The Development of Spacecraft Electronic System

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Abstract. The development of spacecraft electrical system in China has been reviewed. The electronic system has been divided into three generations of stand-alone system, federated electronic system and integrated electronic system. Then, the electrical architectures and features of the federated electronic system and the integrated electronic system have been analyzed. Finally, the development trend of spacecraft electronic system has been discussed.

Keywords: Spacecraft · Electronic system · Federated · Integrated

1 Introduction

Over the last several decades the miniaturization and integration of electronics has revolutionized many systems in various areas as diverse as computing, communications, and household appliances. Advanced systems which use less power but are able to perform more functions with a higher speed, are ideally suited for space applications. Here, we gather all the improvement and important characteristics of spacecraft electronic system. The discussed spacecrafts in this paper don't include new conceptual aircrafts, such as Fractionated Modularized Cluster Spacecraft and Micro-Satellite. Generally, spacecraft electronic system is refer to as the concept of parallel with the mechanical system. [1] And the spacecraft electronic system includes all electronic instrumentations (including the software) which carry out the non-mechanical functions, such as command, control, communication, and monitoring capabilities. The special electronic devices used for payload, or the power subsystem don't take into account in this paper.

The electronic system play an important roles onboard the spacecraft, which is the basis of the mission, function and performance of the spacecraft. The development of new electronic technologies is driven by the requirements of all areas of space applications. It can be said that the capabilities of design, testing, flight support, on orbit maintenance and space applications, are influenced greatly by the spacecraft electronic system. This paper presents the development of spacecraft electronic system from early history to new trends in China.

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2 Electronic System Evolution

Chinese strategy for supporting aerospace developments comprises a number of interrelated efforts. China aerospace has gradually developed from scratch, from small to big, from imitation to independently design, and is in a rapid development period from a big space country to a super power space country currently. The development of China spacecraft electronic system has experienced three stages over the last sixty years:

2.1 Generation 1 (Stand-Alone System)

In order to achieve the electronic functions, such as navigation and communication, the early spacecraft subsystems should be equipped with appropriative and independent sensors, processors, communication modules and other equipments for each function. All of the equipments were independent and interconnected point-to-point in the structure. All of the equipment and data are unique to a particular function and not shared with other functions. The electronic system architecture adopted by the early spacecraft which has no whole system control by the central computer is known as stand-alone system.

The instrument compartment on the first Chinese satellite Dong-Fang-Hong-1 [2] equipped with power, radar transponder for measuring track, radar beacon, telemetry device, electronic sound generator and transmitter and scientific experiment instrument had been launched in April 24, 1970. Its electronic system was stand-alone system. The specificity of the structure of the electronic system was strong. The mechanical and electronic Interface and outside dimensions were not compatible. The chassis just provided simple installation and protection for the internal electronic functional unit. Since each part of this architecture was independent, the error fault would not be spread to the other system, therefore the system had a natural feature of error isolation. However, the strong specificity and poor flexibility leaded to the difficulties in information exchange between the devices. The electromagnetic interference caused by the huge cables between devices was more serious. The reliability of the system was reduced.

2.2 Generation 2 (Federated Electronic System)

The former Ministry of Aerospace Industry Development identified the mission of China-Brazil Earth Resources Satellite (CBERS [3]) in 1986. China and Brazil jointly developed the CBERS based on the satellite of China Resources-1 in 1988. The CBERS was launched in October 14, 1999, and worked on orbit three years and ten month. The onboard data management system [3] which drew lessons from European Onboard Data Handing System (OBDH) architecture called federated electronic system, was first introduced on CBERS. The most of the satellites and spaceships followed by more than twenty years used that architecture.

The functional modules in the combined electronic system were interconnected via the digital bus (1553B). The combined electronic system achieved the functions of low bandwidth data transmission and exchanging by several processors and achieved limited share after the data transfer on the time of terminal control. Each subsystem in the combined electronic system was required to have the own controllers, sensors and actuators in order to achieve the various functions, which easily caused the entire system was extremely complex and also caused lots of unnecessary duplicate device in the system.

