Design of Spaceborne AIS System

Xiangyu Lin(✉), Dong Yan, Yufei Huang, Fan Bai, Xiongwen He, and Panpan Zhan

Beijing Institute of Spacecraft System Engineering, Beijing 100094, People's Republic of China
linxiangyu1981@163.com

Abstract. The AIS communication system is a global positioning aided navigation system, which can improve the safety of ship operation and the reliability of navigation. A spaceborne AIS system can dynamically monitoring ships in the global area. But It has many challenges such as message collision and signal transmission loss. This paper first designed a LEO AIS constellation, analyzed the coverage of this constellation, and then carried out the design of the on board AIS receiving system, including an array antenna and a receiver. Finally, the method of multi-user signal separation and detection was expounded.

Keywords: Spaceborne · AIS · DBF · Message collision

1 Introduction

At the beginning of AIS system design, the global ship monitoring problem was not considered. Therefore, satellite-based AIS system has many challenges. The main problems are message collision, transmission loss of electromagnetic wave, doppler shift phenomenon, transmission delay, and Faraday rotation of signal polarization direction.

Firstly, a low-orbit AIS constellation is designed and its performance is analyzed in this paper. Then, an AIS receiving system is designed, including a polarization diversity array antenna and a receiver. The methods of multi-user signal separation and detection are then described, including digital beam forming technology, frequency and polarization diversity technology.

1.1 Satellite Orbit Design

A spaceborne AIS system needs to have global coverage and to achieve rapid re-access to any maritime target. Moreover, AIS satellites only need the ability to transmit data with ships and base stations in time, so there is no requirement for the return characteristics of satellite orbit.

Considering the factors such as the coverage of the satellite antenna, the length of the single visible segment of the satellite and the information conflict caused by the number of ships in the beam of the satellite antenna, the orbit height of the AIS satellite

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is about 600 km. Since the mission has no special requirements for the altitude of satellites passing through the earth at different latitudes, in order to reduce the control complexity of the satellite operation, the orbit of the satellite is determined to be a circular orbit (Table 1).

The solar synchronous orbit has the advantage of fixed illumination time, and the design of solar array, thermal control subsystem and power subsystem of the satellite is relatively simple. Therefore, most LEO satellites in China choose this type of orbit. For the sun synchronous orbit with a height of 600 km, the orbit inclination is near 97°, and the distribution of the locus of the satellite is between 83° north and south latitude. The satellite can achieve global coverage, that is, it can provide services for ships operating in various sea areas around the world (Fig. 1).

Table 1. AIS constellation orbit

Satellite number	0	1	2	3	4
Orbit height (Km)	561				
Orbital tilt angle (degree)	97.64				
Eccentricity	0				
Ascension point	0	72	144	216	288
Perigee angle (degree)	0	72	144	216	288
Near point angle (degree)	0				

Fig. 1. AIS constellation 2D configuration

1.2 Analysis of Coverage Performance

In order to analyze the coverage performance of AIS constellation, the criterion of judging the coverage performance is to determine the coverage performance. Commonly used coverage performance indicators include global coverage time, maximum revisit time, bandwidth, instantaneous visible area, etc. According to the AIS task requirements, this paper intends to analyze the maximum revisit time and coverage. In the simulation calculation, all the visible areas below the satellite are regarded as "covered".

The revisit time is the time interval between two satellite beams illuminating the same area, that is, the coverage gap. For AIS satellites, the maximum revisit time is the maximum of the time interval between two beams irradiating the same area.

The calculation shows that the AIS constellation composed of 5 satellites in the previous section is the largest revisit time between anywhere from 0.12 h to 1.44 h. With the increase of latitude, the maximum revisit time is gradually shortened. Among them, 84% of the areas had the maximum revisit time of 1–1.5 h,

The ground coverage of AIS constellation increases with latitude. The calculation shows that the AIS constellation composed of 5 satellites in the previous section can achieve 19–30 times per day for 70% of the area, and the coverage of the two level is as high as 60–76 weight/day,

By analysis, 5 satellites operating in 5 orbiting orbit satellites can operate to ensure that the maximum revisit time of the spaceborne AIS system to any area in the world is less than 1.5 h, that is, it can provide updated services for ships in any area of the world less than 1.5 h.

