a particular serial interface. Note that the USB C port (CONSOLE interface) is a virtual COM port and does not have a baudrate that can be changed.

Parameter	**Description**	**Values**
iface	Serial interface to set the baudrate for.	COMMS, GNSS
baudrate	Baudrate, in characters per second.	9600-115200

3.1.2 Query Baudrate

AT+BAUDRATE?
+BAUDRATE=<comms_uart_baudrate>(COMMS_UART),<gnss_uart_baudrate>(GNSS_UART)

Queries the baudrate for the COMMS_UART and GNSS_UART interfaces. Note that the baudrates returned by this query are the actual system baudrates, which should be close to the baudrates that were requested with AT+BAUDRATE but may be slightly different due to the particulars of how baudrates are implemented inside the RP2040.

Parameter	**Description**	**Values**
comms_uart_baudrate	Baudrate on the COMMS_UART interface.	9600-115200
gnss_uart_baudrate	Baudrate on the GNSS_UART interface.	9600-115200

3.2 AT+BIAS_TEE_ENABLE

3.2.1 Turn the Bias Tee On or Off

AT+BIAS_TEE_ENABLE=<enabled>

Enable or disable the bias tee to enable use of an external LNA.

Parameter	Description	Acceptable Values
enabled	Whether the bias tee is enabled (3.3VDC supplied to the RF IN connector) or disabled (no DC voltage supplied to the RF IN connector).	0 – Bias tee is disabled. 1 – Bias tee is enabled.

3.2.2 Query the Status of the Bias Tee

AT+BIAS_TEE_ENABLE?
+BIAS_TEE_ENABLE=<enabled>

Queries the status of the bias tee. See table in 3.1.1 for values and their meanings.

3.3 AT+ESP32_ENABLE

3.3.1 Turn the ESP32 On or Off

AT+ESP32_ENABLE=<enabled>

Turns the ESP32 on or off using its enable line. When the ESP32 is turned off, the ADSBee 1090 will draw less power, but the WiFi and network capabilities will be unavailable. This operational mode is useful for conserving energy in applications where the ADSBee is only being communicated with via its serial interfaces.

Parameter	Description	Acceptable Values
enabled	Whether the ESP32 is turned on.	0 – ESP32 is turned on. 1 – ESP32 is turned off.

3.3.2 Query the Status of the ESP32

AT+ESP32_ENABLE?
+ESP32_ENABLE=<enabled>

Queries whether the ESP32 is turned on or off. See table in 3.3.1 for the values and their meanings.

3.4 AT+FEED

3.5 AT+FLASH_ESP32

3.6 AT+LOG_LEVEL

3.7 AT+PROTOCOL

3.7.1 Set the Reporting Protocol for a Serial Interface

AT+PROTOCOL=<iface>,<protocol>

Parameter	Description	Values
iface	Serial interface to set the baudrate for.	CONSOLE,COMMS_UART
protocol	Reporting protocol for the specified serial interface	NONE – No data reported. RAW – Raw plain text reporting protocol. BEAST – Mode S Beast binary reporting protocol. CSBEE – CSBEE plain text reporting protocol. MAVLINK1 – MAVLINK 1 binary reporting

		protocol. MAVLINK2 – MAVLINK 2 binary reporting protocol. GDL90 – Garmin GDL90 binary reporting protocol.

3.7.2 Query the Reporting Protocol for All Serial Interfaces

AT+PROTOCOL?
+PROTOCOL=CONSOLE,<console_protocol>
+PROTOCOL=COMMS_UART,<comms_uart_protocol>

Queries the reporting protocol set for each of the serial interfaces. See the table in 3.7.1 for protocol definitions.

3.8 AT+REBOOT

AT+REBOOT

Reboots the ADSBee 1090 immediately.