The combined electronic system had the main features of using time-division multiplexed data bus, standard on-board computer, standard development language and standard plug-in unit RTU. The combined electronic system was a transition of the development of spacecraft electronics. The architecture of combined electronic system was a transformational progress compared to the discrete electronic system and was the pioneer on the development to integration of the spacecraft electronics.

2.3 Generation 3 (Integrated Electronic System)

In order to improve the design and research capabilities of spacecraft, it was necessary to adopt the philosophy of integrated design and used standard interface and protocol specification between the onboard electronic equipment and therefore created an electronic system [4] which had the features of internal information share and utilization, functional integration, reorganization and optimization of resources, called *integrated electronic system*. The system achieved the functions of telemetry, remote control, energy management, thermal control, attitudes and orbit control, unlock and drive control, communications within the satellite, time management, data management, payload management, and etc. It achieved the purpose of hardware module generality, information flow rationality, functional density improvement and overall performance optimization.

3 Federated Electronic System Architecture

Because of the rapid development of the gradually improvement of electronic technology and computer technology, the onboard microprocessor had caused a fundamental change of the satellite monitoring technology since the late 1980 s. The OBDH system based on microprocessors synthesized the video portion of telemetry and remote control, but also integrated other information processing of the satellite.

Our first use of the OBDH system was on the China-Brazil Earth Resources Satellite I. The satellite platform integrated the original independent telemetry system and remote control system together to form the data management system which could achieve the functions of telemetry and remote control, but also had a certain amount of functions of self-management, control and etc.

The OBDH system had been widely used in the launched satellites and it had formed into a unified standard of China on board data management system. The data management system of spacecraft was mainly composed of the devices of central terminal unit (CTU), remote control unit, telemetry unit and several remote terminal units (RTU) and the software. The devices which were interconnected via the serial data bus completed the functions of spacecraft data transfer, processing, storage and management together.

The data management subsystem of the huge satellites and large spacecraft such as manned spaceship had the similar architecture, and the only difference was the numbers of RTUs. The difference of the data management subsystem of huge satellites and the satellite service subsystem of small spacecraft such as micro-satellite was that huge satellite used 1553B bus to connected the devices and micro-satellite used the CAN bus. The CTU of huge satellite connected plurality of RTUs, while the satellite service computer of micro-satellite connected with plurality of slave computers. Same micro-satellites embedded the RTU into the payload or control platform subsystem. The typical architecture of the data management subsystem [5] of spacecraft was shown in Fig. 1.

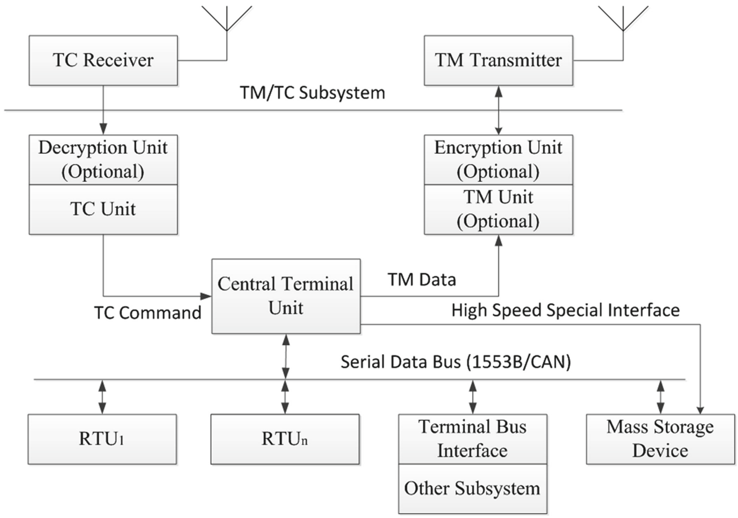

Fig. 1. The typical architecture of the data management subsystem

The main functions of the data management system of spacecraft were as follows:

① Received the upstream remote control commands and data and completed the demodulation, decoding and command verification.
② Acquired and processed the telemetry data of satellite platform and payload subsystems.
③ Provided the on-board time reference signal and managed the time.
④ Supported the information networking and interaction between the computers in the satellite.
⑤ Processed the related information of the satellite.
⑥ Provided dedicated data processing and data format for the related subsystems of the satellite.
⑦ Managed the stage of satellite and could operate in autonomous mode and external intervention mode.
⑧ Provided the mass storage function of satellite service data.

