

Design and Implementation of Satellite ADS-B Receiver

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Abstract. With the rapid development of Chinese aviation industry, the amount of air flights has increased rapidly, and the traditional ground radar surveillance system has a limited geographic range, while the satellite ADS-B surveillance system has the advantages of all-time, all-weather, large-scale, and long-distance. It is an effective supplement to the aircraft ground monitoring system. This paper conducts research from the satellite ADS-B receiver system functions, technical indicators, hardware design, software design, structural design, etc., and establishes a test environment to prove that the satellite ADS-B receiver performance index design meets the technical requirements and has high application value.

Keywords: ADS-B, Receiver, Monitoring.

1. Introduction

The aviation ADS-B system, which is a broadcast automatic correlation monitoring system, as shown in Figure 1, adopts an omnidirectional broadcast method to automatically broadcast model, aviation code, position, speed, altitude and route, etc. [1]. Combining advanced technologies such as satellite navigation, communication technology, airborne equipment, and ground equipment, it provides safer and more efficient air traffic surveillance methods, which can effectively improve the operational situation awareness of controllers and pilots, expand surveillance coverage, and improve air traffic safety level, airspace capacity and operational efficiency [2] [3] [4]. The satellite ADS-B receiver receives the ADS-B information broadcast by the aerial vehicle through air-to-air communication in the form of satellites, and completes the collection of aircraft characteristic information under special conditions such as deserts, wastelands, and seas, and then passes the information through the satellite-to-ground communication link back to the ground to monitor the status of the aircraft, which is an effective supplement to the monitoring methods of ground-based aircraft.

2. System Survey

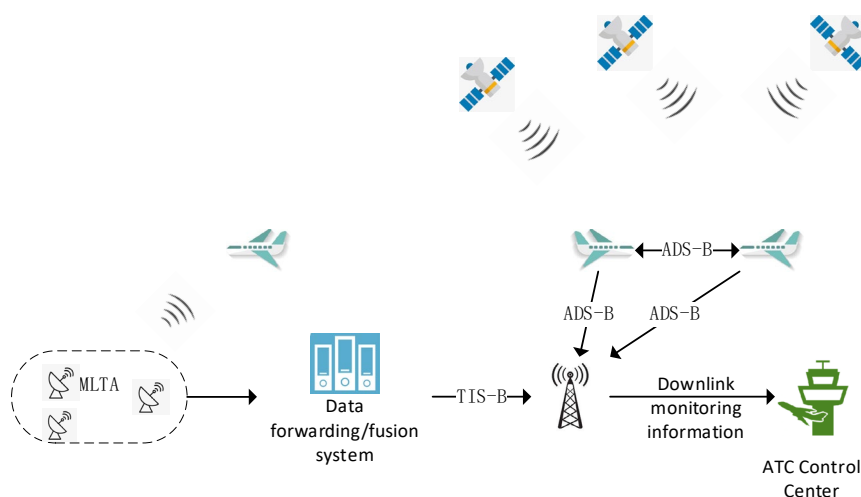


Figure 1. ADS_B System Architecture Diagram

The satellite ADS-B receiver is composed of the L-band information acquisition system, which can collect and store the characteristic information of longitude, latitude, altitude, sailing speed, route trajectory, etc. of aircraft equipped with ADS-B system such as an airplane with a pilot or drone. The information is then sent back to the ground station through the satellite-to-ground communication link to monitor the status of the aircraft, which is an effective supplement to the monitoring methods of the ground-based aircraft.

2.1 System function

Support 1090ES [5] [6] data information collection function;
Support the collection of DF17 and DF18 message information;
The storage capacity on the satellite is not less than 4Gbit;
Suitable for track applications of 600Km and below;
Rich in scalability;
Support data encryption function.

2.2 Technical indicators

The technical index of satellite ADS-B receiver is shown in Table 1.

