Overview of Chinese First C Band Multi-Polarization SAR Satellite GF-3

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Abstract: The GF-3 satellite, the first C band and multi-polarization Synthetic Aperture Radar (SAR) satellite in China, achieved breakthroughs in a number of key technologies such as multi-polarization and the design of a multi-imaging mode, a multi-polarization phased array SAR antenna, and in internal calibration technology. The satellite technology adopted the principle of "Demand Pulls, Technology Pushes", creating a series of innovation firsts, reaching or surpassing the technical specifications of an international level.

Key words: GF-3 satellite, system design, application

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1 INTRODUCTION

The GF-3 satellite, the only microwave remote sensing imaging satellite of major event in the National High Resolution Earth Observation System, is the first C band multi-polarization and high resolution synthetic aperture radar (SAR) in China. The GF-3 satellite has the characteristics of high resolution, wide swath, high radiation precision, multi-imaging modes, long design life, and it can acquire global land and ocean information under all-weather conditions and all day long. The C band multi-polarization microwave remote sensing information can be used in many fields such as oceanography, disaster reduction, water conservancy and meteorology, providing important technical support for marine development, land environment monitoring and disaster prevention and mitigation[1].

As China's first C band multi-polarization SAR satellite, the GF-3 satellite has achieved the integration of design technology covering: mechanical; electrical and thermal; multi-polarization phased array antenna technology; high precision SAR internal calibration technique; deployable mechanism for a large phased array SAR antenna; thermal control technology of SAR antenna; pulsed high power supply technology and satellite control technology with star trackers. The GF-3 satellite has the following characteristics:

1) 12 imaging modes–the GF-3 satellite has the most SAR imaging modes in the world and is the first multi-polarization SAR satellite in China;
2) SAR antenna flatness is better than 5 mm, and the whole array temperature uniformity is better than 7 degrees centigrade, which is achieved through the SAR antenna assembly and thermal control design;
3) The maximum peak power is 15360 W, and the maximum average power consumption is 8000 W, thus the power supply capability can meet the demand for high

power pulse operation;

4) The satellite has high attitude control accuracy and stability, and has the capability of continuous two-dimensional attitude steering;
5) The satellite adopts an independent health management mechanism to reduce the risk of satellite failure;
6) The satellite adopts grid connected control technology, and can revert the payload high voltage bus to 28 V for the platform under an emergency condition to enhance the reliability and safety of the satellite;
7) It is the first remote sensing satellite with a design life of 8 years in China.

In this paper, the overall design of the satellite system and key satellite technology innovations are summarized.

2 SATELLITE SYSTEM OVERALL DESIGN

2.1 Satellite Observation Mission

In China, the demand for spaceborne SAR remote sensing data is very urgent, and considerable amount of spaceborne SAR image data has been imported in fields such as resource investigation and disaster rescue, as there was no civilian SAR remote sensing satellite in orbit in China. Therefore, there has been an internal demand in a number of application areas for the construction of civil SAR satellites in China. The detailed requirements are shown in Table 1.

In order to realize the observation requirements of many users, the GF-3 satellite has 12 imaging modes, such as stripmap, spotlight and scan (shown in Table 2), with the capability

Table 1 Users' requirement of GF-3 satellite

Main user	Observation target and application
Maritime	Sea wave, sea surface wind field, internal wave, frontal surface, shallow sea topography, sea surface oil spill, sea ice, green tide, coastal zone and sea surface targets
Disaster reduction	Flood submerged area, debris flow, landslide, ice or snow, extent of sea ice, drought scope, buildings, temporary housing, traffic, agricultural and land use, flood control facilities
Water conservancy	Characteristics of river basin systems, surface water distribution, flood range, soil moisture content, land use and vegetation coverage. Surface water indicators, lakes, reservoirs (dams), rivers, wetlands, glaciers, snow, other important water sources, irrigation areas, groundwater remote sensing monitoring indicators, karst, phreatic water, springs, geological landforms, etc.
Meteorology	High resolution regional surface soil moisture monitoring, rainstorm triggered landslides and debris flow and other geological disaster prediction and warning

Table 2 The main technical specifications for each imaging mode

Imaging mode		Resolution (m)	Swath (km)	Incident Angle (°)	Polarization
Spotlight		1	10×10	20 - 50	Single
Ultra-fine stripmap		3	30	20 - 50	Single
Fine stripmap 1		5	50	19 - 50	Dual
Fine stripmap 2		10	100	19 - 50	Dual
Standard stripmap		25	130	17 - 50	Dual
Narrow scan		50	300	17 - 50	Dual
Wide scan		100	500	17 - 50	Dual
Full polarization 1		8	30	20 - 41	Full
Full polarization 2		25	40	20 - 38	Full
Wave		10	5×5	20 - 41	Full
Global		500	650	17 - 53	Dual
Extended incidence angle	Low	25	130	10 - 20	Dual
	High	25	80	50 - 60	Dual

of 1 - 500 m resolution and 10 - 650 km swath.

2.2 Satellite System Design

The GF-3 satellite is a three-axis stabilized Earth observation satellite, with a launch weight of about 2779 kg, and a design life of 8 years. The satellite works in an orbit altitude of about 755 km in a sun synchronous orbit in a side looking attitude.

