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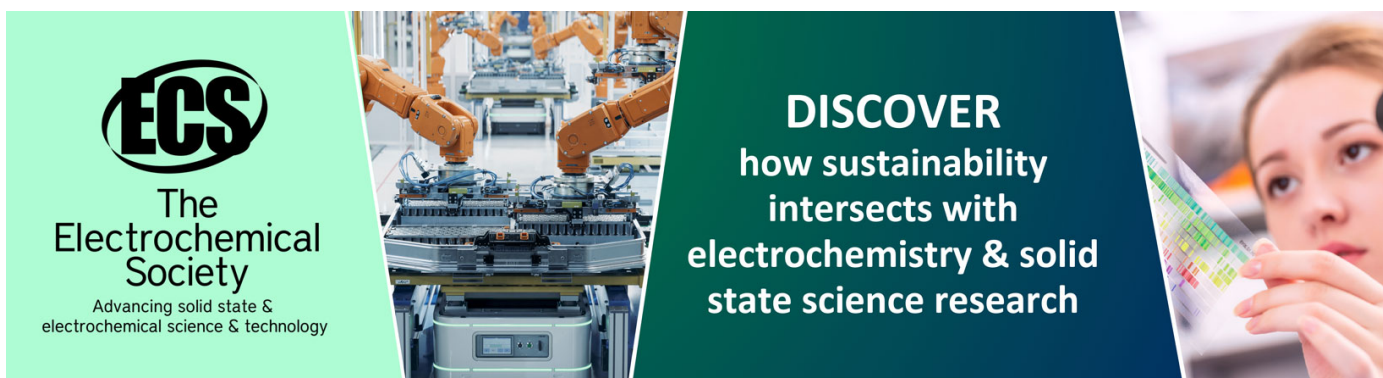
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Development and Trend of Space Plug-and-Play Avionics

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Abstract. The rapid construction of satellite systems has become a priority development direction of space technology. Space plug-and-play avionics (SPA) technology has the characteristics of short development cycle, low cost, strong pertinence, and quick results, so it has become a hot research topic in various countries today. This paper comprehensively summarizes the technical system and development trend of SPA. Firstly, the SPA hardware architecture and its three generations evolution process is analyzed; then, the application of SPA technology, including the development of PnP series satellites, OSR-1 satellite, panel extension satellite is introduced; finally, the development trend of SPA technology, including coordinated development of hardware and software technologies, and transforming traditional satellite test methods is also put forward.

1. Introduction

With the development of space technology in various countries, it has become a trend to complete the deployment of spacecraft in a few days or even less. Therefore, the modularity, easy integration, easy operation and adaptability to the environment of the system become the priority in the design. Considering that spacecraft may undertake many tasks, many similar subsystems must be interchangeable. Mechanical, electrical and software must be standardized like the design of the computer industry, that is, plug and play (PNP) design. The satellite's structural platform, loads and components must also be standardized [1], which is a fundamental change to traditional satellite design and manufacturing methods.

Plug and play technology was originally an industry standard for automatically handling the installation of PC hardware equipment, which greatly simplified the installation of hardware equipment without the need for jumpers and software configuration programs. The research institutions represented by the Air Force Research Laboratory (AFRL), European Space Agency (ESA), etc. have extended the concept of plug and play to the spacecraft field. Based on the layered spacecraft model, the space plug-and-play avionics (SPA) architecture was proposed [2-3]. As shown in figure 1, the SPA architecture is similar to the interface standard for USB devices [4]. Its purpose is to realize the rapid discovery of equipment and the self-configuration of services provided by the equipment through this system. Its significance lies mainly in: reducing labor costs and achieving rapid production, testing and maintenance of the spacecraft; improving the reliability of the spacecraft; realizing rapid replacement of components under error conditions; simplify the satellite configuration in the AIT phase, to make the spacecraft's processing tasks more flexible.



