Development and Challenge of Spacecraft Embedded Computer

Feng Xie, Hua Qu, Weiguo Guo

***Abstract*—Spacecraft is characterized of high cost, long development period and low recoverability; therefore equipments comprising computer system thereof are required of high reliability and long service life as well as high performance demand. Currently the solution with wide application that adopts high-level component as space level component has the defects of constrained supply channel, high price and low performance, thus most aerospace countries promote COTS solution for solving these problems. In this paper, based on the application requirement analysis of COTS, key technologies of COTS comprising anti-radiation design, function redundancy design, testability & maintainability design and systematic design are introduced of current situation and design examples. Practices indicate that based on present technology, the application of COTS in non-key system can effectively improve system performance and requirement adaptability without affecting reliability and safety.**

***Index Terms*—COTS; Spacecraft; Embedded Computer; Redundancy Design**

I. INTRODUCTION

SPACE mission is one mega-complex system engineering, comprising the developments of spacecraft, launch vehicle, launch site system, ground support system, and ground-borne & space-borne remote detection and control system, and the like. The development period of general spacecraft is 5 to 10 years while the service period is 20 to 50 years; the cost of general spacecraft is millions to billions of dollars while the cost for launching payload to earth orbit reaches about ten thousand dollar per pound; and because of off-ground operation, there has poor treatments for dealing with the faults of in orbit spacecraft.

Practices indicates that the spacecraft is characterized of long development period, high investment and low recoverability, thus the devices comprising embedded computer system of spacecraft are firstly required of high reliability and long service life on the basis of satisfying performance requirements.

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For satisfying the requirements of high reliability and long service life, the anti-radiation design is most important to spacecraft embedded computer systems which are generally set as key systems of spacecraft, since even the spacecraft operates at low orbit, and the energetic charged particles are deflected under high geomagnetic intensity in some degrees, the devices under the influence of the south Atlantic anomaly and the high latitude cosmic rays are still easy to produce Single Event Upset (SEU). And therefore, the solution of applying high-level components is widely preferred in anti-radiation design, thermal design and EMC design and the like of spacecraft embedded computer systems.

However high-level component has the disadvantages of high price, supply channel bottleneck and low performance. In order to solve the disadvantages thereof, most aerospace countries are promoting COTS (Commercial Off The Shelf) solutions, wherein COTS is defined as the products which are offered by commercial market and capable of being provided f government or army at any time, and is also defined as using low level components to manufacture high reliable system [1].

II. ANALYSIS OF COTS APPLICATION DEMAND IN SPACECRAFT

A. Low Cost Demand

The cost of spacecraft keeps at high level since it begins. Actually even in China generally having lower cost than other space countries, the cost of CZ-3B launch vehicle is at least 60 million dollar per launch, and therefore each space country is exploring a cost-reduction way.

One reason causing high cost is the application of high-level components in spacecraft manufacture while the price of space level component is generally ten times more than commercial component. Meanwhile since the high-level component market demand is significantly lower than commercial component and of long manufacture period, manufactures have less enthusiasm than before and spend more energy and investment in commercial market which has greater demand, thus the price of high-level component is obviously higher and higher and the supply channel is at bottleneck.

The 2011 American Space Industrial Base Presentation indicates that the components comprising optical solar

TABLE I
2011 SPACE INDUSTRIAL BASE PRESENTATION (HIGH RISK TABLE)

TECHNOLOGY	SATELLITE OR LAUNCH VEHICLE	NO U.S. SUPPLIER	U.S. SOLE SUPPLIERS	DEFREE OF DIVERSIFICATION
Optical solar reflectors	SAT	U.S. stockpile; one foreign supplier		Reliant on space business
Solar cell cover glass	SAT	U.S. stockpile; one foreign supplier		Reliant on space business
Space-qualified cadmium-zinc telluride dectors	SAT		√	Significant space business
Space-qualified harmonic drive transmission	SAT and LV		√	Significant space business
Space-qualified optical encoders	SAT and LV		√	Significant space business
Space-qualified potentiometers	SAT and LV		√	Significant non-space business
Space-qualified slip ring assemblies	SAT and LV		√	Significant non-space business
Space-qualified torque rods	SAT		√	Significant space business
Space-qualified travelling wave tubes	SAT		√	Significant non-space business
Ammonium perchlorate (AP)	LV		√	Significant space business

reflector, solar cell cover glass and space-qualified cadmium-zinc telluride detector and the like are at supply channel bottleneck as shown in Table I.