Table 1. The technical index of satellite ADS-B receiver

Number	Indicators	Requirements
1	Uplink standard frequency	1090MHz
2	Demodulation mode	BPPM
3	Code rate	1Mbps
4	Noise factor	≤ 4
5	Capture threshold for receiver signal channel	$\leq -98\text{dBm}$
6	Detection probability	$\geq 95\%$ (receiver signal strength better than -95dBm) $\geq 75\%$ (receiver signal strength better than -98dBm)
7	Receiver dynamic range	$\geq 40\text{dB}$
8	Anti-Doppler frequency shift	$\geq \pm 50\text{kHz}$
9	Detection signal power	$0\text{dBm} \pm 2\text{dBm}$
10	Channel gain	100dB
11	Storage capacity	$\geq 4\text{Gbit}$
12	SWR of the input /output interface	≤ 1.5
13	Electrical impedance of the input /output interface	50Ω

3. System Design

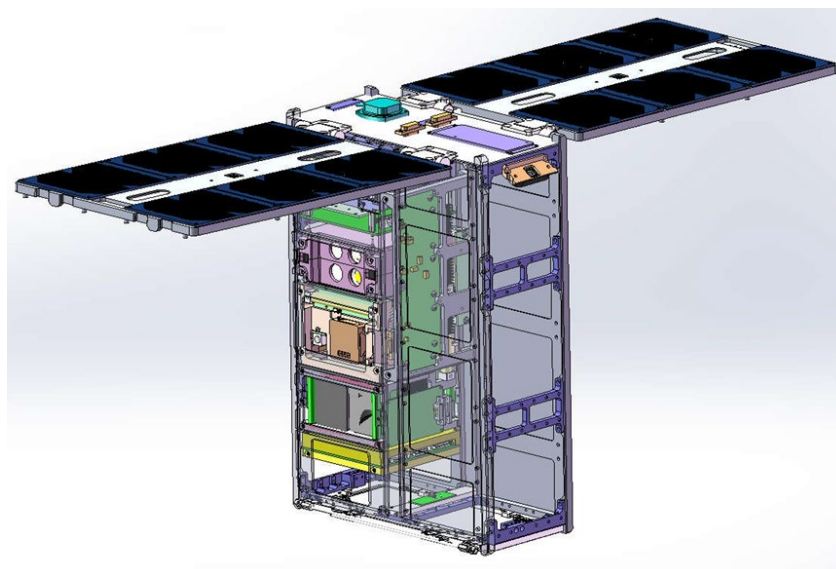


Figure 2. Schematic diagram of commercial small satellite platform

The satellite ADS-B receiver is equipped with a commercial small satellite platform and adopts a standardized design to realize the information collection function of the aircraft equipped with the ADS-B system. The schematic diagram of the small satellite platform is shown in Figure 2.

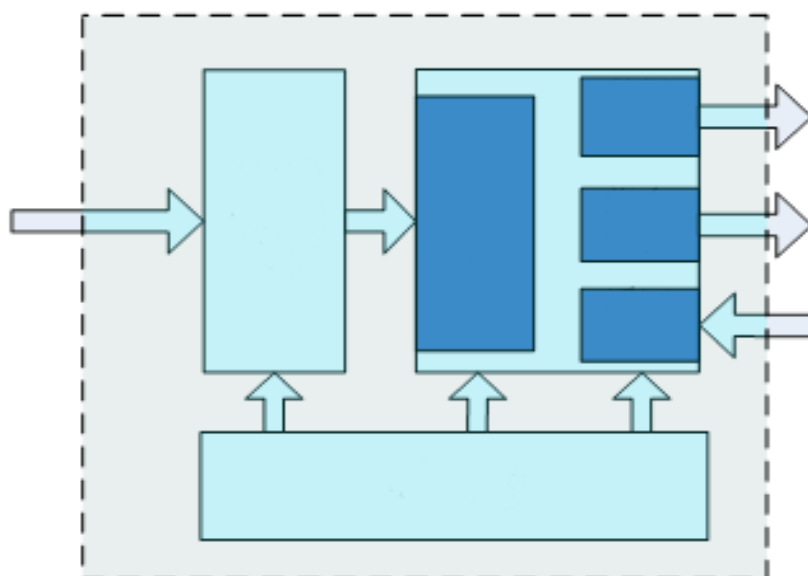


Figure 3. System composing module

The satellite ADS-B receiver works in the L frequency band, and the receiving antenna receives the uplink radio frequency signal from the aircraft. The signal form is a PPM position modulated signal; the uplink radio frequency signal enters the receiving channel of the satellite ADS-B receiving load to complete filtering and low noise amplification, detection and AD sampling; The intermediate frequency signal enters the digital baseband part for A/D sampling. The sampled data completes the signal processing in the digital baseband. The aircraft status information is obtained through demodulation, and then the information is packaged according to the framing mode, then the information is packaged according to the framing mode and transmitted to the satellite service computer through the RS422 interface; The baseband collects telemetry information, packs it into a proprietary telemetry packet format, and sends it to the satellite service computer; The satellite ADS-B receiving load is the primary power supply equipment, and the power supply and instruction module are designed to realize the processing from the primary power supply to the secondary power supply. Its system composing module is shown as in Fig. 3.