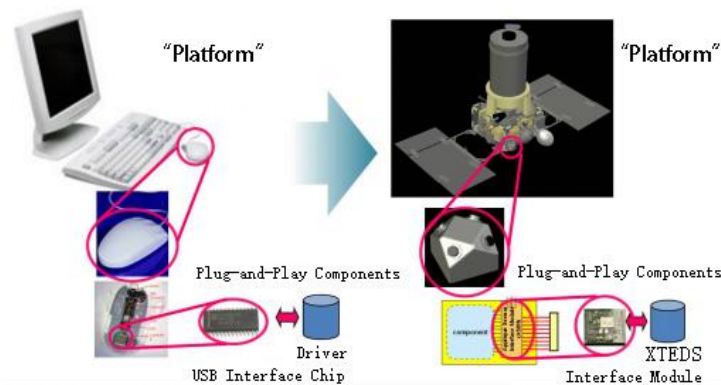


Figure 1. SPA standard is similar to USB interface standard

SPA technology has received extensive attention since its inception, and has made great progress [5-7]. In terms of hardware, NASA has formulated the SPA interface standard and related hardware architecture; ESA has designed a plug-and-play serial bus (SPA-Spacewire) with high-speed, scalable, low-power, and low-cost, and designed related routers and interface conversion modules. In terms of standards, AFRL proposed the SPA standard, which specifies the physical interface, power supply, clock synchronization, middleware software SDM, electronic data table xTEDS, and corresponding testing technologies; ESA has proposed a PUS standard close to the bottom of the hardware, which improves the reusability of the software and reduces the R&D cost and cycle of plug-and-play satellites. It can be seen that the low-cost, standardized, and fast-response space plug-and-play technology has become a consensus in the design of space spacecraft, which is the general trend.

2. SPA hardware architecture

SPA satellite is composed of four parts: high-performance satellite-borne computer cluster, adjustable wiring interface, plug-and-play network and high-speed equipment. Figure 2 shows the logical relationship between the 4 parts [8].

The high-performance satellite-borne computer cluster is composed of one or more CPU nodes and is the carrier operation of satellite software. The SPA technology connects the CPU nodes through a specially developed physical circuit, and uses a special mechanism to ensure that the CPU nodes can be expanded to meet the different computing power requirements of different satellites.

The adjustable wiring interface is located between the processor node and the external device. A large number of miniature electromechanical switches are integrated inside, and the adjustable wiring interface can respond to control commands from the satellite service system to dynamically generate a physical link that connects external devices and CPU nodes.

The plug-and-play network is made up of a large number of interconnected hubs and simple sensors attached to them. The hub has plug-and-play features and can be connected to each other in any form. The simple sensor has a single function and a simple structure, and is distributed on the entire satellite system. It is mainly responsible for detecting the temperature and gravitational status of the satellite body. It supports PnP and has low requirements for data transmission speed. The plug-and-play network can be understood as a network formed by interconnecting sensors (such as thermometers and magnetometers) necessary for the aircraft itself.

The high-speed equipment can be understood as the loads of satellite, which are often powerful and complex, and they also support PnP. For example, loads such as cameras and ground-air communication equipment are high-speed equipment. Because of the high requirements on data transmission rates, high-speed equipment are directly connected to the CPU nodes of the spaceborne computer.

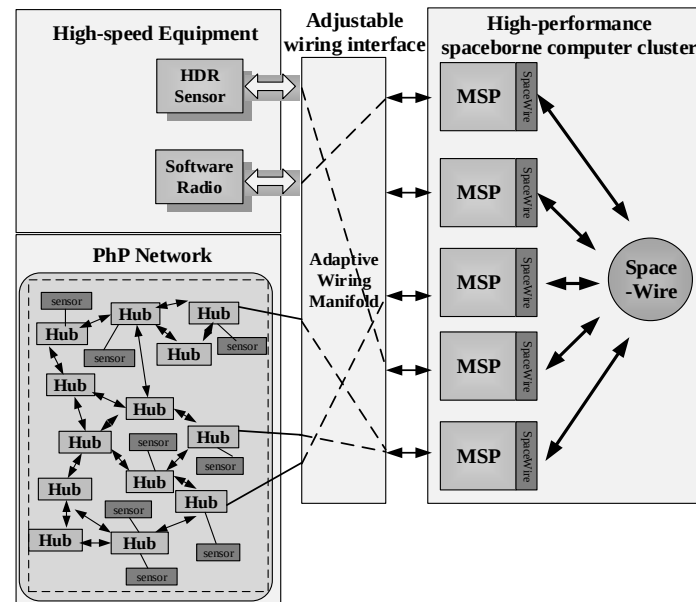


Figure 2. SPA hardware architecture.

