Design on Universal Flight Test Platform for Aerospace Components

Hongwei Zhang, Aibin Xiao, Zhe Wang, Hui Liu and Zhichao Wei
China Academy of Space Technology, Beijing, 100094, China
penguindoudou@163.com

Abstract. In view of the current problems such as immethodical in-orbit testing and verification of components, and complex and diversified methods of development of test verification devices and in-orbit testing of components, the paper proposes a systematic design scheme for a universal flight verification platform for components. The paper elaborates on the demand analysis, functional module division, in-orbit test methods, etc. with regard to the platform, analyzes the platform's advantages in carrying out in-orbit tests to different types of components, and realizes the generalization, standardization and modularization of the flight test platform.

1. Introduction
Currently, independent development capabilities are needed for China's aerospace industry, so localization requirements have been proposed for key components of aerospace models. As an important link of the development and application of newly developed components, flight test of components plays an important role in obtaining reliability data of components in the space environment and evaluating the aerospace applicability of components [1]. China has already carried out flight-carrying tests of various components through test satellites and found problems in the aerospace applicability of more than 10 domestic component products, including FPGA and CPU. However, former flight tests of components were mostly carried out on the spacecraft electronics, and the functional performance parameters obtained in the in-orbit tests were generally at the electronic level. Such flight test mode requires corresponding functional circuits developed according to different components to be tested and features problems such as long development cycle of functional circuits, few types of test components, and inability to manifest the degradation of key component parameters in detail.

This paper describes a systematic design scheme of a universal flight test platform for components, and provides the in-orbit test methods of typical aerospace components, which is of great significance in improving the flight-carrying opportunities of components, shortening the development cycle, and improving the quality of the test [2], and can provide support for the subsequent establishment of a complete component flight test database.

2. Demand analysis of in-orbit tests of components
The in-orbit flight test of components should fully cover the working status, functional correctness, key application feature parameters, and space environment effect of components; the flight tests of components need to be carried out according to the specific application conditions of the components and in-orbit tests for different key parameters should be conducted to ensure the comprehensiveness, validity and correctness of the monitoring data. Based on the experience of the previous flight-
carrying test with test satellite, the component test circuit is analyzed, and the component under test can be classified into the following four categories:

1) DC/DC, operational amplifier, voltage reference and other power supplies or analog devices require external power supply or analog signal source and peripheral auxiliary devices to form a typical application circuit to achieve the test task. The main measurement signals are the analog quantity signals input and output by the device.

2) Digital devices, such as memories, bus controllers and reset circuits, need to be equipped with processors to build typical application circuits. The processors provide address/data buses for the devices and run the inherent functions of the components and determine the functional status of the devices through the test cases run by them. The main measurement signals are the functional status and key waveform parameters of the devices [3].

3) FPGA, DSP, SoC, SiP and other signal processing devices need to build a minimum system based on the devices’ own resources and interfaces. The functional status of the devices should be verified through built-in self-test (BIST). The main measurement signals are the devices’ functional status, matching of external interfaces and key waveform parameters.

4) A/D, D/A and other digital-analog hybrid devices need to be equipped with a processor and an analog signal source to build a typical application circuit. The processor controls the component under test to complete the test of typical application functions. The main measurement signal is the functional status of the device and key waveform parameters.

5) The paper selects DC/DC and FPGA as examples among the above four types of devices, and analyzes the in-orbit flight test parameters of the components. The analysis results are shown in Table 1.