3.1 Hardware design

The satellite ADS-B receiver hardware is composed of three functional modules: receiving channel, digital baseband, and power control. The functional division of each module is shown in Table 2.

Table 2. Function division of each module of the ads-b satellite

Number	Module name	Module function
1	Power and interface module	a. Primary power treatment b. Secondary power filter c. Control and state telemetry function d. CAN/422 bus interface between satellites
2	Receive channel	a. Collecting signal using detection scheme b. Achieving the amplification of weak received signal
3	Digital baseband	a. Baseband signal processing in FPGA b. Communicate with satellite computer

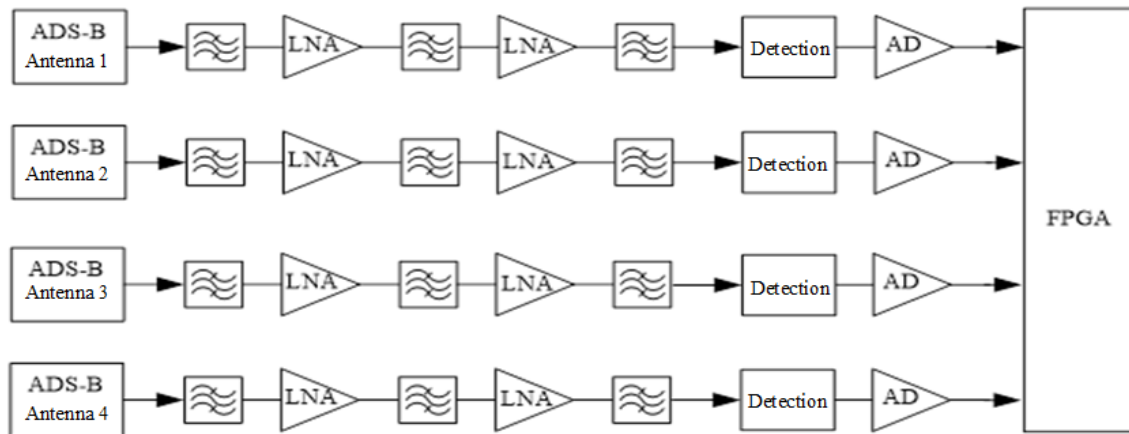


Figure 4. Flow chart for Satellite load receive channel

1) Design of receiving channel: The satellite ADS-B receiver receiving channel module is responsible for filtering, amplifying, detecting, AD sampling the input radio frequency signal, and then sending it to the digital baseband for signal processing. This article adopts the double-conversion super heterodyne receiver mode. The process is shown in Figure 4. The basic design considerations for the receiving channel are:

Lower noise performance. Since the noise inside the receiver is an important factor affecting the receiving sensitivity, the noise inside the receiving channel should be as small as possible and meet the technical requirements within 3dB.

Appropriate working frequency band. Generally, low-noise amplifiers have a wide frequency band, and the bandwidth is usually not less than 10% f_i (f_i is the center frequency). Due to the existence of image noise and the requirements of equipment noise performance, the intermediate frequency signal frequency should be appropriately selected higher.

High enough gain. For the satellite ADS-B receiver, the gain of the receiving channel must reach 100dB to meet the requirements of the digital baseband demodulation level.

Automatic gain control loop design. According to the form of the uplink signal and the requirements for the dynamic range of the receiver, the components of the AGC loop are analyzed and designed to achieve a control range and control accuracy of 40dB, and to ensure that there is no additional adverse effect on the demodulation.

Linear characteristics. Including the dynamic range of amplifiers and mixers, intermodulation and spurious output, group delay characteristics, etc.