B. *High Performance Demand*

The information that processed by variable sensors of spacecraft is more greater than before, which will occupy most of satellite-ground bandwidth and bring heavy burden to relay satellites and ground-borne remote detection and control system when all being transmitted to ground, thus the data relay satellite, broadband communication satellite, remote sensing satellite, navigation satellite and the like have need of the information processing platform with high performance.

The AirForce2025 of United States Air Force has presented that in orbit data processing means key information can be quickly transmitted to combat units on earth, via which the land, air and space ruling ability can be confirmed, and therefore higher performance of spacecraft embedded computer system is required.

High-level component as space level component generally lag behind commercial component of 1 to 2 generations while performance distance there between is larger than 10 years [2], as shown in Fig. 1. The high-level component cannot satisfy the high performance requirement of future space missions.

Giving concrete examples, the processing ability of radiation-hardened processor PowerPC BRE440 having top performance in space level components is not higher than 300MIPS@133MHz; and the AT697F which is a 32-bit RISC aerospace microprocessor and promoted by ESA has dominant frequency of 80MHz, that can satisfy basic space application requirement, can be applied in general communication and control, and has high reliability and wide application in different series, but is still not capable of dealing with increasing data processing and communication requirements.

C. *Demand of Manned Spacecraft*

Compared with unmanned spacecraft, the manned spacecraft has more systems as instrument system and crew system and the like, therefore the information processed by manned spacecraft is significantly more than unmanned spacecraft.

And for confirming in orbit safety of crews, manned spacecraft should realize strict real-time information processing, self health management and on-time fault treatment, thus leads to more information processing, and fast and intelligent processing requirements.

In addition, manned spacecraft should provide variable entertainment equipments, and since commercial computer of

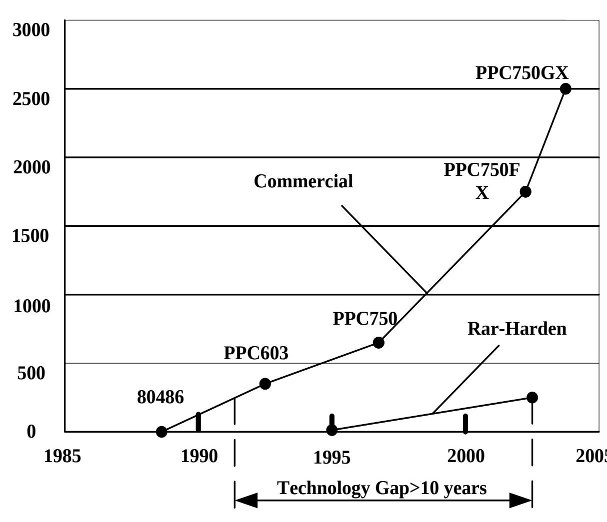

Fig. 1. Performance Comparison between Radiation-Harden Component and Commercial Component

high performance has already supported HD and 3D movie that was accustomed by crews, for providing a ground-similar environment to crews, the embedded system of manned spacecraft is required of high level graphics and image processing and high level information service and the like.

D. Demand of Fast Response Small Satellite

COTS solution has been applied in fast response small satellite area in order to manufacture fast, intelligent and low-cost system and realize standardized, modularized and serialized design, with the advantages of reduced satellite weight, volume, cost and manufacture period and improved function density.