2 Design of the AIS Receiving System

2.1 Design of Spaceborne AIS Antenna

Aiming at the fading characteristics of the AIS signal transmitted to the 600 km height and the polarization mismatch caused by Faraday rotation, a polarization diversity receiving antenna is designed to improve the reception quality of the signal. At the same time, in order to solve the problem of signal separation, array antennas should be used. Because the wavelength of the signal is 1.85 m, the size of the antenna array is also limited. Designing a better antenna system that can be carried on the satellite is one of the keys of the whole system.

Therefore, taking into account the needs of spaceborne AIS system and the available resources of the satellite platform, taking full account of the radiation unit, geometry structure and DBF processing technology of the antenna, the spaceborne AIS antenna is designed as a two element array antenna consisting of three orthogonal crossed half wave oscillator, and its intention is shown in Fig. 2. In the figure, the Z direction is the local direction, the Y direction is the satellite flight direction, and the X direction realizes the DBF beam scanning to expand the coverage area (Fig. 3).

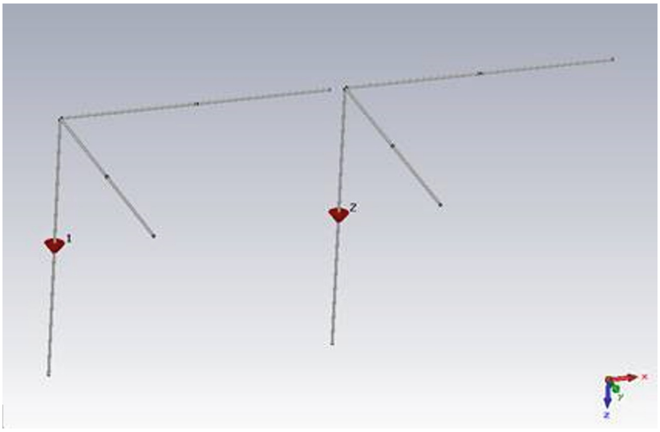

Fig. 2. Antenna array for satellite borne AIS system

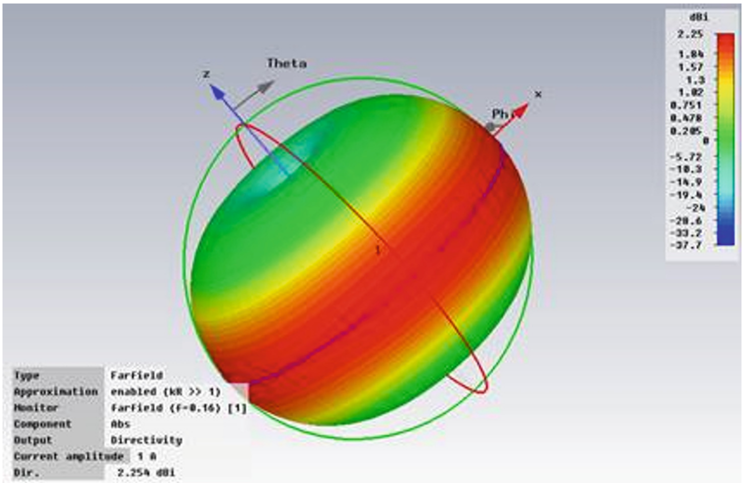

Fig. 3. Antenna 3D radiation pattern

2.2 Design of Spaceborne AIS Receiver

The task of the receiver is to select the weak high-frequency signal received by the antenna from the accompanying noise and interference by proper filtering, and then send it to the signal processor and other equipment after amplification and demodulation.

The spaceborne AIS receiver adopts direct frequency conversion receiver technology. Because it works in the VHF band, it can be regarded as if signal. Therefore, in order to guarantee the sensitivity index, an amplifier is added after the LNA. The receiver mainly includes limiter, band-pass filter, low noise amplifier, broadband amplifier, variable gain amplifier, automatic gain control unit, mixer, demodulator and other modules.

Therefore, the scheme of spaceborne AIS receiver is to receive the signals of three orthogonal antenna antennas in each antenna array separately when receiving the AIS signal. The dual frequency signal of AIS is separated by band-pass filter, and the baseband sampling method is adopted for A/D acquisition, and the block diagram is shown in Fig. 4.