| Device name | Test parameters | Test methods |
|-------------|-----------------|--------------|
| DC/DC       | Input voltage and current | The analog quantity of the input voltage and current under the working conditions of the DC/DC is obtained with the Hall device and the resistance voltage divider, to conduct A/D acquisition |
|             | Output voltage and current | The analog quantity of the output voltage and current under the working conditions of the DC/DC is obtained with the Hall device and the resistance voltage divider, to conduct A/D acquisition |
|             | Conversion efficiency | The percentages of input and output power |
|             | Output ripple & noise | The AC voltage component in the output voltage of the DC/DC module can be obtained through the waveform recorded based on A/D acquisition |
| FPGA        | Working voltage and current | Test the working current of FPGA under two conditions: the static working condition under which no function is configured after the circuit is powered on; the dynamic working current under the condition that 70% resources are run after the function is configured |
|             | Logic resource monitoring | Based on the built-in self-test (BIST) method, using internal FPGA resources to build a test pattern generator (TPG) and output response analyzer (ORA) to determine the internal faults of the FPGA through the state variables output by the ORA |
|             | Clock monitoring | Lead the clock inside the FPGA to the I/O port, and record the waveform of the clock through intervention test |
|             | Space environment effect | Record the total number of single event upsets through SMAP readback, timed reading and writing configuration memory |
According to the analysis in the above table, the in-orbit test parameters of different types of components can be divided into three types: DC analog quantity, AC waveform and digital state variables. For example, the working voltage, working current, device case temperature, etc. are DC analog quantity parameters; output ripple, working frequency, conversion delay, etc. are waveform parameters; logic resource status, device-level single event upsets, etc. are state parameters. The flight test platform described herein will design a standardized measurement module according to the type of test parameters to detect the component under test [4].

3. Design principles of the test platform
The in-orbit flight test platform for components is designed based on the principles of generalization, standardization and modularization, with the purpose to build a universal in-orbit detection system to provide a technical basis for subsequent implementation of in-orbit flight verification tasks in batches. The scheme design is realized based on the following principles:

1) The system adopts the design philosophy of modularization, and divides the in-orbit flight verification system into two parts: the flight test platform and the test module. The flight test platform is divided into three modules according to functions, including the public support unit, the measurement unit, and the space environment monitoring unit, to reduce functional coupling between modules, and simplify the functional interfaces between modules.

2) The interfaces between all functional modules of the system adopt the standardized interfaces commonly used in aerospace. The system modules feature integrated design, and the functional modules can be increased or decreased according to the test requirements, which improves the flexibility and replaceability of the system [5].

3) The in-orbit reconfiguration of test cases is achieved through the application of in-orbit excitation and software control, which improves the configurability of the flight test platform and supports simultaneous in-orbit tests of multiple types of components.

4) The system has certain redundancy measures and takes necessary interface protection measures to prevent system-level functional failure caused by errors of unit module.

4. Design of the universal verification platform
The flight test platform is divided into three modules according to functions: the public support unit, measurement unit and space environment monitoring unit, and specific information is shown in Figure 1.

Figure 1. Schematic diagram for the composition of the universal flight test platform for components.
4.1. The public support unit

Main functions of the public support unit: to achieve comprehensive management of each test module and functional unit, and provide data transmission interfaces, general power supply interfaces, and control command interfaces; to be responsible for the storage and transmission of test data, and achieve in-orbit software reconfiguration by reading the test software package of the test module; to realize the automatic isolation function of the faulty component under test through the status monitoring and power on/off control of the test module; the public support unit is composed of four parts: comprehensive management module, data storage module, power supply and distribution module, and interface module. Its internal connections and external interfaces are shown in Figure 2.

![Block diagram for the internal structure of the public support unit.](image)

The public support unit is the core management unit of the universal flight test platform and is responsible for the management of other functional units. The specific implementation is as follows:

1) Autonomous management: The processors in the comprehensive management module adopt a redundant backup design, and are designed with an autonomous fault-tolerant circuit. The autonomous fault-tolerant circuit monitors the state of the processor. When the host fails, the host will be automatically shut down and the backup processor will be started; The comprehensive management module implements power on/off management for other functional units by monitoring the status of other functional units.

2) Autonomous monitoring of the working temperature: paste thermocouples in the measurement equipment area, and the comprehensive management module collects and interprets the ambient temperature signal of the measurement equipment. When the temperature exceeds the allowable range of the measurement equipment, the automatic test and health monitoring unit will be notified to compensate the errors of measured data.

3) In-orbit reconfiguration of software: The test requirements of different test modules will be different. The test information program can be uploaded on the test module on the ground. The public
support unit will automatically load the test information program and notify the automatic health monitoring unit to change the test channel and switch the test cases.

4) Autonomous health management: The comprehensive management module periodically obtains the status parameters of each function and performs fault detection after data processing. After judging that the fault occurs, the comprehensive management module will integrates the current status information and the stored status information for fault diagnosis. After fault location, the comprehensive management module will carry out different levels of disposal strategies such as redundant switching, function replacement, or degraded operation according to the established countermeasures.