The American Operationally Responsive Space (ORS) can complete satellite manufacture in 12 months, wherein the platform electronic equipment adopts standard modularized design, and the energy, remote sensing, electronic and guidance systems and the like are set on combat reserve state at ordinary time, which can be assembled and launched in 2 to 7 days.

On the basis of above analysis, further popularizing application and extending research of COTS solution can effectively improve the performance of manned spacecraft electronic system and fast response small satellite system and the like. COTS solution has the advantages of low component cost, good and steady supple channel, flexible structure and superior performance. Meanwhile based on the development of fault detection, tolerance and correction technologies, the quality and reliability of COTS system can be confirmed effectively. Therefore the application basis of COTS in space mission especially in manned space flight has been established.

III. KEY TECHNOLOGIES OF COTS HIGH PERFORMANCE EMBEDDED COMPUTER

The research focus of COTS comprises the selection and ageing process control method of component, the space application electric, mechanical and thermal design, the space environment effect protection and hardened technology, the reliability analysis, verification and evaluation technology and the like, wherein the key problem that affects COTS application significantly is the reliability design in space environment.

A. Anti-Radiation Design

COTS solution has the disadvantages that the anti-radiation ability of single component is lower than space-level component, while SEL (Single Event Latchup) and SEU (Single Event Upset) resistance are the main design difficulty which is currently resolved by the reliability design of system structure and fault detection and correction currently [3-5].

Along with the development of Deep Submicron Semiconductor and CMOS/SOI technology, SEL probability of COTS component has be reduced significantly while SOI Trench technology can completely avoid SEL. Additionally, SEL probability can be reduced effectively by adopting self power off or regional current limitation and the like.

Meanwhile some methods have been proposed for SEU reduction, comprising Triple Modular Redundancy (TMR), Double Modular Redundancy (DMR), Time Triple Modular Redundancy (TTMR), state machine state encoding hardened design, and I/O pin configuration and the like; using EDAC or ECC circuit at data memory or program memory at CPU system; using redundancy coding as RS coding to correct the fault caused by SEU in some degrees without affecting data correctness and program running; and setting watch dog monitoring circuit to monitor the execution correctness of