3.9 AT+RX_ENABLE

3.10 AT+SETTINGS

3.11 AT+TEST

3.12 AT+TL_READ

3.13 AT+TL_SET

3.14 AT+WIFI

Command	Parameters
AT+LOG_LEVEL	**Log Level Command**
AT+TL_SET *Write with echo of values that were set.* AT+MTLSET=<tl_lo_mv:uint16_t>,<tl_hi_mv:uint16_t> +MTLSET=<tl_lo_mv:uint16_t>,<tl_hi_mv:uint16_t> *Read present set value (stored setpoint, not read by ADC).* AT+MTLSET? +MTLSET=<tl_lo_mv:uint16_t>,<tl_hi_mv:uint16_t>	**RF Comparator Trigger Level (TL) Setpoint Command** NOTE: tl_lo_mv should be set to a value lower than tl_hi_mv. Reducing the level of tl_lo_mv will make the receiver more sensitive to weak RF signals, but will also increase the noise that it receives. Increasing the difference between tl_lo_mv and tl_hi_mv will filter out signals with smaller dynamic range (difference in power level between max amplitude and min amplitude), thereby requiring a higher Signal to Noise ratio for a transponder signal to be decoded. This may reduce the likelihood that the ADSBee tries to decode a

	transponder signal with invalid bits that will trigger a checksum error. tl_lo_mv: TL Low Threshold [milliVolts] • 0-3300 = Low-side trigger threshold of the comparator circuit on the output of the RF detector. Refer to the AD8313 datasheet and adjustable gain stuff for a conversion from mV (RF detector output signal amplitude) to dBm (RF signal power level in). tl_hi_mv: TL High Threshold [milliVolts] • 0-3300 = High-side trigger threshold of the comparator circuit.
AT+TL_READ *Read with echo of values that were read.* AT+MTLREAD +MTLREAD=<tl_lo_mv>,<tl_hi_mv>	**RF Comparator Trigger Level (TL) Read Command** Used an ADC to read the value of tl_lo_mv and tl_hi_mv. Should be roughly in line with the values of tl_lo_mv and tl_hi_mv set in the AT+TL_SET section.
AT+HELP AT+HELP <command>:<command help string> <command>:<command help string> <…>	**Help Command** Prints out a list of available commands and their associated help strings.
AT+RX_GAIN *Set gain to 100x with echo of gain value that was set.* AT+RX_GAIN=100 +RX_GAIN=100 *Read gain value.* AT+RX_GAIN? +RX_GAIN=100 *Test +RX_GAIN command.* +RX_GAIN=<gain:uint16_t>	**Receiver Gain Command** Adjust the gain of the operational amplifier located after the AD8313 in the receive signal chain. Gain is set as a positive integer value between 1-101. gain: Receiver Gain [ratio] • 1-101 = Gain value of operational amplifier operating on AD8313 output.

4 Reporting Protocols

ADSBee 1090 supports the following reporting protocols on CONSOLE and COMMS_UART.

- CSBee
- GDL90 (not yet implemented)
- MAVLINK 1
- MAVLINK 2
- Mode S Beast
- Raw Packets

The CONSOLE interface reports debug messages and AT command responses in addition to the selected reporting protocol. If the CONSOLE interface is being used as a reporting interface, it is recommended to send AT+LOG_LEVEL=SILENT to silence any debug logs that might corrupt the reported data, and to avoid sending additional AT commands while reading reported data in order to avoid the reported data being interspersed with OK and other AT command responses from the ADSBee 1090.

4.1 CSBee

Comma Separated Bee protocol containing information about tracked aircraft as plain text.

The CSBee protocol is heavily inspired by the Aerobits Aero CSV protocol.

4.1.1 Aircraft Message

This message contains information about an aircraft being tracked via ADS-B (1090MHz). Aircraft reports are provided once per second, per aircraft, until contact with the aircraft has been lost for 60 seconds.

```
#A:ICAO,FLAGS,CALL,SQUAWK,ECAT,LAT,LON,ALT_BARO,ALT_GEO,TRACK,VELH,VELV,SIGS,
SIGQ,ACFPS,SFPS,SYSINFO,CRC\r\n
```