5) Data management: The comprehensive management module receives the test information data, the health status data of the component under test and the environmental monitoring data for local storage, and stores the data in the data storage module according to the unified time information. The data storage module consists of the data storage array. With large-capacity storage capacity.

4.2. **Automatic measurement unit**

Main functions of the automatic test unit: to realize the measurement of the key status parameters of the component under test; to generate digital and analog signal excitation; to realize the automatic test of the device by controlling the conversion of the measurement channel; the specific test design is as follows:

1) Weak signal acquisition: Due to the wide range and strong interference of the signal under test, to ensure the accuracy of the measurement, the signal conditioning circuit is designed at the front end of the automatic test and health status monitoring unit, which is responsible for balancing the signal bandwidth and filtering noise, and performing multi-stage amplification on weak signals, to filter, shape, and amplify the signal under test, so that the signal under test meets the requirements of the post-level acquisition [6].

2) In-orbit self-calibration of the measurement reference: a highly stable reference is the basis of the measurement accuracy, select a reference voltage source that meets the accuracy requirements, and design a negative feedback circuit to control the accuracy of the reference source.

3) Signal isolation design: In order to ensure that the component under test will not be damaged due to the failure of the test system during the measurement, an isolation circuit is designed between the test equipment and the component under test. The high input impedance isolation method and a three-terminal isolation amplifier with safe electrical isolation are chosen, with the maximum range of the input voltage signal -100V ~ 100V and the input impedance greater than 1MΩ.

4) Automatic test: The automatic test unit is equipped internally with a control processor. The processor receives the instructions of the public support unit, controls the switch matrix to change the measurement channel, and conducts the measurement of different status parameters of the component under test. The switching program of the switch matrix is obtained by the public support unit through reading the measurement information stored in the test module memory, which can be uploaded and updated through the ground-based software and achieves the in-orbit reconfiguration of the measurement to the largest extent.

4.3. **Space environment monitoring unit**

Main functions of the space environment monitoring unit: to carry out real-time in-situ detection of silicon equivalent LET spectrum and solid state nuclear track measurement, collect and analyze the monitoring data of the orbital radiation environment of the space station, and provide space environment data within the duration/section of device fault. It is mainly composed of CR-39 and thermoluminescence detector to realize the in-situ radiation environment measurement of the test object [7]. The specific installation method is shown in Figure 3. The data of solid track detector needs to be downloaded to the ground for processing and analysis, and the implementation of space environment monitoring can be determined based on the return of the carrying aircraft.
4.4. Test module
The test module is mainly built as the minimum application system of the component under test. The standard analog quantity interfaces and data bus interfaces are adopted to lead out the signal under test. The automatic test unit measures and collects the data of the component under test and transmits the data to the public support unit for storage and downloading.

5. Application example analysis
The universal flight test platform of components plans to carry out the assessment of the space environment suitability of components through the space station, technical test satellites and other platforms, and the development of the spacecraft electronics has been completed. The external interfaces of the flight test platform are configured based on the resources provided by the spacecraft platform. The coupling design of internal interfaces is adopted between the modules of the flight test platform, which can realize the modularized development of the flight test platform and the standardized development of functional circuits corresponding to different components under test and effectively improved the applicability of the flight test platform of components.

Power supply and distribution module: It needs to be selected according to the bus voltage of the carrying platform. The completed spacecraft electronics adopt a 100V power bus, and selects DC/DC converters from 100V to 5V and 12V Research Institute to meet the power supply demand of the public support unit and most test modules.

Comprehensive management module: the main backup dual-machine cold backup working mode is the control core of the entire system. The domestic SoC2008 with anti-irradiation index is selected as the main controller. The external interface is designed as a 100M Ethernet interface and LVDS interface to facilitate the download of a large quantity of test data. The internal interface is designed as RS422 and RS485 interfaces to meet the digital transmission requirements of the test module. With 32 indirect command circuits (OC output + level output), the universal flight verification platform can realize the power-on and power-off control of each test module or some domestic components, which can effectively eliminate the failure of the whole machine due to the abnormal in-orbit current of the single board.