The GF-3 satellite is based on the ZY1000B platform and consists of two parts: payload and service system. The payload consists of the SAR load, data transmission system, data transmission antenna system. The service system provides power supply, installation, maintenance and test temperature, including a power supply, attitude control, propulsion, monitoring and control, data management, structure and thermal control system[2].

GF-3 satellite payload has many characteristics, such as multi-polarization and multi-modes, high resolution with wide swath, large size of antenna, high power consumption, high radiation resolution, long imaging time, plus both internal and external calibration functions. The system has 12 imaging modes including spotlight, stripmap, scan, and dual aperture. The longest continuous working time is 50 minutes. It can obtain C band polarimetric SAR images with a resolution of 1 - 500 m, swath of 10 - 650 km. The radiometric resolution is better than 2 dB, with a radiometric accuracy of up to 1 dB. The system is configured with a 15 m x 1.232 m, four polarized waveguide slot phased array SAR antenna, which is composed of the waveguide slot antenna, four channel T/R module, delay wave control unit, RF transceiver and calibration for the feed network, power, a high frequency cable network, structural framework, deployment mechanism and thermal control etc.. The antenna can flexibly shape, scan and broaden the two-dimensional beam. It has the characteristics of high polarization isolation, flexible aperture configuration, high power consumption, light weight etc..

The satellite adopts a three-axis stabilized ground directional control mode, the pointing accuracy is better than 0.03°, the stability is better than 5×10^{-4}°/s, and has $\pm31.5°$ roll maneuver capability. The satellite using a dual independent bus power configuration, a three-junction GaAs solar cell array, a 100 Ah NiCd battery and a 225 Ah lithium-ion battery, can meet the demand of the satellite imaging requiring nearly a million kilowatts of power. When the output power of the platform bus is not enough or the bus output is abnormal, the payload high voltage power supply can be converted into a low voltage power supply through a grid controller and be used for the platform equipment. The satellite has an autonomous health management system, which can continuous monitor critical events, evaluate the product status and take a variety of effective measures in advance to ensure satellite safety in orbit[3].

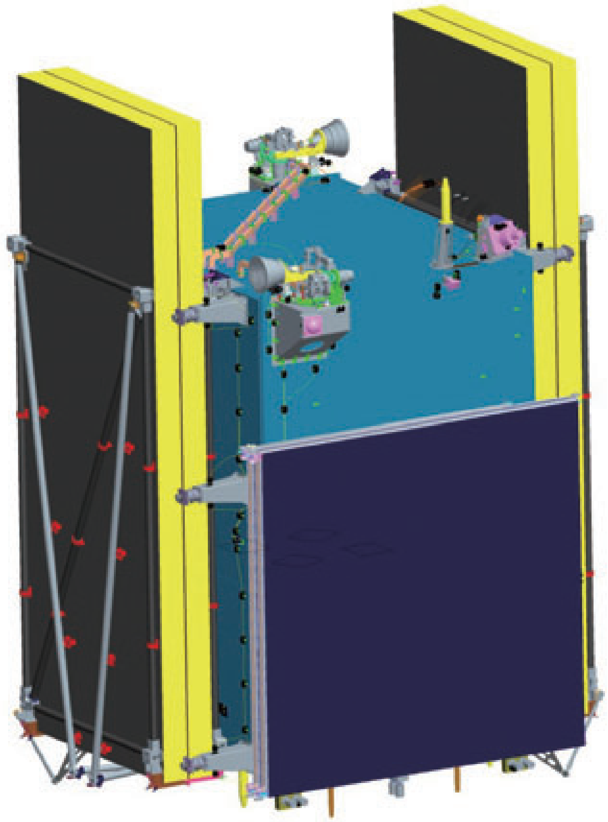

Figure 1 Attitude of the GF-3 satellite before launching

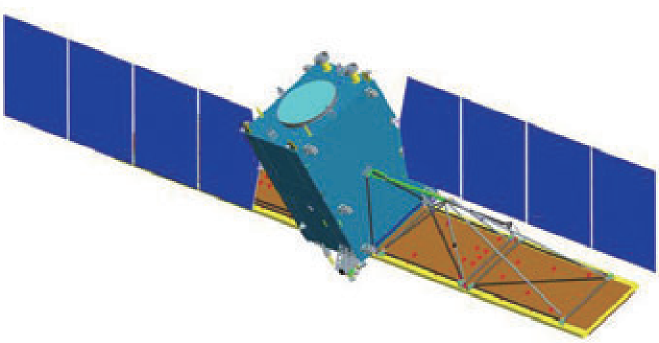

Figure 2 Attitude of GF-3 with right sidelook in orbit

3 SATELLITE TECHNOLOGY FEATURES

3.1 Multi-Polarization and Multi-Imaging Mode Design

The GF-3 satellite has 12 imaging modes, including spotlight, stripmap and scan, with four polarization capability. In order to realize multi-polarization and multi-imaging modes, the following design ideas were adopted:

1) Multi-polarization data is obtained by using polarization time division and a positive and negative frequency modulation slope, so as to improve the ambiguity of point targets.
2) Active phased array antenna is used to realize flexible control of imaging modes and flexible switching of wave positions. Using a waveguide slot antenna, H polarization waveguide and V polarization waveguide are designed respectively, which can effectively reduce the mutual coupling between the two antennas, improve the port isolation of the antenna, and then improve the polarization isolation of the antenna.
3) The system has a variety of LFM signal bandwidth and time width combinations. The 12 kinds of imaging modes correspond to 18 kinds of LFM signals, with different filters used in the signal path to ensure that different bandwidth signals are suppressed.
4) To achieve multi-beam and multi-polarization, the SAR has dual receiving channels. In order to ensure the consistency of amplitude and phase in dual channels, a digital receiver scheme using intermediate frequency sampling is proposed.
5) In order to achieve dual-aperture and multi-polarization modes, a receive switching matrix is used to switch the received echo signals of different apertures of the antenna to form two receiving channels[4].