#A	Aircraft message start indicator	Format	Example value
ICAO	ICAO number of aircraft (3 bytes).	Hex Integer	3C65AC
FLAGS	Flags bitfield, see table 4.1.1.1.	Hex Integer	12F356A8
CALL	Callsign of aircraft.	String	N61ZP
SQUAWK	SQUAWK of aircraft.	Octal Integer	7232
ECAT	Emitter category, see table 4.1.1.2.	Integer	14
LAT	Latitude, in degrees.	Float	57.57634
LON	Longitude, in degrees.	Float	17.59554
ALT_BARO	Barometric altitude, in feet.	Integer	5000
ALT_GEO	Geometric altitude, in feet.	Integer	5000
TRACK	Ground track of aircraft, in degrees [0,360).	Integer	35
VELH	Horizontal velocity of aircraft, in knots.	Integer	464
VELV	Vertical velocity of aircraft, in ft/min.	Integer	-1344
SIGS	Signal strength, in dBm.	Integer	-92
SIGQ	Signal quality, in dB.	Integer	2
ACFPS	Number of valid Mode A and Mode C frames received from the aircraft during the last second.	Integer	2
SFPS	Number of valid Mode S frames received from the aircraft during the last second.	Integer	5
SYSINFO	Aircraft data integrity and physical dimensions, see table 4.1.1.3.	Hex Integer	31BE89F2
CRC	CRC16 (described in 4.1.1.4).	Hex Integer	2D3E

4.1.1.1 FLAGS Bitfield

Note: All bits 17-32 are momentary (cleared and updated every reporting interval).

Bit	Bit Name	Meaning if the bit is set (1)
0	IS_AIRBORNE	Emitter is airborne.
1	POSITION_VALID	Emitter has a valid position (ADSBee has received a valid pair of even and odd Compact Position Reporting packets and decoded an unambiguous location for the aircraft).
2	IS_MILITARY	Emitter has transmitted at least one packet using a military format, such as Military Extended Squitter (DF=19).
3	IS_CLASS_B2_GROUND_VEHICLE	Emitter is actually a ground vehicle using a Class B2 transponder with a transmission power < 70W.
4	HAS_1090_ES_IN	Emitter has receive capability for 1090MHz Extended Squitter transmissions.
5	HAS_UAT_IN	Emitter has receive capability for UAT (978MHz Universal Access Transceiver) transmissions.
6	TCAS_OPERATIONAL	Emitter has a functional TCAS (Traffic Collision Avoidance System) onboard.
7	SINGLE_ANTENNA	Emitter is using a single antenna, instead antennas above and below the fuselage. Transmissions may be weak or irregular during maneuvering.
8	SURFACE_POSITION_USES_HEADING	Surface position messages provided by the aircraft indicate a heading and not a track angle.
9	HEADING_USES_MAGNETIC_NORTH	Heading reported by the aircraft while on the surface uses magnetic north instead of true north.
10	IDENT	The aircraft has its SPI (Special Position Identification) bits set in Mode A/C or Mode S messages. This indicates that the pilot has depressed the momentary IDENT switch on their transponder, most likely at the request of air traffic control.
11	ALERT	The aircraft is issuing either a permanent or momentary alert. This could correspond to an operational mode change or something else.
12	TCAS_RA	The aircraft has an active TCAS resolution advisory (i.e. the aircraft is warning the pilot to take action in order to avoid colliding with another aircraft).
13	RESERVED	
14	RESERVED	
15	RESERVED	
16	RESERVED	
17	UPDATED_BARO_ALTITUDE	Barometric altitude has been updated within the last reporting interval.
18	UPDATED_GNSS_ALTITUDE	GNSS altitude has been updated within the last reporting interval.
19	UPDATED_POSITION	Position (latitude / longitude) has been updated within the last reporting interval.
20	UPDATED_TRACK	Track has been updated within the last reporting interval.
21	UPDATED_HORIZONTAL_VELOCITY	Horizontal velocity has been updated within the last reporting interval.
22	UPDATED_VERTICAL_VELOCITY	Vertical velocity has been updated within the last reporting interval.
23		
24		
25		
26		
27		
28		
29		
30		
31		

4.1.1.2 ECAT Field

The ECAT field indicates the Emitter Category (i.e. airframe type) for each ADSB emitter that is being tracked. This field contains information about what kind of aircraft, ground vehicle, obstacle, or other airspace user is emitting ADS-B packets, and can be used to understand the emitter's maneuvering capability and potential for wake vortex impact.