2) Design of digital baseband: The digital baseband hardware part of the satellite ADS-B receiver is mainly composed of input, processing and output parts, as shown in Figure 5:

a) Input unit: The input unit processes a 70MHz signal from a satellite ADS-B receiver, using a piece of AD9258 for AD conversion processing, the chip is powered by 1.8V, the rate is up to 80MSPS, dual-channel 14-bit, and supports SPI.

b) Processing unit: The core of the processing unit adopts the Xilinx industrial grade device Spartan6 series, the working voltage is 1.2V, the I/O working voltage is 1.8V, and the chip resources meet the needs of the satellite ADS-B receiver.

c) Output unit: The output unit uses an interface conversion chip to realize the distribution and control of external interfaces, including radio frequency interface, power supply interface, telemetry, remote control interface and internal intermediate frequency interface, etc. To prevent open circuit or poor contact, the contact arrangement of low-frequency plug or socket is adopted "Two-point two-line" connection method.

3) Design of power control: The satellite ADS-B receiver power module is responsible for converting the satellite's primary power supply to the secondary power supply for the receiving channel, digital baseband, and external interface. After the 5.2V power supply module is connected to the baseband, it passes through the DC-DC isolation module (MORNSUN WRB0505S-3W), and outputs 3.3V and 1.2V through two LM20123, and one LP38853 outputs 1.8V. The EMC design of

the power loop input is shown in Figure 6, part ① is used for EMS protection, part ② is used for EMI filtering, and part ③ is reserved for control.

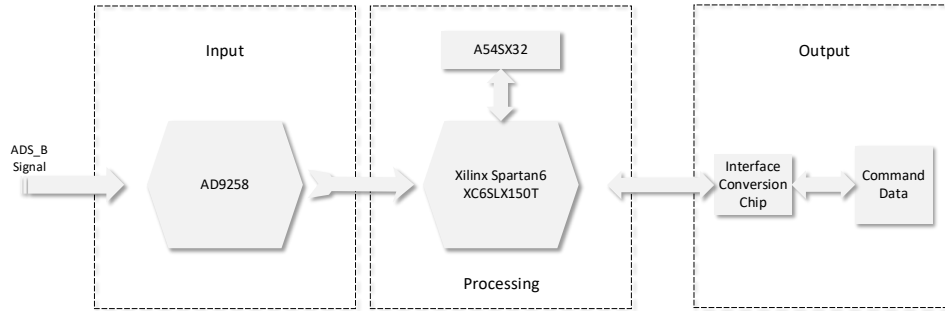


Figure 5. Digital baseband block diagram of satellite ADS-B receiver

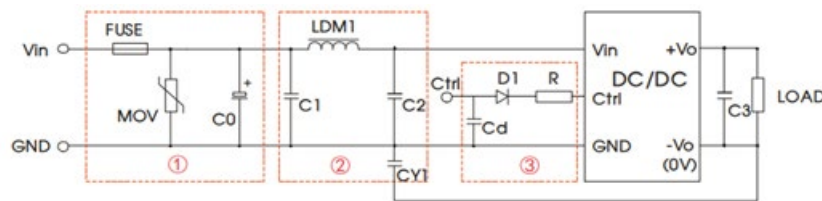


Figure 6. Power circuit diagram of satellite ADS-B receiver

3.2 Software design

1) Information demodulation process: The reception of the satellite ADS-B receiver signal must first complete the preamble identification and determination in the message. After the signal is determined as a satellite ADS-B receiver signal by the previous header detection, the obtained data bits are decoded and error corrected. The demodulation algorithm mainly explores the following two aspects:

For the response signal of S mode, the first $8.0\mu\text{s}$ is the preamble pulse, and the following is the data block of pulse position modulation (PPM). The data block is 112bit, and each bit period is $1\mu\text{s}$, including two chips (station and vacancy). One chip is high and the next chip is low represents data "1", and the next chip is high and the previous chip is low represents data "0". The pulse width error is $0.05\mu\text{s}$, the rising edge is 50-100ns, and the falling edge is 50-200ns. Through leading pulse detection, parameters such as signal arrival time and pulse reference level are obtained, and data block decoding is performed according to these parameters, and the value of "0" and "1" of the data bit and the level of confidence coefficient are determined. In this paper, the multiple point decision method based on confidence coefficient detection is used to obtain the confidence corresponding to its 112-bit data by calculation, and perform CRC error correction on the data with reference to the confidence coefficient.

After the decoding process of the satellite ADS-B receiver, the accuracy of the 112-bit serial code needs to be verified. According to the data transmission standard of the satellite ADS-B receiver, the last 24 data bits are transmitted with the CRC (cyclic redundancy check) code. In this design, it is not only necessary to complete the proofreading of the information, but also to correct errors according to the confidence matrix obtained by decoding. The cyclic redundancy check algorithm based on confidence detection first uses CRC for error detection. If an error is detected, the result of the confidence determination is combined with the characteristics of the CRC code to find the error position, thereby completing the error correction.