3. SPA architecture evolution

It is difficult to realize the envisioned satellite system at one time, because it contains some abstract concepts such as adjustable wiring interfaces. A more appropriate method is to use multiple generations of research methods, each of which solves several pre-designated problems, thereby achieving step-by-step approximation [8]. The SPA architecture has evolved 3 generations since its inception.

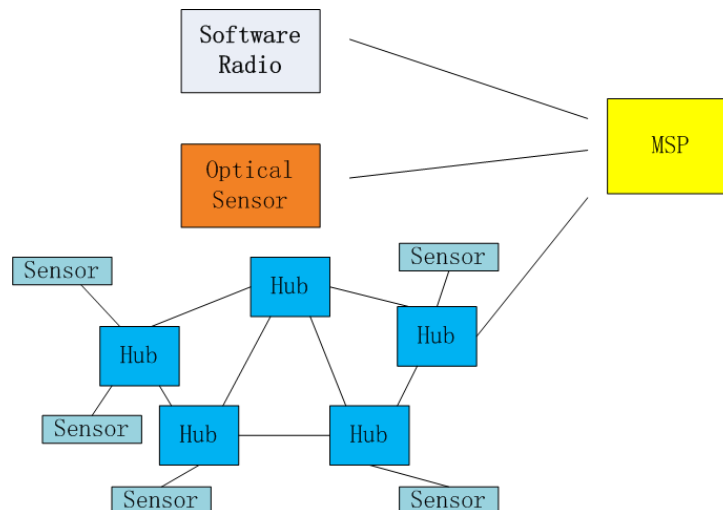


Figure 3. First-generation SPA system architecture.

The first generation (2006-2008): 1) Development of plug-and-play hardware, software and communication protocols suitable for spacecraft. 2) Develop the plug-and-play device that meets the requirements of space radiation resistance levels. 3) Unify various standards to build an open architecture, so that various types of components can be easily connected to the system. Focus on the plug-and-play technology based on USB bus, USB + Spacewire bus and Ethernet.

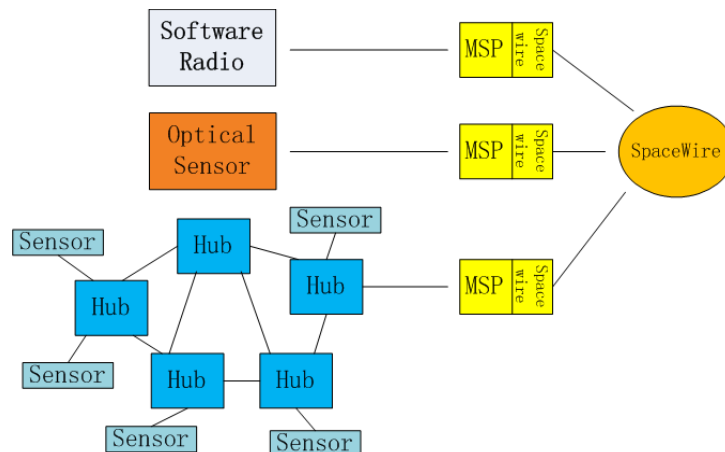


Figure 4. Second-generation SPA system architecture.

The second generation (2008-2010): 1) The architecture was changed from centralized to distributed; 2) Maintain compatibility with first-generation equipment; 3) Develop easy-to-expand interfaces for complex components so that they can be easily connected to the system; 4) Find a data transmission standard that supports a bandwidth of 1Gbps.

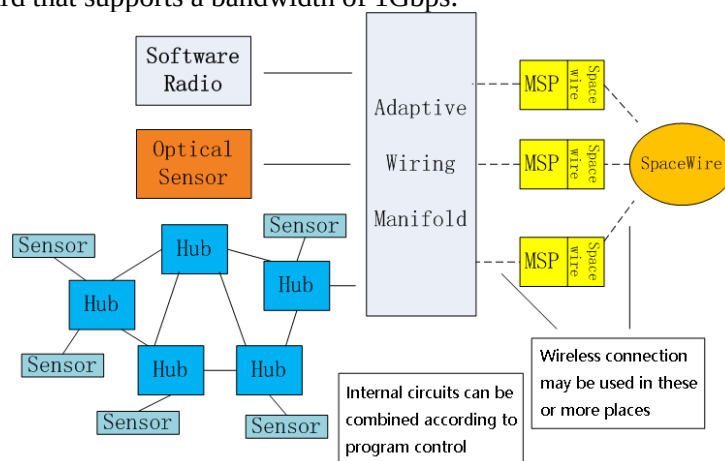


Figure 5. Third-generation SPA system architecture.