ECAT Value	Emitter Category
0	Invalid
1	Reserved
2	No Category Information
3	Surface Emergency Vehicle
4	Surface Service Vehicle
5	Ground Obstruction
6	Glider / Sailplane
7	Parachutist / Skydiver
8	Ultralight / Hang Glider / Paraglider
9	Unmanned Aerial Vehicle
10	Space / Transatmospheric Vehicle
11	Light Aircraft (< 7,000kg)
12	Medium 1 (7,000kg – 34,000kg)
13	Medium 2 (34,000kg – 136,000kg)
14	High Vortex Aircraft
15	Heavy (> 136,000kg)
16	High Performance (> 5 G acceleration and > 400 kts speed)
17	Rotorcraft

4.1.1.3 SYSINFO Bitfield

SYSINFO Bitfield													
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
			Aircraft Maximum Dimension (MDIM)							GNSS Antenna Offset Direction (GAOR)	GNSS Antenna Offset Distance (GAOD)		GNSS Antenna Offset Known (GAOK)	System Design Assurance (SDA)	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Source Integrity Level (SIL)		Geometric Vertical Accuracy (GVA)		Navigation Accuracy Category: Position (NAC_p)				Navigation Accuracy Category: Velocity (NAC_v)			Navigation Integrity Category: Barometer (NIC_{baro})	Navigation Integrity Category (NIC)			

SYSINFO[0-3]: Navigation Integrity Category (NIC)

The radius of containment (NIC) indicates how much trust should be placed in an aircraft's reported location in the horizonal plane. The NIC reports a radius of containment specified by the avionics system of the emitter. The probability that the aircraft is outside of this radius of containment due to its avionics system receiving a faulty signal from one of its inputs (without displaying an error) is provided by another bitfield called the Source Integrity Level (SIL). Combined, the NIC and SIL indicate how likely it is that an aircraft is not actually contained by a bubble of a specified size, centered at the aircraft's reported location, assuming that the avionics onboard the aircraft are functioning correctly but may be given faulty inputs.

A higher NIC value indicates more trust in an aircraft's reported latitude / longitude position.

NIC Value	0	1	2	3	4	5	6	7	8	9	10	11
Radius of Containment	Unknown	< 20 NM	< 8 NM	< 4 NM	< 2 NM	< 1 NM	< 0.6 NM	< 0.2 NM	< 0.1 NM	< 75 m	< 25 m	< 7.5 m

SYSINFO[4]: Navigation Integrity Category: Barometer (NIC_{baro})

The barometric altitude integrity (NIC_{baro}) indicates how much trust should be placed in an aircraft's reported altitude. The field is a single bit that indicates whether the aircraft uses an altimeter that has been cross-checked against other sources. Old school encoding altimeters have many parallel wires and output an altitude in a format called a Gillham Code, and have no built-in method of error checking. A single faulty wire can result in erroneous readings, so this bit lets air traffic control know whether to take altitude readings from the aircraft with a grain of salt. A 0 indicates that the transponder is outputting altitude from a Gillham coded source (with no way to cross check the value), while a 1 indicates that the transponder is outputting altitude from a Gillham coded source while using another sensor to cross-check it, or is using a more modern barometer that supports a protocol with built-in error checking.

A higher NIC_{baro} value (i.e. 1 instead of 0) indicates more trust in the aircraft's reported altitude.

NIC_{baro} Value	0	1
Barometric Altitude Integrity	Altitude is from a Gillham-coded input, not cross checked.	Altitude is from a Gillham-coded input that is being cross-checked with another source, or from a non Gillham-coded input with built-in error checking features.

SYSINFO[5-7]: Navigation Accuracy Category: Velocity (NAC_v)

The horizontal velocity error (NAC_v) indicates the expected accuracy of the reported velocity of the aircraft when systems are operating nominally. This varies depending on the accuracy capabilities of the measurement equipment onboard the aircraft, and not how often we expect said equipment to fail.

A higher NAC_v indicates a more accurate velocity measurement system.