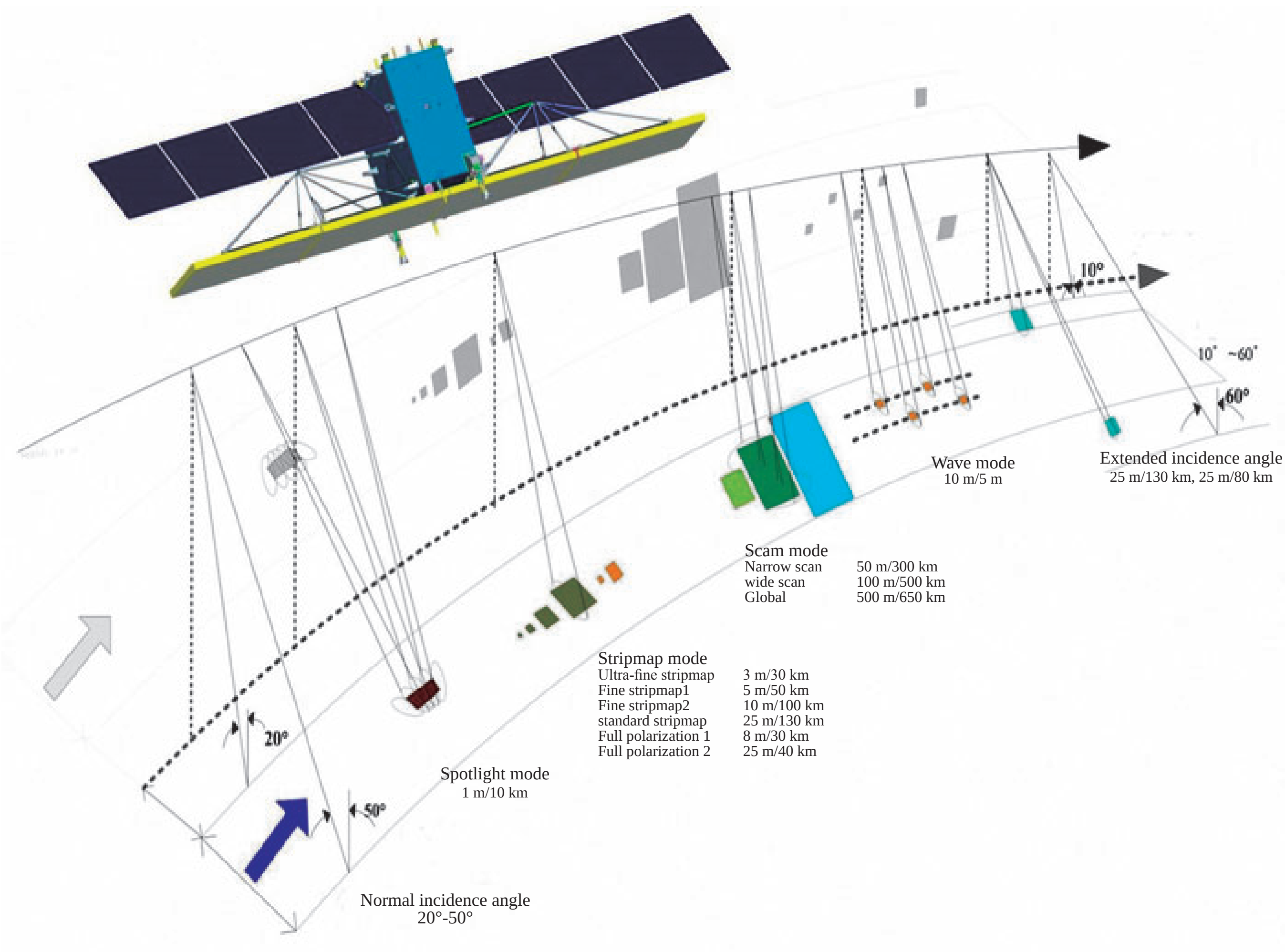

Figure 3 GF-3 satellite imaging modes

3.2 Multi-Polarization Phased Array SAR Antenna

GF-3 SAR satellite antenna with multi-polarization and multi-imaging modes using the two-dimensional scanning active phased array antenna system, can realize spotlight, stripmap, scan and other imaging modes. The antenna works in C band, has multi-polarization and provides multi-operation modes, adopting an expanded plane two-dimensional scanning active phased array antenna system. In transmit mode, the transmit link amplifies the power of the input chirp signal and radiates electromagnetic energy to the specified space. In the receiving mode, the antenna array receives horizontal or vertical polarization echo signals, and simultaneously receives dual polarized echo signals also, which are sent to the SAR central electronic equipment via a low-noise amplification link[5]. In order to realize the antenna performance detection, fault detection and isolation, the antenna can be calibrated under the control of the central electronic device. Antenna with multi-polarization, high polarization isolation, and the massive shaped beam function has a peak output power of 15360 W, using a mechanical lightweight T/R module and thin wall waveguide design technology. The antenna deployment mechanism satisfies the functions of folding, unfolding and supporting the antenna array. The array thermal control realizes the temperature control function for the SAR antenna array surface, meeting the requirement of the use of each single electric single equipment, and guarantees the service life of the electric equipment.