2) Signal decoding algorithm: The downlink data of the S-mode data link, that is, the satellite ADS-B receiver information is the PPM modulation method, specifically for one signal bit, if the signal energy appears in the first half (CHIP1), it means "1", if it appears in the second half (CHIP 0), it means "0". Therefore, the confidence coefficient level of each bit can be determined according to the difference in energy distribution, that is, make full use of the 10 points obtained through

sampling, and there are 5 sampling points in each CHIP, and calculate the score of the energy value in each CHIP. The calculation method as follows:

a) Divide the 10 points sampled in one cycle into two parts, namely CHIP0 and CHIP1, where CHIP contains $S_{chip0} = S_0, S_1, S_2, S_3, S_4$, and CHIP1 contains $S_{chip0} = S_5, S_6, S_7, S_8, S_9$.

b) From the reference power (power_{ref}) obtained in the preprocessing, the points within $\pm 3\text{dB}$ of the reference power in the two CHIPS before and after are taken out, namely:

$$CHIP0_A = S_i, |S_i - power_ref| \leq 3\text{dB}, S_i \in S_{chip0}$$

$$CHIP1_A = S_i, |S_i - power_ref| \leq 3\text{dB}, S_i \in S_{chip1}$$

c) Output unit: The In the same way, take out the points whose amplitude is less than 6dB above the reference power, namely:

$$CHIP0_B = S_i, power_ref - S_i \geq 6\text{dB}, S_i \in S_{chip0}$$

$$CHIP1_B = S_i, power_ref - S_i \geq 6\text{dB}, S_i \in S_{chip1}$$

d) Perform a weighted accumulation on the point sets in these 4 groups (CHIP0_A, CHIP0_B, CHIP1_A, CHIP1_B), where the weight of is 1, and the other points have the weight 2, and the total weighted value of the 4 point sets is obtained, namely: w_chip0_A , w_chip1_A , w_chip1_B , w_chip0_B .

e) Calculate the possibility of code 0 -- $score_0$ and the possibility of code 1 -- $score_1$:

$$score_1 = w_chip1_A - w_chip0_A + w_chip0_B - w_chip1_B$$

$$score_0 = w_chip0_A - w_chip1_A + w_chip1_B - w_chip0_B$$

f) Compare the size of the two values, the highest value determines the value of the code bit (1/0). If the results of the two values are equal, the code value of this bit is 0. If the difference between the two values is greater than or equal to 3, the code has high confidence coefficient, otherwise it is marked as low confidence coefficient. Thus we get the decoded data and the confidence matrix of each bit of data.

3) Structural design: The physical prototype of the satellite ADS-B receiver adopts a box and is integrated with 9 M3 screws. The box body is made of 2A12-H112 aluminum alloy block according to electrical performance requirements. The surface is plated with D.Ag10.SG, which is conducive to electrical performance requirements. The outer surface of the six integrated boxes uses 1mm 5A03-0 aluminum alloy plate as the outer shell, and the outer surface is black anodized $\eta_h > 0.85$; the bottom surface of the mounting feet is no longer hollowed out, which can increase the contact surface and rigidity; Reinforcing ribs are used at the 6 outer ends of the mounting feet. This kind of structure is compact, with few interconnections, and is a worthy structure. In the whole design, comprehensive consideration was given to issues such as radiation protection, mechanical conditions, and heat dissipation of the digital baseband.

a) Structural requirements

Overall dimensions and installation dimensions:

Body size (mm): 120×150×20;

Mounting hole: 6- $\varnothing 4.5 + 0.1$ (mm);

Contact area: 28809(mm²);

A reference hole R mark is marked on one of the mounting feet;

Installation bottom surface: flatness is better than 0.1/100*100, roughness is better than 3.2 μm .

The quality of the prototype

Single machine: 3kg $\pm$ 0.1kg

Thermal control coating

Except for the bottom plane, the other outer surfaces are black anodized $\eta_h > 0.85$, which is in accordance with the regulations of the institute standard Q/W181.1-90 (technical conditions for aluminum alloy black anodized thermal control coating).

Irradiation protection

The wall thickness of the instrument shall not be less than 2mm.