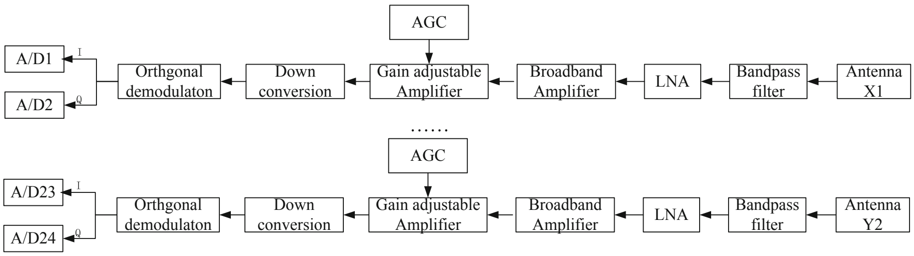

Fig. 4. Scheme of AIS receiver

Because each antenna oscillator channel has two frequency points, each frequency point data acquisition is divided into I and Q orthogonal two channels. The spaceborne AIS system adopts 3 cross oscillator array, so 24 channels of data acquisition are needed.

Because the signal bandwidth of AIS system is 12.5 kHz or 25 kHz, plus Doppler frequency shift + 4 kHz, it is considered that more than 8 times the sampling rate should be adopted, and the quantization bits should be more than 14 bits. Therefore, the sampling rate above 240 kHz can be satisfied, and the core chip with a sampling frequency of 250 kHz is initially selected, and the quantization bits are 16 bit, which can meet the requirements.

Due to the need for buffering, parallel conversion and other data processing before multiple storage data is collected, considering the system data processing speed and IO pin requirements, Xilinx Virtex IV series XQR4VSX55 is selected.

The real-time data unit processes the collected signal data in real time, detects the ship information, and sends it to the data storage unit for storing the data to the ground receiving station. The real-time data processing unit and its relationship with other stand-alone computers are shown in Fig. 5.

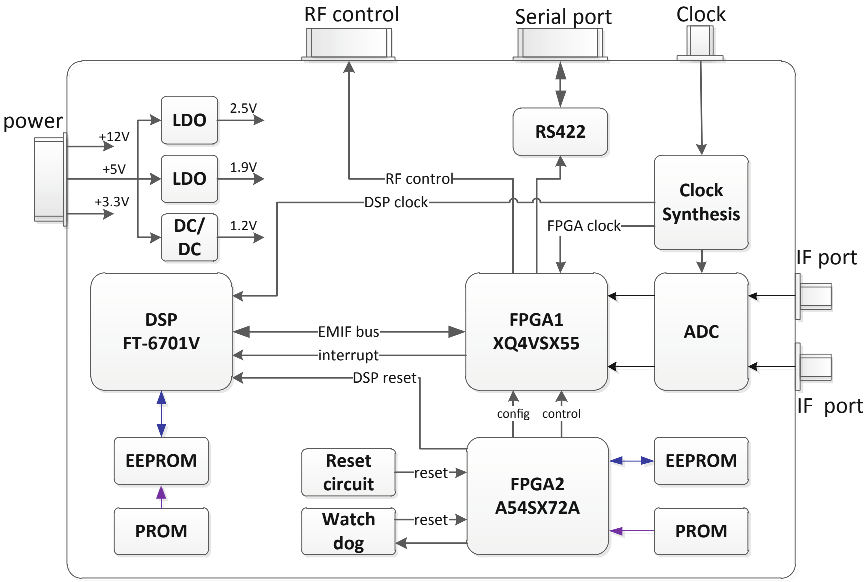

Fig. 5. Real-time data processing unit

3 Multiuser Signal Detection

3.1 Multiuser Signal Detection Overall Scheme

On the two central frequencies of 161.975 MHz and 162.025 MHz channels, the bandwidth of the standard signal is 25 kHz and the Doppler shift frequency is + 4 kHz, so the bandwidth of the two channels is 33 kHz. After the RF front-end processing, the I/Q branch is formed, and then the digital baseband signals of AIS1 and AIS2 are formed by 8 times bandwidth sampling.

As shown in Fig. 6, each channel is processed by digital beam forming of six channels (corresponding to six antenna units), and then the beam diversity of the received data is carried out. Then, the ship information detection based on the frequency diversity is carried out.