The antenna is optimized on the basis of a traditional SAR satellite antenna design, and has main features as follows:

1) High polarization isolation. Through the isolation of the antenna unit, the T/R module channel and the electromagnetic shielding of the cable, the antenna can simultaneously receive dual polarization (H/V) signals with a higher polarization isolation (>35 dB).
2) High energy utilization efficiency and thermal control accuracy. By ensuring the higher power efficiency, improving the radiation efficiency of microwave devices, and considering the thermal control of the antenna array simultaneously, the antenna works within a reasonable temperature range to ensure the stability of the beam pointing.
3) High precision control of the two dimensional beam. The amplitude and phase stability of the transceiver channel, the speed of the beam switching response, and the reliability of the dual-polarization beam control are designed to meet the requirements of the 12 modes and achieve flexible beam scanning and shaping.
4) Lightweight. The antenna is lightweight mainly through two approaches: one is the overall reasonable scheme during the antenna selection, reducing the amount of hardware and interconnect complexity; the other is to improve the design and technology level, increasing the intensity of integrated design.

3.3 Internal Calibration of SAR System

In order to realize the high-precision and quantitative application requirements for imaging data, an on-board calibration function was fully considered. A number of calibration loops were designed to cover the whole receiving and transmitting link and have the capability of polarization calibration.

The SAR system has the capability of single polarization and multi polarization calibration. Through calibration, real linear FM signal, system gain calibration, antenna pattern and gain can be obtained[6].

The array calibration can be divided into full array calibration and single T/R module calibration. For full range calibration, the T/R modules work simultaneously to scale full array transmit power and full array receive gain scaling; single component calibration is to monitor the RF characteristics of each T/R module. In addition, the thermal noise of the whole system can be recorded when the whole array T/R module is in its high impedance state.

The calibration circuit includes: non-delay calibration, delay reference calibration, drive amplification calibration, full array/single T/R emission calibration, full array/single T/R receiving calibration, full array transmiting receiving calibration, and noise calibration. Through the six calibration loop and the noise recording mode, the SAR system can calibrate the real chirp signal, the system gain, the antenna pattern and gain, the phase shifter, the attenuator and the network delay line component.

3.4 Thermal Control Design of SAR Antenna

SAR antenna thermal control, in addition to the embedded heat pipe network, opening the radiating surface and coating multilayer insulation materials and other conventional means, has also taken the advantage to control the temperature and heat during the temperature control design, by enabling a good thermal environment on orbit during the period of SAR antenna operation. SAR antenna temperature is maintained at -10°C-+25°C, with a single module within 2.5°C, and a full array of temperature gradient of less than 5.9°C.

The purpose of active temperature control is to ensure that the temperature of the antenna and its equipment is not too low while maintaining the temperature consistency when the antenna is not operating for a long time. The thermal tracking temperature control technology realizes tracking temperature control by using the heating power of active temperature control, and ensures the temperature gradient of each array of the SAR antenna to meet the requirements. The temperature control equipment acquisition installation plate full array temperature reference point temperature value, through the mounting plate used for reference temperature comparison, measures the highest temperature value and the temperature value compared with the target temperature and other temperature control loops, enabling closed loop control.

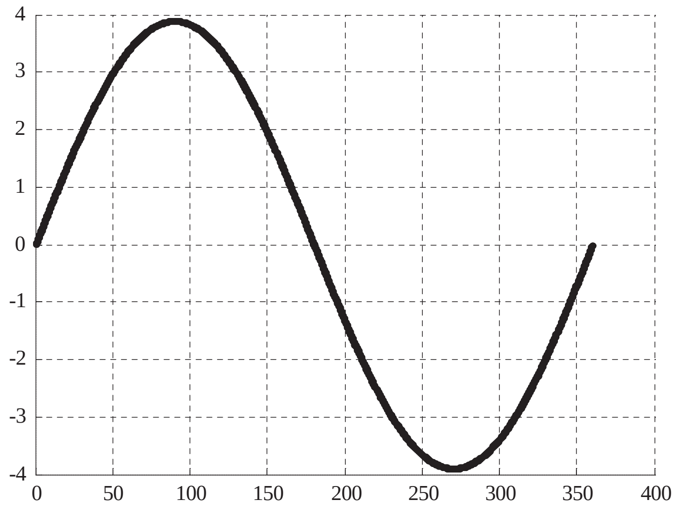

Figure 4 Curve of yawing steering

3.5 High Precision Two-dimensional Attitude Steering

The satellite has the requirement for attitude steering in both left and right flight conditions. The attitude of steering is designed to eliminate the Doppler center frequency changes caused by ellipticity over the Earth orbit, the Earth rotation and oblateness. According to the look angle and the orbit, the attitude steering angle of the target is calculated. The formula of yaw steering is:

$$\psi = \arctan\left(\frac{\sin i \cos u}{N - \cos i}\right)$$

In the formula, i is the orbital inclination, u is the satellite latitude, and N is the number of satellite regression times per day. This formula is applicable to a spherical Earth model. Under the ellipsoid earth model, this angle has a slight deviation from the actual angle. The yaw control curve within a circle obeys the cosine law and the maximum is 3.8928 degrees. On the basis of yaw steering, pitching steering can be used to correct the difference of pitching attitude, and the formula for pitching angle is:

$$\gamma = \arccos\left(\frac{1 + e\cos\theta}{1 + e^2 + 2e\cos\theta}\right)$$

Among them, e is orbital eccentricity, θ is true near heart angle. The pitch control curve of one rail obeys the cosine law, and the maximum is 0.0659 degrees.