Data storage module: the storage array composed of the large capacity FLASH (4G*16bit) of SUMSANG can realize the long-term in-orbit data storage and the ability to save such data when the system is powered off.

Automatic measurement unit: using V7 series FPGA with 4-channel high-speed AD of Xilinx can achieve high-precision analog quantity measurement with a sample size of 16 bits and a sample frequency of 300MSPS. It can be expanded to 40 analog quantity acquisition channels and 8 temperature measurement channels through matrix switch. In such case, the flight verification platform can acquire the in-orbit test performance parameters such as voltage, current temperature of the domestic components.
Test module: The completed spacecraft electronics test multiple types of domestic devices, including FPGA and SRAM, and monitors the corresponding key parameters for different types of devices to assess the applicability of domestic devices under comprehensive space stress. The specific measurement parameters are shown in Table 2.

Table 2. Description of measurement parameters of completed test modules.

| Device name | Test parameters | Test methods |
|-------------|-----------------|--------------|
| BQVR300RH   | Working voltage and current | Collect and record the working voltage and current of FPGA through analog quantity acquisition based on high-precision measurement |
|             | Logic resource monitoring | Judge the internal faults of the FPGA based on the built-in self-test (BIST) method, and transmit the results to the public support unit through the RS422 bus |
|             | Clock monitoring | Record the clock waveform by intervention test and analog quantity acquisition through high-precision measurement, |
|             | Space environment effect | Record the total number of single event upsets through SMAP readback and timed reading and writing of the configured memory, and transmit the results to the public support unit via the RS422 bus |
| Stacked package memory | Working voltage and current | Collect and record the working voltage and current of SRAM through analog quantity acquisition based on high-precision measurement |
|             | Space environment effect | Record the total number of single event upsets, by reading and writing SRAM regularly with FPGA , and transfer the results to the public support unit via RS422 bus |
| 2N2222      | Current magnification | Record the current of the base and transmitter of the triode through analog quantity acquisition based on high-precision measurement |
|             | Space environment effect | The samples after ground-based quantitative radiation are used to assess the degradation of the triode subject to low dose rate by monitoring the change of the beta value of the triode |

6. Conclusion
With the continuous improvement of the manufacturing process and technical platform of domestic components, the gradual replacement of imported components by domestic components has become the current development trend of China's spacecraft research and development. To elevate the technology readiness level of domestic components, there will be a large quantity of domestic devices with urgent need for flight verification.

This paper analyzes the flight test cases of domestic components carried out in the past and finds that although there are different test methods for different components, they have similar requirements in terms of hardware resources. Therefore, adoption of standard measurement circuits and standard bus interfaces for unified test of different types of components can realize the universalization, standardization and modularization of the flight test platform. Meanwhile, the flight test platform supports the flight verification work of components on different spacecraft, which provides a support for subsequent product development of in-orbit verification platform for components in the aspect of technical theories.
References
[1] Weixing NI, Ming SUN, Jinliang SHA, et al. Research and Practice of the Flight-carrying Tests on Aerospace Components [J]. Microelectronics, 2012(4): 592-595.
[2] Hong XIA, Weixing NI. Conception on the Verification System for the Test Project on Domestic Components of a Certain Satellite [C]/Proceedings of the 2010 Annual Meeting & Academic Report Meeting of the Science and Technology Commission of China Aerospace Science and Technology Corporation. Beijing: China Aerospace Science and Technology Corporation, 2010: 173-184.
[3] Sipei SHAO. Research on Universal In-orbit Test Platform of Domestic Components [J]. 2011 Small Satellite Technology Exchange Conference, 2011.
[4] Jianfeng ZHENG. Research on and Design of Reusable Model of In-orbit Test Software[J]. Computer Science and Technology, 2004.
[5] Jianguo CHEN. Research on the Overall Technology of the In-orbit Test System of the Satellite Navigation Constellation [J]. Measurement and Control of Remote Sensing and Navigation and Positioning, 2009Vol.39.
[6] Yu TIAN. Design and Implementation of Universal Test Platform for Electronic Systems[J]. Measurement and Control Technology, 1000-8829(2004) 10-0021-04.
[7] Zonghai YE. Space Particle Radiation Detection Technology. Science Press, 1986: 57-61.