The combined electronic system was divided into a number of subsystems according to the function. Each subsystem (such as the subsystem of thermal control, attitudes and orbit control, and power) completed the dedicated control tasks by their own computer, and a CTU which was specially configured responded for management of the whole system. That system not only held relatively independent subsystems, but also had the feature of centralized and unified management of whole system.

The combined electronic system achieved the purpose of reduce the size and weight of whole system through the integrated use of a variety of techniques, provided a great solution for the processing and control of the system, greatly promoted the integration of the electronic system and enhanced the system performance. The combined electronic system achieved data sharing on the information level, but didn't achieve the integration of signal. Each subsystem still used dedicated software system and hardware equipment and had low degree of integration and independent function. The low bandwidth of the data bus gradually couldn't meet the growing requirements for data transmission. The system which was centrally controlled by a bus controller was lack of robustness.

The data management system of spacecraft based on the on-board computer had been moving towards to the miniaturized, integrated and modular direction with the rapid development of microelectronics and computer technology. Meanwhile, the increasing demand for space missions also putted forward higher requirements for the data processing capability, scalability and adaptability and data transmission standards of the data management system.

4 Integrated Electronic System Architecture

The "integrated electronics" (Avionics) was a generic term of the electronic systems of the spacecraft, and was the spacecraft's brain and nerves. The avionics system is an integrated electronic system which was based on the management of central computer, adopted the hierarchical distributed network architecture as the system architecture, completed in orbit scheduling and integrated information processing, managed and controlled of each task which was running on the satellite efficiently and reliably, monitored the state of entire satellite, coordinated the works of entire satellite, managed the payload, and achieved the unified processing and sharing of the information within the entire satellite and even the entire constellation. The system could take into account of the different requirements of the existing standard and future development electronic devices by using standard interfaces between systems.

The design of the integrated electronic system of spacecraft broke the boundaries of traditional devices and subsystems. The architecture was design according to platform information flow and energy flow and was divided into the standard modules which would be combined to the device reference to mission requirements. The system achieved the integration of information, software and hardware, and significantly improved functional density.

The traditional spacecraft platform was divided into different subsystems according to the function. The subsystems mainly included monitoring, control and communication subsystem, thermal control subsystem, power subsystem, institutional structure subsystem, attitudes and orbit control and propulsion subsystem and other subsystems. The function of each subsystem was implemented by specific device. Compared to previous system, the biggest difference was that the integrated electronic system of spacecraft emphasized that all components were placed into a complete and reasonable architecture and adopted the systems engineering approach of top-down to complete system development.

The integrated electronic system of spacecraft established a unified common architecture, divided the system into the standard modules which would be combined to the device reference to mission requirements and significantly improved the system performance and functional density (Fig. 2).

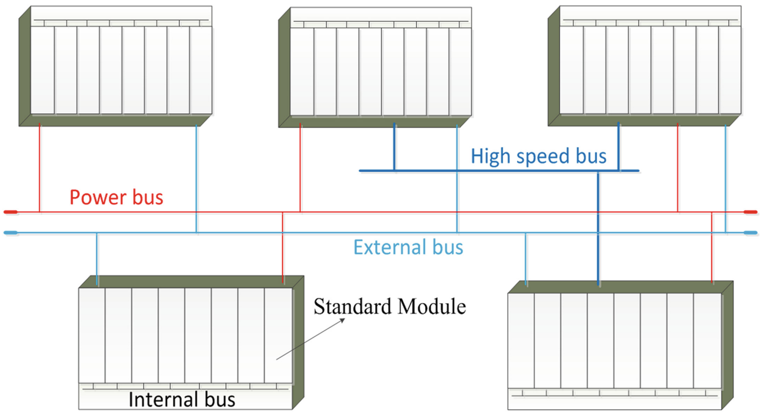

Fig. 2. The architecture of avionics

As shown in the above figure, the avionics system used the distributed and modular architecture and usually composed by a satellite management unit and several integrated business units which were connected through the external bus. The architecture of that electronic system had great flexibility and scalability of configuration and could flexibly equip with the functional modules according to different mission requirements. Making the mature functional modules into standardized shelf-type products used by different projects could shorten the development cycle, reduce the development cost and improve the system reliability.