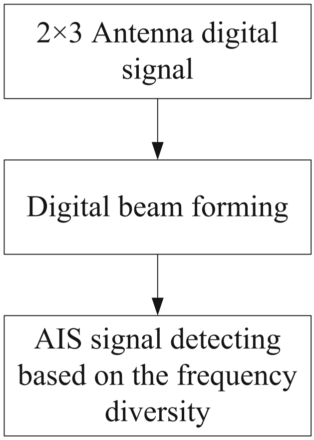

Fig. 6. Overall digital processing scheme on satellite (AIS1 and AIS2 have the same processing scheme)

3.2 Digital Beamforming Scheme

The basic digital baseband I and Q signals need to be synthesized into complex baseband signals in digital processing. As shown in Fig. 7, the y-polarized signal digitally forms two beams, and the x-polarized and z-polarized beams form four beams, respectively.

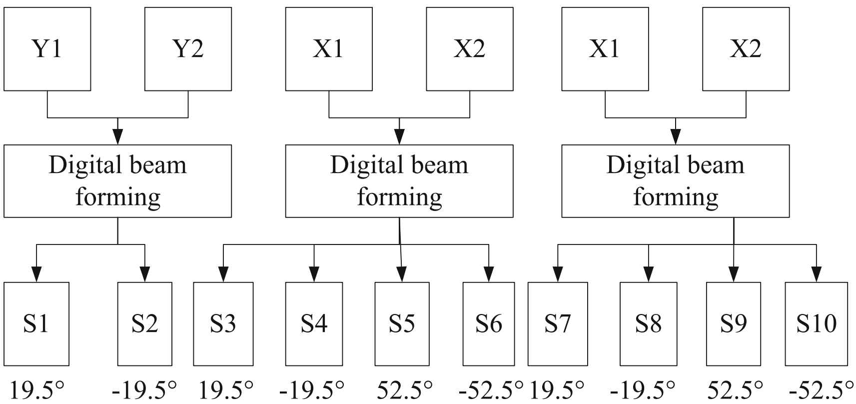

Fig. 7. Beam forming structure diagram

3.3 Multiuser Signal Detection

Due to the Doppler shift and multi-user signals, the bandwidth of each beam signal exceeds the bandwidth of a single user without frequency offset signal, which is close to 8 kHz, which brings great difficulties to frequency offset estimation and ship information detection. The mixed signal in the wideband can be divided into several narrow band signals by frequency diversity method, which can reduce the dynamic range of the frequency offset estimation parameters, improve the estimation accuracy, reduce the number of multi-user signals, and improve the detection rate of ship information. Frequency diversity is realized by band-pass filters. The frequency division parameter estimation and signal detection structure based on the band filter are shown in Fig. 8

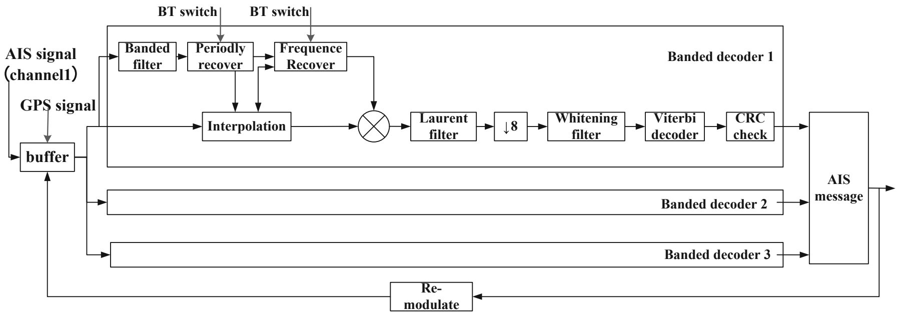

Fig. 8. Block diagram of demodulation based on frequency diversity method (single channel)

4 Conclusion

The research and application of spaceborne AIS has been developing abroad for many years. With the development of China's shipping industry, the number of ships on the sea has increased and maritime traffic has become increasingly crowded. Although China has established a relatively complete shore based universal AIS system, and has also established a corresponding network in some inland rivers, its monitoring range is very small. It can only monitor ships near the coast (not exceeding 100 km). Receiving AIS signal through satellite can get the information of ship navigation in the world, and carry out safety monitoring for our ships, so as to better serve China's maritime safety, economic development and national defense construction. Satellite-borne AIS system has a wide range of application prospects in the areas of commercial vessel route tracking, dangerous cargo supervision, fishing vessel monitoring, anti-piracy and so on.

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