Lap resistance

The housing material and structural materials used on this instrument are all LY12 R.LF3 M aluminum alloy plates, which are compatible. Except for the temperature control coating on the surface, the other parts are silver-plated. Therefore, the contact resistance between any two points of the instrument can be guaranteed to be less than 5 m Ω .

Selection of materials

Material selection is selected in accordance with Q/W126.1-90 "Scope of Selection of Commonly Used Satellite Metallic Materials", and the relevant departments of the selected metal material factory shall be subject to material re-inspection work, and the quality assurance form shall be attached.

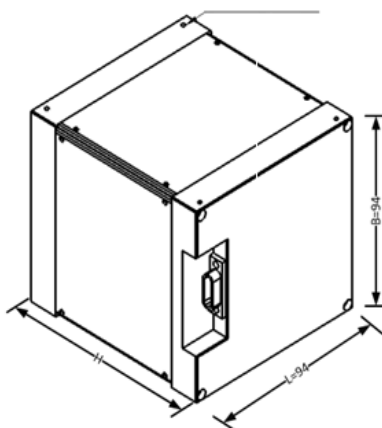


Figure 7. Satellite receiver envelope diagram

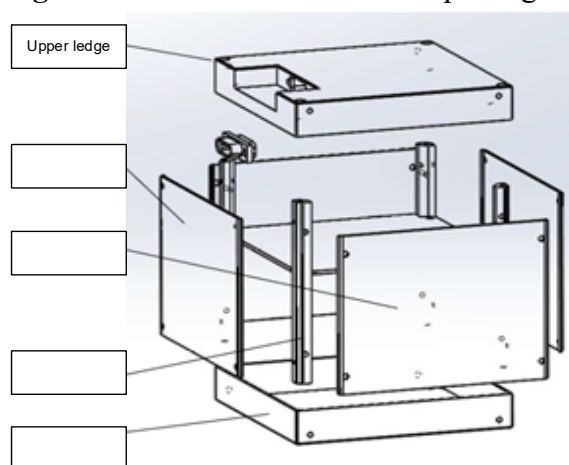


Figure 8. Satellite receiver explosion diagram

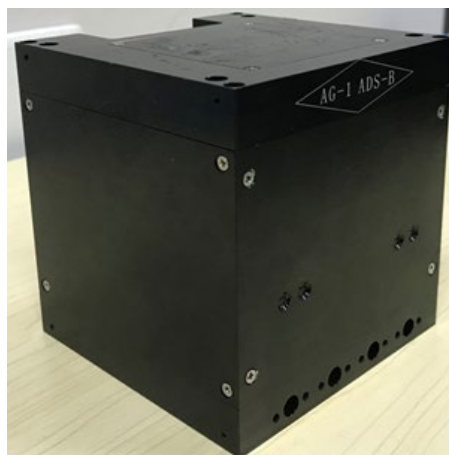


Figure 9. Satellite receiver's picture

Fasteners

Fasteners are made of non-magnetic titanium alloy materials, and fasteners with anti-loosening function.

b) Appearance of the prototype

The appearance and structure design of the satellite ADS-B receiver is shown in Figure 7 and Figure 8, and the actual product is shown in Figure 9.

4. Performance Test

4.1 Test plan

The satellite ADS-B receiver transmits the satellite ADS-B receiver signal through the analog signal generator, and the receiver receives the satellite ADS-B receiver signal. The verification is obtained by comparing the transmitted signal and the received signal, as shown in Figure 10.

4.2 Test results

The satellite ADS-B receiver index test results are shown in Table 3, and the aircraft status monitoring display is shown in Fig. 11.