The third generation (2010-present): 1) Expanded data transmission methods, including the introduction of wireless data transmission technology; 2) Improve the software's independent management capabilities; 3) Provide support for multiple data transmission methods.

4. SPA technology application

After years of continuous research, SPA technology has made significant progress, found a solution to achieve plug-and-play in spacecraft, established relevant standards, and completed the development of demonstration verification satellites. AFRL launched the "Plug and Play Satellite" (PnPSat) project, using the SPA-S (SPA-Spaceware) interface standard, to verify the feasibility of rapid research and development, integration and testing under low cost requirements. In addition to a series of plug-and-play rapid response satellites developed in the ORS program, the "Panel Extension Satellite" (PETSAT) program launched by Japan have also generally adopted modular designs and have plug-and-play capabilities to varying degrees.

4.1. PnP series satellites

Based on the research results of SPA, AFRL launched a demonstration project of (PnPSat) in 2006 [9]. This project has developed two verification satellites, namely Plug and Play Satellite-1 (PnPSat-1) and Plug and Play Satellite-2 (PnPSat-2). The PnPSat-1 satellite uses the SPA-S interface standard, which

is mainly used to verify the feasibility of rapid development, integration and testing. The PnPSat-2 satellite uses the second-generation SPA module, and it is verified that the platform development is carried out under the lower cost constraints.

4.2. Operationally Responsive Space-1 (ORS-1) satellite

The ORS-1 satellite is the first satellite for operational users developed by the ORS project [10]. It will provide the much-needed battlefield situational awareness capabilities for the US Central Command in charge of operations in Afghanistan, Iraq, and other Middle East and Central Asia regions, with the outstanding feature of integrating aerial reconnaissance loads and combat response modular satellite platforms for space fast-response missions. The design of the ORS-1 satellite platform relies on the research results of the ORS standardized platform. The launch of the ORS-1 satellite signals that the standardized platform is moving from development, testing, verification and evaluation to practical application.

4.3. Panel extension satellite

PETSAT was led by the University of Tokyo in cooperation with the East Osaka Enterprise Group to build a modular small satellite with each functional module independently designed. PETSAT is a new concept small satellite. It consists of several independent module boards such as CPU board, battery board, communication board and attitude control board. These functional modules are connected together by standard plug-and-play interfaces and form a fully functional spacecraft.

5. SPA development trend

5.1. Coordinated development of hardware and software technologies

Hardware modularization and standardized design are the basis for plug-and-play. At the same time, the software architecture should be improved based on the need for rapid response. Rapid assembly, testing, and expansion and replacement of on-orbit hardware modules require software technology. Therefore, it is necessary to coordinate the development of hardware and software technologies when developing SPA. The open, modular, and reconfigurable spaceborne software system can be combined and reconfigured according to the satellite hardware composition, and after the hardware is in place, the hardware module search, identification, switching, and grid connection are quickly completed. The plug-and-play software technology can drive the rapid response spacecraft system from "hardware-centric" to "data-centric", and then completely realize the transition of spacecraft system design from hardware-oriented design to task-oriented design.

5.2. Transforming traditional satellite testing

The SPA technology changes the "global + single line" test mode of the conventional satellite test to a "local + parallel" test mode with functional modules as the object. Each functional module is tested in parallel through a ground test system. After assembly, it can be put into use after a simple interface test and a full-satellite information flow test. Once a problem is found in an individual functional module, the module can be replaced and retested immediately, and the process will not affect the test process of other functional modules. Therefore, SPA technology can significantly reduce the satellite test cycle and improve the satellite's rapid operational response capabilities.

6. Conclusion

The SPA technology is a hot research topic in space technology. The advantages of low cost, standardization, and rapid response promote the development of this field. The SPA technology promotes the standardization of structural platforms, loads and components in spacecraft design, and further promotes the development of space science and technology. At present, SPA technology has shifted from the development, testing, verification, and evaluation stages of standardized platforms to the actual application stage. This article starts from the SPA technology architecture, sorts out the

evolution path of the SPA architecture, analyzes the typical application of the current SPA technology, and summarizes the future development trend of the SPA technology.

Acknowledgments

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