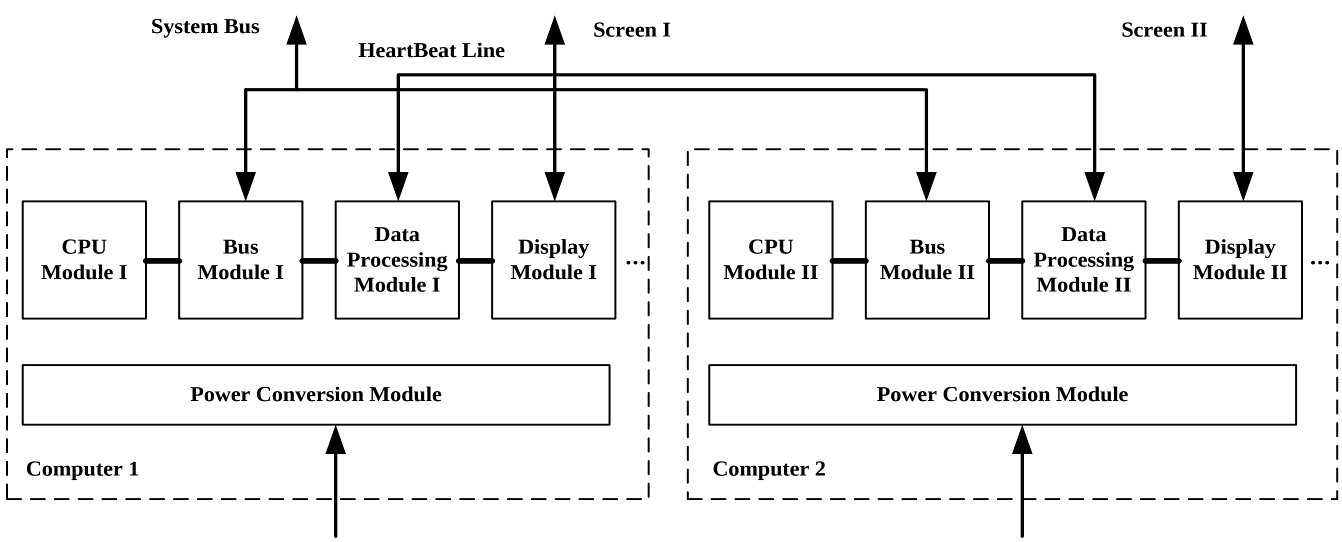

Fig. 2. Typical Double-Computer Hot Standby System

microprocessor with designed suitable reset program, thereby confirming automatic system reset after program dead, and the like [6].

The anti-radiation technology especially the SEU resistance technology in space application has been researched much in COTS field, while the single event mechanism, fault mode and characteristic should be researched further. And resource consumption and performance should be balanced in design.

B. *Function Redundancy Design*

Since COTS component has limited performance of anti-adverse space environment, the application of function redundancy design at system level as multi-computer fault tolerant system is the way capable of effectively realizing practical COTS application in space flight.

Present redundancy system mainly comprises double-computer comparison system, double-computer hot/cold standby system, TMR system and heterogeneous redundancy system and the like.

One double-computer hot standby system is shown in Fig. 2, wherein the double-computer hot standby system adopts symmetric design of hardware and structure; two consistent computers run independently; and a watch dog circuit is adopted to detect heartbeat to realize fault computer-switch strategy.

In the double-computer hot standby system, when the CPU module of on-running computer is abnormal, the bus interface is abnormal or the computers are switched manually, the on-running computer will be switched to the standby computer. The double-computer hot standby system has the advantages of being capable of limiting fault region, and realizing seamless switch and no-pause operation.

C. *Testability and Maintainability Design*

In orbit testability and maintainability design can effectively support the maintenance safety of COTS system. The testability is a character designed for realizing on-time and accurate analysis of work state of system and equipments; and the maintainability is an inherent character of product provided by original design and comprises fault detection, diagnosis and isolation.

According to statistics, the crews of ISS generally spend 2356 hours per year at MWA (Maintenance Work Area) on testing and repairing failure equipment, and the crews of Russian Cabin generally spend 75% of working time on the repair and maintenance of equipments.

By adopting the design of fault detection, fault diagnosis, self recovery and function reconstruction, the reliability and service life of spacecraft can be improved significantly. Further if equipment can be maintained by crews of manned spacecraft, the service life and safety of whole system can be improved.

The most important fact of maintainability and testability design is the realization of modularization, standardization and expansibility, wherein the modularization is that each module is systematically designed of function level and has module-level hardware/software; the standardization is that each module adopts uniform design of internal and external interfaces; and the expansibility means setting suitable design margin in the initial design of spacecraft for adapting to the requirement change in long operation period.

For example, the power conversion module, bus module and memory module and the like as shown in Fig. 2 can adopt