NAC_v Value	**Horizontal Velocity Error**
0b000	Unknown or ≥ 10 m/s
0b110	< 10 m/s
0b010	< 3 m/s
0b011	< 1 m/s
0b100	< 0.3 m/s

SYSINFO[8-11]: Navigation Accuracy Category: Position (NAC_p)

The estimated position uncertainty (NAC_p) indicates the expected accuracy of the aircraft's reported location when systems are operating nominally. This varies depending on the capabilities of the aircraft's positioning system and not on how often we expect said equipment to fail.

A higher NAC_p indicates a more accurate positioning system.

NAC_p Value	0	1	2	3	4	5	6	7	8	9	10	11
Estimated Position Uncertainty	Unknown or ≥ 10NM	< 10 NM	< 4 NM	< 2 NM	< 1 NM	< 0.5 NM	< 0.3 NM	< 0.1 NM	< 0.5 NM	< 30 m	< 10 m	< 3 m

SYSINFO[12-13] Geometric Vertical Accuracy (GVA)

The geometric vertical accuracy indicates the 95% confidence interval (vertical figure of merit) provided by the aircraft's onboard GNSS system (i.e. assuming some distribution of altitudes, the aircraft's GNSS system is confident that 95 out of 100 times, the aircraft falls within some height of the reported geometric altitude.

GVA Value	0	1	2	3
95% Vertical Figure of Merit (VFOM)	Unknown or ≥ 150 m	< 150 m	≤ 45 m	< 45 m (Was previously "reserved", the actual value of this field may change but is guaranteed to be < 45 m).

SYSINFO[14-15] Source Integrity Level (SIL)

The source integrity level indicates the probability that the aircraft exceeds the bounds of its horizontal radius of containment (NIC) due to a silent fault in signals received by the aircraft (no avionics failure).

SIL Value	**Probability of Exceeding NIC Radius of Containment Due to Silent Fault**
0	Unknown or > $1x10^{-3}$ per flight hour.
1	≤ $1x10^{-3}$ per flight hour.
2	≤ $1x10^{-5}$ per flight hour.
3	≤ $1x10^{-7}$ per flight hour.
4	Unknown or > $1x10^{-3}$ per sample.
5	≤ $1x10^{-3}$ per sample.
6	≤ $1x10^{-5}$ per sample.
7	≤ $1x10^{-7}$ per sample.

SYSINFO[16-17] System Design Assurance (SDA)

The system design assurance indicates how robust the aircraft's position reporting systems are to failures of various severities. For instance, SDA = 1, a low SDA value, corresponds to Software and Hardware Design Assurance Level D, which states that a minor failure could cause the aircraft to transmit misleading position information with a probability of ≤ $1x10^{-3}$ per flight hour. A more robust system with SDA = 3, corresponding to Software and Hardware Design Assurance Level B, is expected to transmit misleading position information with a probability of $1x10^{-7}$ per flight hour even under a Hazardous failure condition.

Software Design Assurance categories used in this field are classified under RTCA DO-178B, Airborne Electronic Hardware Design Assurance are classified under RTCA DO-254, and failure classification levels are defined in FAA Advisory Circular AC-23.1309-1E.

SDA Value	Supported Failure Condition	Probability of Undetected Fault causing transmission of False or Misleading Information	Software and Hardware Design Assurance Level
0	Unknown / No Safety Effect	> $1x10^{-3}$ per flight hour or unknown.	N/A
1	Minor	≤ $1x10^{-3}$ per flight hour.	D
2	Major	≤ $1x10^{-5}$ per flight hour.	C
3	Hazardous	≤ $1x10^{-7}$ per flight hour.	B

SYSINFO[18] GNSS Antenna Offset Known (GAOK)

This field indicates whether the aircraft has reported the installation location of its GNSS antenna relative to its centerline (roll axis). A field for reporting this value is only available in ADS-B messages emitted by aircraft on the ground, and even then, the aircraft may not report a value in this field.

GANTO Value	Aircraft reported location of its GNSS antenna relative to roll axis?
0	No
1	Yes

SYSINFO[19-20] GNSS Antenna Offset Distance (GAOD)

This field indicates the distance that the GNSS antenna is offset from the centerline (roll axis) of the aircraft. Aircraft only report even values for their GNSS antenna offset distance, between 2-6 meters, so the reported offset distance can be calculated using the equation below.