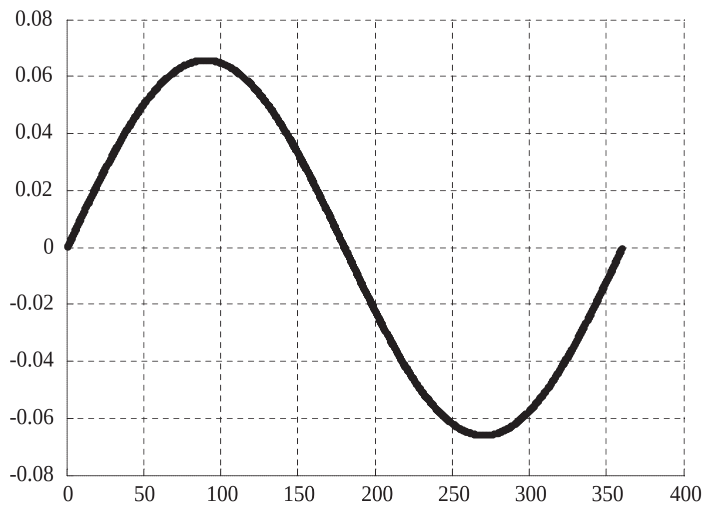

Figure 5 Curve of pitching steering

3.6 Grid Connected Control Technology

The satellite power system adopts a two-bus power supply system, one for platform and the other for SAR payload. The two buses are independent of each other and do not interfere with each other. The two buses are in a single spot at the whole star. The platform bus system adopts the S4R two domain control, the full adjustment bus, and the T/R bus adopts the non regulating bus.

In order to improve the safety of satellite power supply, when the platform bus battery fails, the payload bus can switch from the 45 V - 67.5 V into the platform required 28 V through a DC/DC converter, and supply the platform service system with power.

3.7 Autonomous Health Management

At present, Chinese remote sensing satellite orbit management is inseparable from the support of the ground TM&TC

Table 3 Characteristics comparison of SAR payload between GF-3 satellite and foreign satellites

Item	GF-3	Sentinel-1	Radarsat-2
Orbit	Sun-synchronous orbit	Sun-synchronous orbit	Sun-synchronous orbit
Orbit altitude	755 km	693 km	798 km
Band	C	C	C
Satellite weight	2779 kg	2300 kg	2300 kg
Peak power	1.5 kW	4700 W	1.27 kW
Incidence angle	10° - 60°	20° - 45°	20°- 60°
Antenna area	15 m×1.5 m	12.3 m×0.84 m	15 m×1.37 m
Signal bandwidth	0-240 MHz	0 - 100 MHz	0 - 100 MHz
Polarization	Single/Dual/Full	Single/Dual	Single/Dual/Full
Antenna system	Waveguide slot	Waveguide crack	Microstrip
Angle of elevation	±20°	±11°	±20°
Imaging mode	12	4	10
Resolution	1-500 m	5 - 20 m	1-100 m
Swath	10-650 km	20-400 km	20-500 km
Life	8 years	7.25 years	7.25 years

stations. However, it is impossible for the Earth stations to track satellites in real time and not be able to take corrective actions in time. This requires the satellite to have an independent fault diagnosis and recovery function, to ensure a non-proliferation failure, hence obtain the best opportunity to deal with, and improve the satellite's viability in orbit.

The GF-3 satellite features a self health management strategy, health index, satellite real-time intelligent servo control, satellite autonomous grid control and dual frequency GPS receiver autonomous monitoring and recovery, abnormal SAR independent management and a further 18 innovative measures. On-orbit testing showed that the sensitivity and the health of the satellite fault recovery time has been significantly improved, and the system can master in real-time the satellite health status, initiate the safety management strategy, enabling the fault processing time reduced from 190 minutes to less than 10 seconds.

3.8 Precise Orbit Determination

In order to satisfy the SAR imaging accuracy requirements, real-time orbit determination accuracy of the satellite must be better than 10 m (1 sigma), and the precision of post event processing is better than 20 cm (1 sigma). Therefore, the GF-3 satellite adopts a dual frequency GPS system to realize precise orbit determination. The dual frequency GPS system consists of one dual frequency GPS antenna, one dual frequency GPS receiver and one pre-amplifier. Based on the GPS antenna optimization design, this reduces the impact on the antenna performance of satellite cabin, and improves the stability of antenna phase center. In the post event precise orbit determination, an orbit determination accuracy of 4 cm is realized by using a high-precision dynamic model combined with the original observations.

3.9 Summary

Based on the SAR payload and the basic configuration of the system, research has been carried out on the GF-3 satellite on the match between the platform and SAR payload, deducing a series of satellite characteristics and technology innovation. The main technical indicators have reached or exceeded those of a level similar to international satellites, as shown in Table 3.