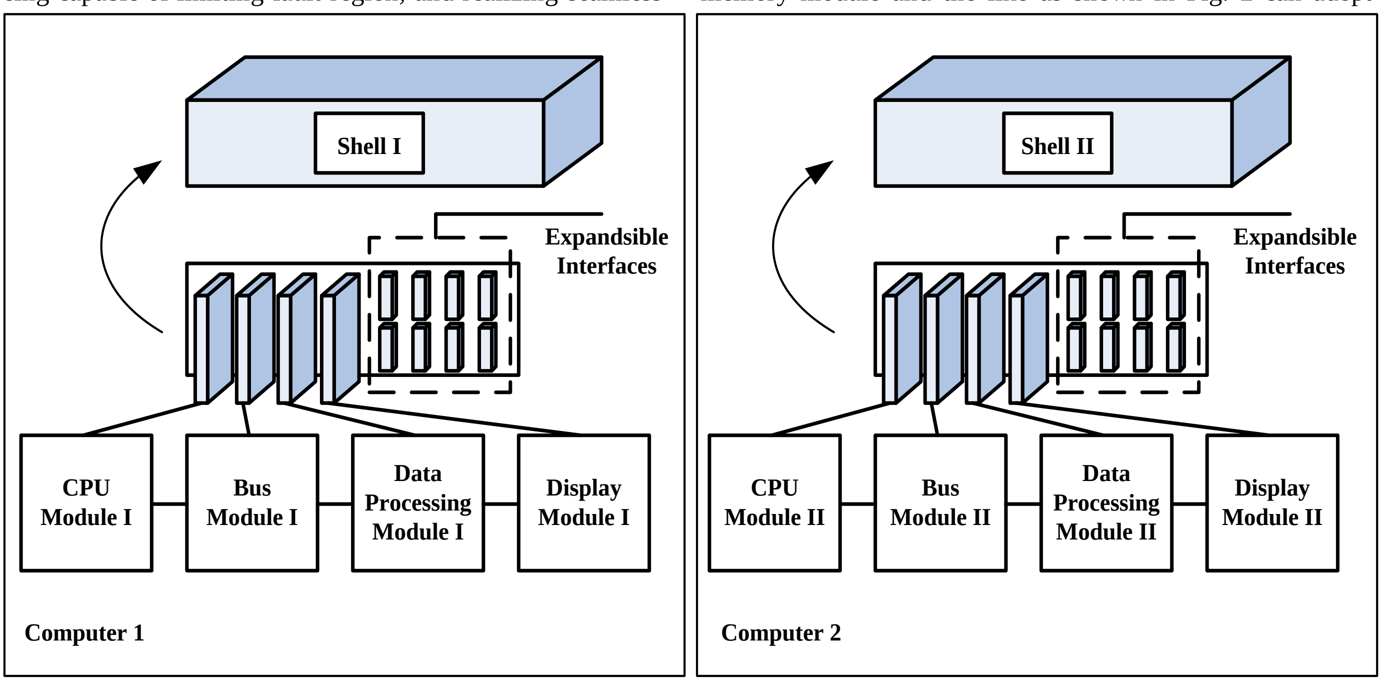

Fig. 3. Double-Computer Hot Standby System of Modularized, Standardized and Expansive Design

modularized design of function level as shown in Fig. 3, wherein when the on-running computer fails, spacecraft crews can switch system to standby computer automatically or manually, test and find failure module, and then exchange failure module with a prepared module, while in the whole maintenance operation, running mission is not interrupted. Additionally, the system function can be expanded by adding different modules easily.

D. Systematic Design

The reliability and safety design are the most important factors in spacecraft development especially in manned spacecraft. For confirming reliability and safety of flight space flight mission, COTS solution and component should be firstly applied in display system, information transformation system and entertainment service system and the like which operation state is nearly irrelative to the safety of crews, therefore present research is focused on the system reliability management technology and the COTS application level identification. In addition, the design difficulty as thermal design that is difficult to solve in local system can be considered in whole spacecraft system, such as the heat radiation problem can be effectively resolved by external thermal control system.

IV. Conclusion

The application of COTS solution and component in space flight mission can reduce cost, improve system performance and shorten develop period and the like, thus nearly each aerospace country has set a series of support policies for promoting COTS research and application. For example, The National Space Policy of American set the development policy of commercial aerospace mission as that commercial space product and service should be applied as much as possible to satisfy government demands.

Actually NASA spends 10 million dollar per year on supporting the COTS application research in space technology and has established user white paper about commercial plastic encapsulated devices applied in space mission; COTS solution has been introduced into Gate array IC and CMOS IC in satellite area; and the Falcon launch vehicle taking Dragon spaceship of Space X has been launched successfully, while the Falcon launch vehicle and Dragon spaceship both adopt much COTS components.

Practices indicate that based on present technology level, the application of COTS in non-key system can avoid affecting the reliability and safety of whole system and effectively improving system performance and requirement adaptability with suitable anti-radiation, function redundancy, testability and maintainability designs.

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