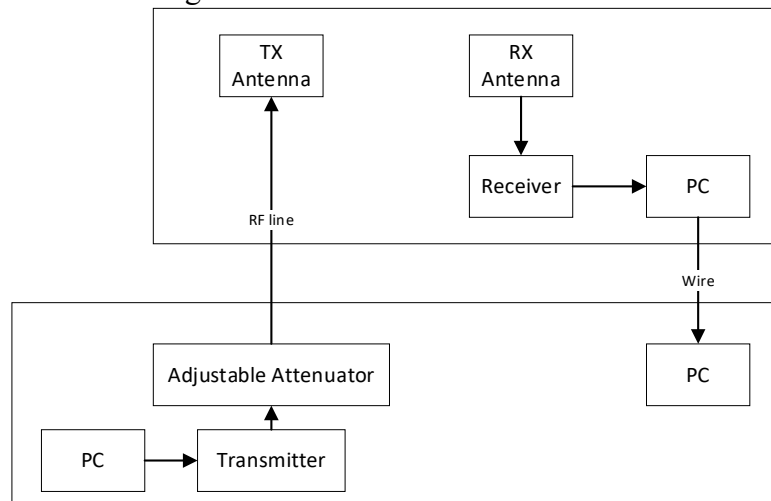


Figure 10. Satellite receiver's test diagram

Table 3. The testing result of satellite ADS-B receiver

Number	Indicators	Requirements	Testing results
1	Uplink standard frequency	1090MHz	1090MHz
2	Demodulation mode	BPPM	BPPM
3	Code rate	1Mbps	1Mbps
4	Noise factor	≤ 4	2.5
5	Capture threshold for receiver signal channel	$\leq -98\text{dBm}$	$\leq -99\text{dBm}$
6	Detection probability	$\geq 95\%$ (receiver signal strength better than -95dBm) $\geq 75\%$ (receiver signal strength better than -98dBm)	RF1:97.17%@ -102dBm RF2:78.25%@ -99dBm
7	Receiver dynamic range	$\geq 40\text{dB}$	45 dB
8	Anti-Doppler frequency shift	$\geq \pm 50\text{kHz}$	$\pm 50\text{kHz}$
9	Detection signal power	$0\text{dBm} \pm 2\text{dBm}$	0dBm
10	Channel gain	100dB	101dB
11	Storage capacity	$\geq 4\text{Gbit}$	4Gbit
12	SWR of the input /output interface	≤ 1.5	1.36
13	Electrical impedance of the input /output interface	50Ω	50Ω

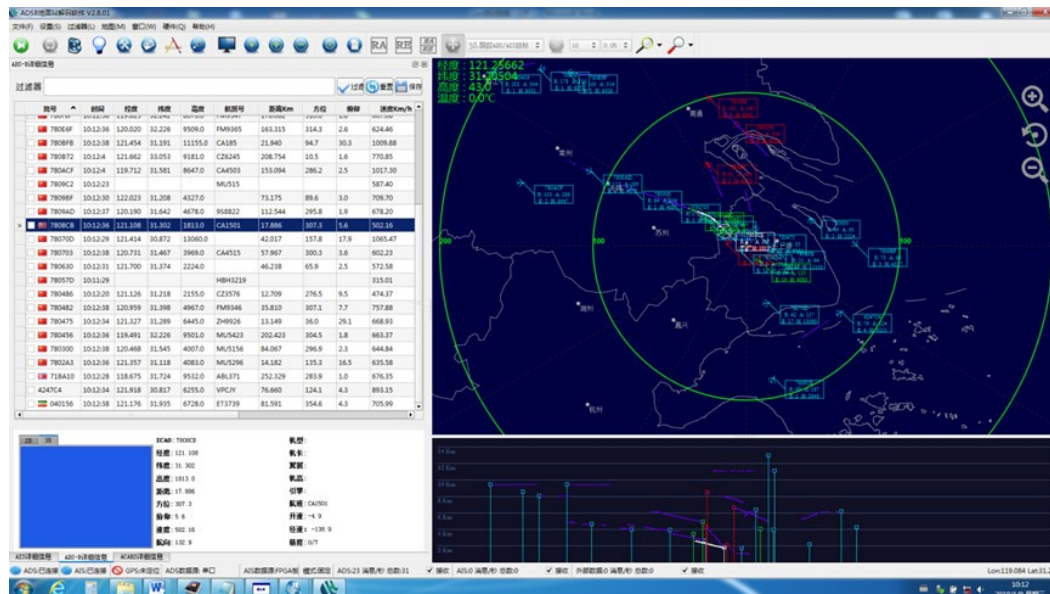


Figure 11. The aircraft status monitoring interface

Acknowledgments

This article starts from the satellite ADS-B receiver application requirements, and conducts research on its system functions, technical indicators, hardware design, software design and structural design. Through the establishment of a test environment, the satellite ADS-B receiver's transmitted signal and the received signal are tested and compared and analyzed. The results show that the performance of the satellite ADS-B receiver prototype meets the technical indicators and has high practical value. In the future, it will be beneficial to China's real-time supervision and control of aviation vehicles, and will improve the quality and efficiency of air control, thereby promoting the rapid growth of China's aviation economy.

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