4 APPLICATION

Since August 10, 2016, the GF-3 satellite has acquired

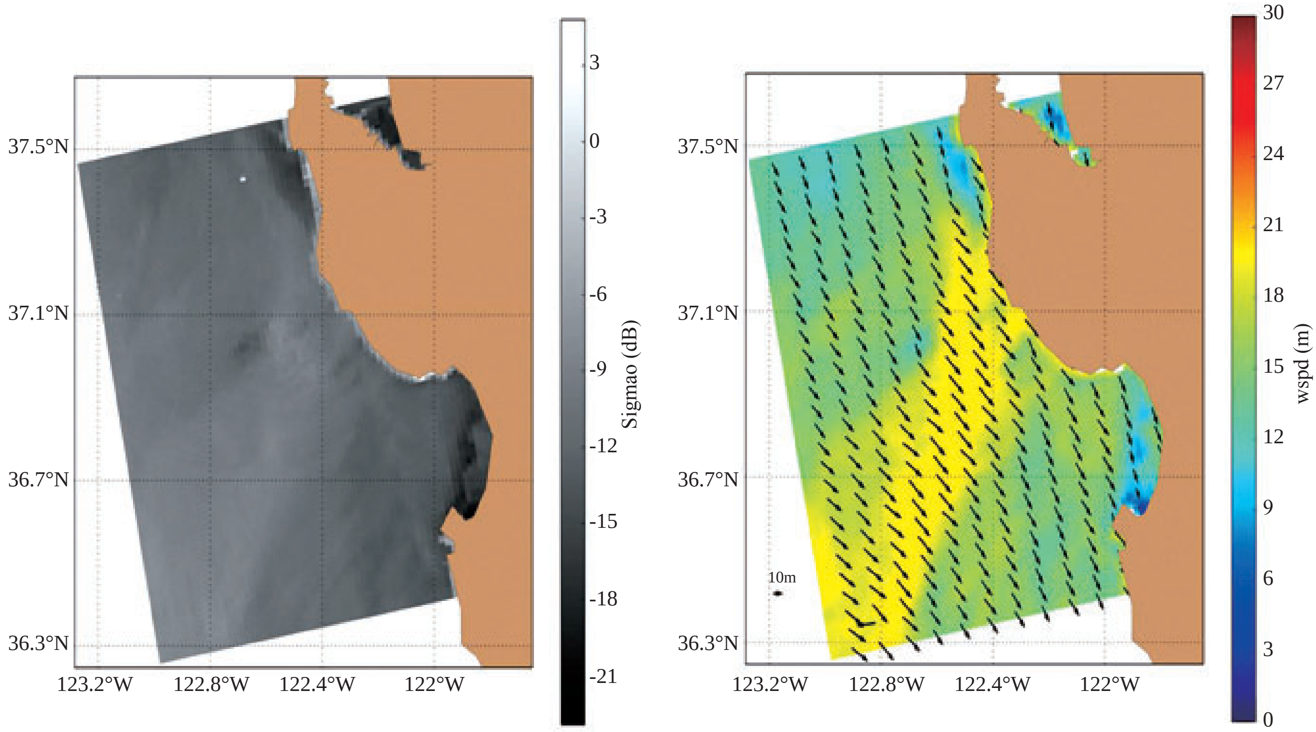

Figure 6 Sea surface wind field thematic map of standard strip mode

nearly 200 thousand scene images, provided a large number of image data for the State Oceanic Administration, the Ministry of Civil Affairs, Ministry of Water Resources, Meteorological Bureau, State Administration of Science, Technology and Industry for National Defence, and the national security departments and other users. The GF-3 satellite has obtained major global ocean wind field and wave field information, especially after the implementation monitoring and forecasting on typhoon "Tiange". Combining the GF-3 satellite, HY-2 satellite and GF-4 satellite, China has greatly improved its capability of marine surveillance, monitoring and typhoon warning.

In 2017, the GF-3 satellite obtained high precision images of Sichuan landslide, Jiuzhaigou earthquake and southern China heavy rainfall for the first time, providing important information guaranteeing the implementation of disaster rescue and disaster assessment.

The GF-3 satellite has also carried out the verification work in orbit of various new systems and new technology which are 0.5 m resolution images (range direction), through differential interferometry for deformation monitoring of ground centimeter, ground moving target detection.