GNSS antenna offset distance = GAOD << 1

Note that this value is only reported by some aircraft while operating on the ground. Aircraft operating in the air do not report this value. Always check the value of the GAOK bit to see if the value of GAOD is worth paying attention to.

SYSINFO[21] GNSS Antenna Offset Direction (GAOR)

GAOR Value	GNSS Antenna Offset Direction
0	GNSS antenna is offset to the left of centerline (roll axis).
1	GNSS antenna is offset to the right of centerline (roll axis).

SYSINFO[22-28] Aircraft Maximum Dimension (MDIM)

This field indicates the value of the maximum dimension (length or width) of an aircraft, and is only reported by aircraft while on the ground. This field has no special coding, and can be interpreted directly as a binary unsigned integer value.

4.1.1.4 CRC Field

CSBee messages use a 16-bit Cyclical Redundancy Checksum (CRC-16), which can be calculated using the algorithm in the C++ code snippet below. Note the "swap16" helper function which also needs to be included.

```
uint16_t swap16(uint16_t value) { return (value << 8) | (value >> 8); }

uint16_t CalculateCRC16(const uint8_t *data_p, int32_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);
}
```

4.1.2 Statistics Message

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

```
#S:DPS,ACFPS,SFPS,TSCAL,UPTIME,CRC\r\n
```

#S	Statistics message start indicator	Example
DPS	Number of attempted demodulations in the last second.	106
ACFPS	Number of MODE-A or MODE-C frames received in the last second.	20
SFPS	Number of valid Mode S frames received in the last second.	3
TSCAL	Calibration value for TS field in raw frames	13999415
UPTIME	Time from last enter to RUN mode, in seconds.	134
CRC	CRC16 (described in 4.1.2.1).	2D3E

4.1.2.1 CRC Field

See 4.1.1.4.

4.2 MAVLINK

Tracked aircraft information is sent in MAVLINK ADSB_VEHICLE messages, in a data burst once per second. The data burst consists of Nx ADSB_VEHICLE messages, where N is the number of tracked aircraft, and 1x MESSAGE_INTERVAL message as a delimiter which indicates the end of the list of tracked aircraft. Note that this is a binary protocol which is not human readable.

WARNING: Windows has a bug, which causes some machines to recognize a serial port reporting MAVLINK packets as a mouse, which can result in phantom mouse movements and clicks (ask me how I know). Please use caution while running MAVLINK on a serial port while the computer is unattended.

4.2.1 MAVLINK ADSB_VEHICLE (Message ID 246) Packet Definition

From: https://mavlink.io/en/messages/common.html#ADSB_VEHICLE

Field Name	Type	Units	Values	Description
ICAO_address	uint32_t			ICAO address
lat	int32_t	degE7		Latitude
lon	int32_t	degE7		Longitude
altitude_type	uint8_t		ADSB_ALTITUDE_TYPE	ADSB altitude type.
altitude	int32_t	mm		Altitude(ASL)
heading	uint16_t	cdeg		Course over ground
hor_velocity	uint16_t	cm/s		The horizontal velocity
ver_velocity	int16_t	cm/s		The vertical velocity. Positive is up
callsign	char[9]			The callsign, 8+null
emitter_type	uint8_t		ADSB_EMITTER_TYPE	ADSB emitter type.
tslc	uint8_t	s		Time since last communication in seconds
flags	uint16_t		ADSB_FLAGS	Bitmap to indicate various statuses including valid data fields
squawk	uint16_t			Squawk code

4.2.2 MAVLINK MESSAGE_INTERVAL (Message ID 244) Packet Definition

From: https://mavlink.io/en/messages/common.html#MESSAGE_INTERVAL

Field Name	Type	Units	Description
message_id	uint16_t		The ID of the requested MAVLink message. v1.0 is limited to 254 messages. NOTE: For ADSBee 1090, message_id is always 246, corresponding to the ADSB_VEHICLE message.
interval_us	int32_t	us	The interval between two messages. A value of -1 indicates this stream is disabled, 0 indicates it is not available, > 0 indicates the interval at which it is sent. NOTE: For ADSBee 1090, message_id is always 1000 us.