5 The Development Trend of Spacecraft Electronic System

The current integrated electronic system has significantly improved in the respects of the architecture, the capacity of data processing, transport and storage, functional integration, standardization and modularity and etc. However, the system is insufficient in the respects of the autonomous intelligent, the dynamic reconfiguration and configuration in orbit of the system function, the comprehensive of RF and sensor, and etc. The development trend of the future spacecraft electronic system has the following aspects.

5.1 Open Architecture

The open integrated electronic system can achieve the portability of software applications and operators, complete the application interoperability between the multi-nodes within the spacecraft platform network, implement the global security of the system through adopting appropriate standard architecture and appropriate software and hardware in the embedded computer environment. Using Hierarchical division method and standard interface between the layers make it easier to the interconnection, intercommunication and interoperability of system components, migration and reuse of the hardware and software, enhancement and expansion of the system function. The standard hardware modules and the standard software functions that are summarized and optimized from the same functions of the different areas and mission tasks form the core of the system and the uniform standards, specifications and design resources database, and turn into the base framework of spacecraft electronic systems.

5.2 Networking

The future aerospace applications present the trend of architecture and network. A single spacecraft works as an intelligent node in the network and each node exchanges the information through the network. Multiple nodes fly in formation [6] and complete the mission coordinately. This requires that the spacecraft electronic systems could exchange real-time information through the advanced data link networking technology and complete the tasks of the situational awareness, the information sharing and exchange, the information fusion [7], the distribution of intelligence and command and tec. This trend will lead the spacecraft electronics technology to develop in the direction of network which is targeted the information superiority, build an integration network which is global coverage of sea and air and space, and provide the rasterized information service.

5.3 Autonomous Intelligent

The intelligent planning and scheduling is one of the key technologies to achieve the autonomous spacecraft management. The electronic system plays a crucial role as a decision-making center. The electronic system will efficiently schedule all of the in-orbit hardware and software resources according to the specified flight mission. And it will reduce the dependence of the flight control center on the ground and improve the ability to complete the mission.

5.4 Software Defined

The development trends of spacecraft are the standard Interface, the modular hardware and the dynamically configured function. The spacecraft hardware architecture will be highly uniform. The specific application of the electronic systems will be defined by the software running on them. That will achieve the system reconfiguration and function redefinition of the spacecraft on board. The "Software Configured Electronic System" is the basis that allows the spacecraft to achieve that transformation. The electronic system constitutes a software communication operating environment which may cause the developments of the software applications and the underlying hardware and software separate completely through the core framework and middleware. The application software completes the required function by using a variety of standard interfaces provided by the operating environment to invoke the underlying hardware and software resources.

5.5 Integration of the Platform and Payload

The platform and payload of the current spacecraft are mostly developed separately and they are relatively independent. There is only a small amount of data exchange between the platform and payload. With the development of technology, the integration and optimized design of the platform and payload have become an important development direction. The functions of the platform and payload can be performed by the electronic system based on the same hardware. The electronic system can provide the necessary capacity of computing, storage and processing for the functions to be achieved by loading different application software. So the designers of the payload can mainly focus on the payload performance improvement and the payload data processing algorithms implement and the designers of electronic system can focus on the development of highly configurable, high performance and general purpose platform.

6 Conclusion

This paper presented an overview of the architecture development rather than a detailed implementation of spacecraft electrical system. With the space application requirements of the spacecraft continually increased, the electronic system plays a more important role in the spacecraft. The current spacecraft electronic system has already could not meet the user expectation and the expectation will birth a profound change in aerospace electronics technology. For future work, we intend to design a soft defined next generation space avionics system that provides open architecture, flexibility within implementation, networking, third party participation, and a layered approach to both hardware and software modules that utilizes Time, Space, and I/O partitioning to realize a highly reliable and available fault tolerant system.

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