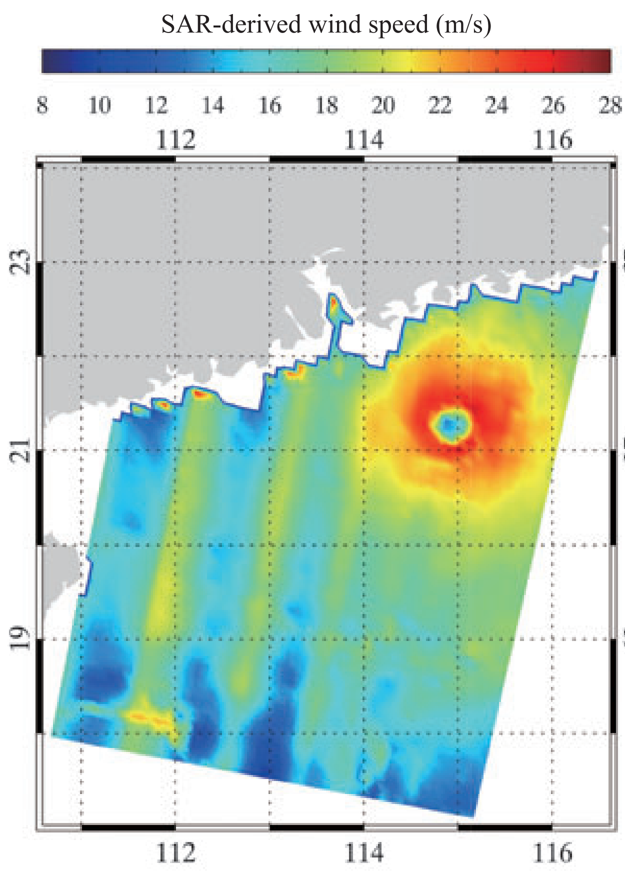

Figure 7 GF-3 satellite "Tiange" typhoon monitoring result

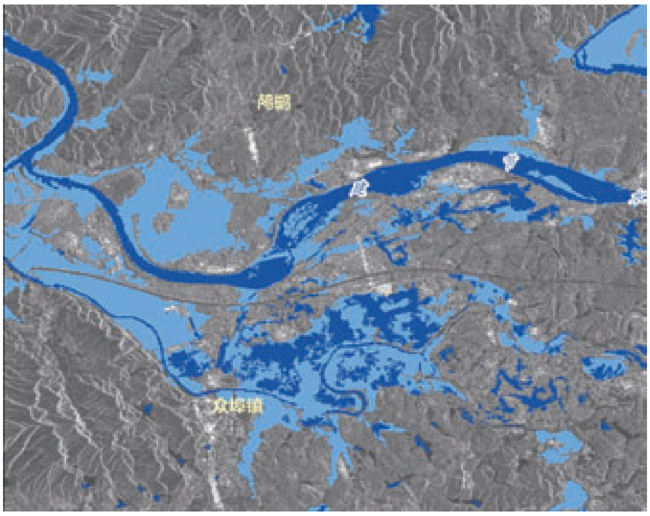

Figure 8 GF-3 satellite monitoring results of flood disaster in Jiangxi in 2017

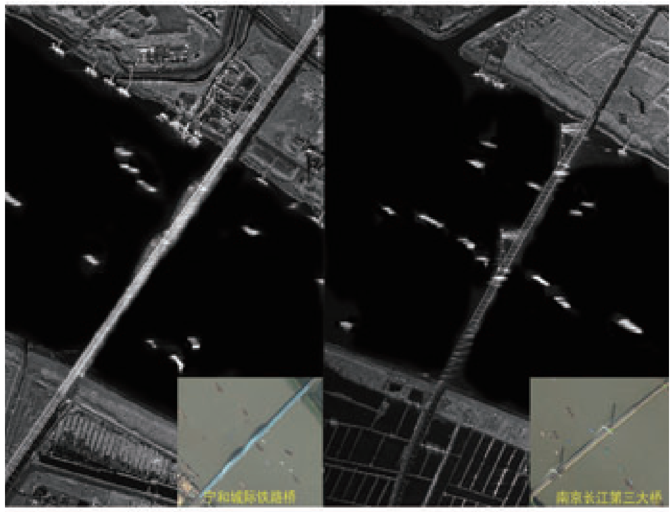

Figure 9 GF-3 satellite 0.5 m resolution imaging mode

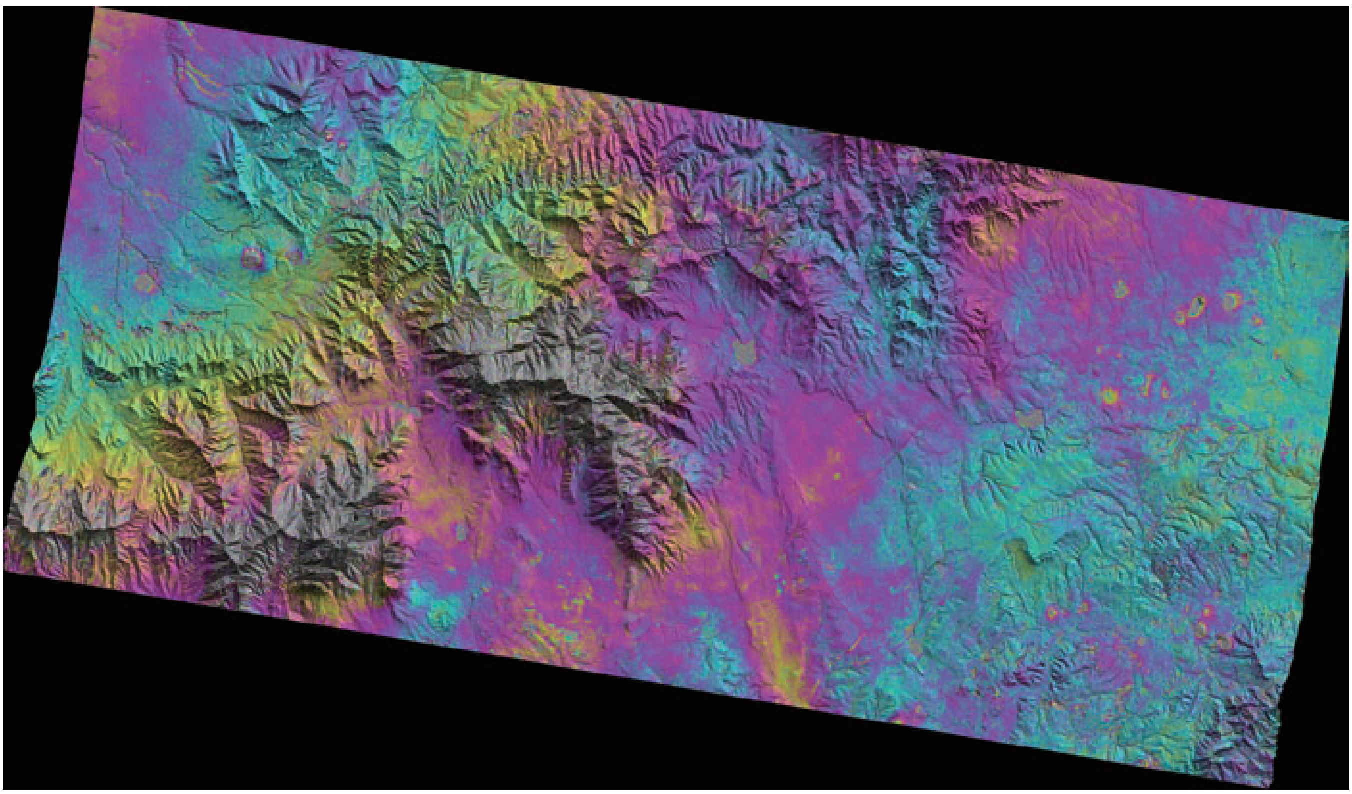

Figure 10 GF-3 satellite differential interference phase diagram in Songshan area (10 m grid)

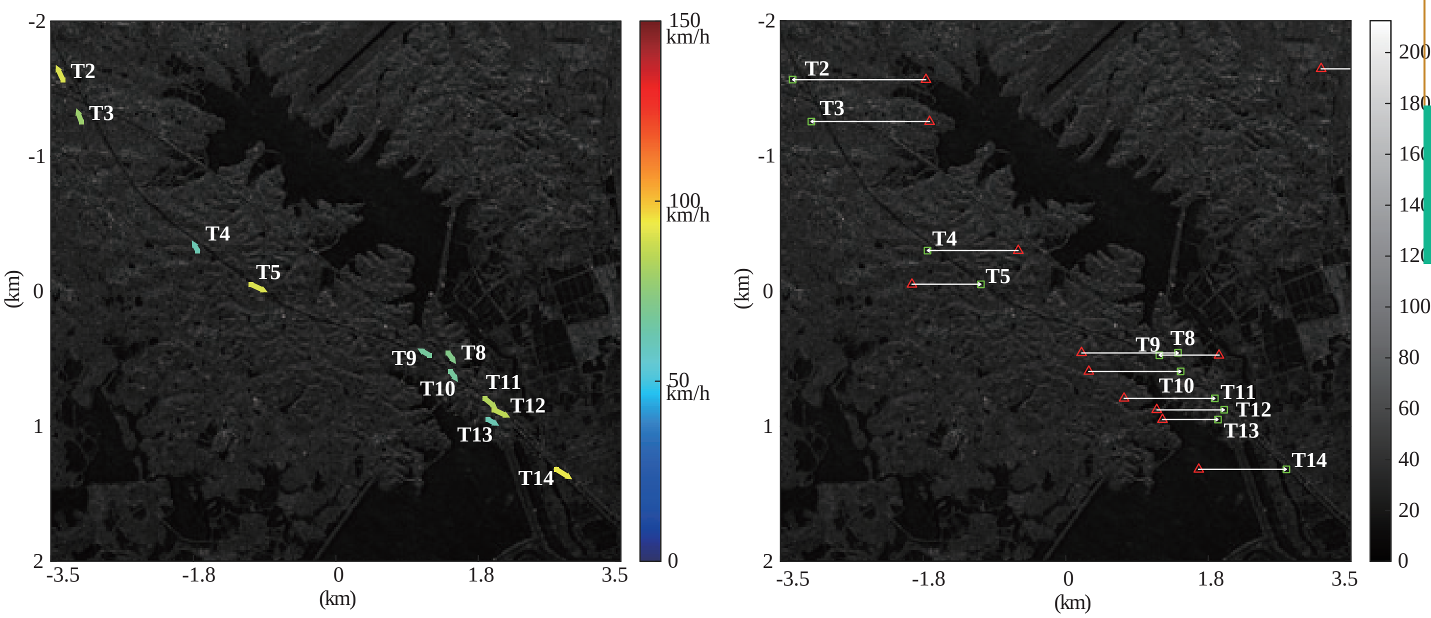

Figure 11 GF-3 satellite moving target detection and reposition results

5 CONCLUSIONS

The GF-3 satellite has successfully obtained high resolution multi-polarization microwave images, greatly changing the situation in the past when Chinese civilian high resolution SAR images all relied on imports, providing high quality and precision Earth observation data for domestic users in various industries. The development of the GF-3 satellite project will play an important exemplary role in guiding the application of civil high resolution microwave satellite remote sensing in China. Its development and application are of great significance. According to the "Chinese national spatial infrastructures programme", there will be three satellites, the GF-3 satellite and two follow-on satellites in orbit in 2020, which will further support and promote the construction and development of the civil military integration of space-based information systems, while becoming an important technical support tool for the implementation of marine development, China land resources and environment monitoring and disaster prevention and mitigation.

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