The Design of a LEO Constellation Satellite Integrated Electronic System and the Reliability Analysis

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Abstract. Targeting the needs of low-earth orbit (LEO) Internet constellations for the high performance, high reliability, and high functional density of satellite-borne integrated electronics, the study was implemented on domestic LEO mobile constellation satellite-borne integrated electronic technology. Upon benchmarking foreign advanced LEO mobile constellation satellite-borne integrated electronic products, we analyzed the architecture of the domestic ones, and proposed solutions based on domestic devices; For the requirements of long service life and high reliability, the reliability analysis was carried out on several working modes with the components and parts stress analysis method, and a reliability improvement plan was proposed on the basis of software and programmable devices. Finally, we obtained a design plan of a satellite-borne integrated electronic system for LEO mobile constellation applications. With the overall performance comparable to those of advanced foreign solutions, the processing performance trebling that of existing domestic satellite-borne computers, and the 10-year reliability of 0.99999, it meets the needs of domestic LEO mobile constellation services.

Keywords: Low-earth orbit (LEO) internet constellation · Integrated electronics · High performance · Reliability

1 Introduction

In recent years, with the development of satellite communication technology and the changes in the Internet application environment, in order to meet the globally growing demands for satellite broadband access and, especially, to solve the problem of Internet access in rural areas and other remote areas, satellite Internet has become an inevitable trend for the combination of satellite communication and Internet. Unlike satellite communication systems, satellite Internet serves Internet applications, uses a unified network layer as a bearing platform, and can work independently as a network system (an effective component of the Internet system). Promoted and supported by the Internet giants such as Google and Facebook, Space X, OneWeb and other innovative companies in the United States have planned to build their mobile constellation systems composed of small

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LEO satellites to actively seize new resources for space Internet access, consequently triggering a global upsurge [1–3].

The OneWeb satellite system, a LEO Internet satellite constellation system rapidly developing in recent years, is dedicated to providing terrestrial users with high-speed, broadband space-based access services. After the completion, the system will provide affordable network access for remote areas or areas with outdated Internet infrastructure, thus realizing the full coverage of the earth.

For the past few years, relevant Chinese institutions have also proposed development plans for LEO mobile constellations, such as the "Xingyun", "Hongyan" and "Hongyun" constellations. The study on the OneWeb and other foreign advanced LEO mobile constellation- related technologies might provide good references for the development of domestic systems.

Regarding the OneWeb constellation satellite platform, the electronic system developed by Airbus is used with the PureLine Amethyst centralized integrated electronic system as the core, which uses lots of automotive-grade devices to provide OneWeb satellites with an integrated high-performance, low-power consumption and low-cost solution featuring a computing performance of above 215 DMIPS and a reliability of above 99.999% [4].

In contrast, China's existing on-board computers and integrated electronic systems are characterized by the problems of low performance and large size. There is no integrated electronic system designed for LEO Internet constellation satellites, leading to the failure in meeting the developmental requirements of LEO satellite constellations [5, 6]. Besides, LEO Internet satellites are mass-produced small satellite platforms. Compared with large satellite platforms, their satellite-based integrated electronics pose requirements of higher integration, higher information fusion, and lower costs. There is still a certain gap between the domestic systems and the required. It is imperative to develop a satellite-based high-performance, high-integration and low-cost integrated electronic system for LEO Internet constellation satellite applications.

In order to meet domestic services and requirements for LEO Internet satellite constellations, an integrated electronic system for LEO Internet constellation satellite applications was designed in the paper upon the foundation of benchmarking foreign advanced products. With a new domestic high-performance processor and based on the modular design idea, the system is characterized by high performance and high integration. Besides, targeting the requirements for a long service life and a high reliability of the integrated electronics, components and parts stress analysis method was used to analyze the reliability under different working modes, and an on-orbit repair-based reliability improvement plan was proposed correspondingly.

2 Analysis on OneWeb Constellation Satellite Integrated Electronic Products

OneWeb constellation is one of the earliest and fastest-growing LEO Internet constellations in foreign countries. Its related technologies, especially the low-cost, high-performance satellite-borne integrated electronic technology, are worth of careful exploration to provide reference for domestic system design.

The core of the electronic system for the OneWeb constellation satellite platform is the PureLine Amethyst integrated electronic system designed by Airbus. The electronic system provides the satellite platform with the functions including on-orbit redundant computing and processing capabilities, TM/TC that satisfies CCSDS, GPS reception, secondary power distribution, attitude and orbit control sensors and actuator interfaces (incl. magnetic torque and solar array stepping motors), time and space partitioning of space software, etc. All Amethyst components have gone through irradiation experiments and are immune to latch-up, guaranteeing the LEO on-orbit service for 10 years. The block diagrams of the product appearance and functions are shown below (Fig. 1).

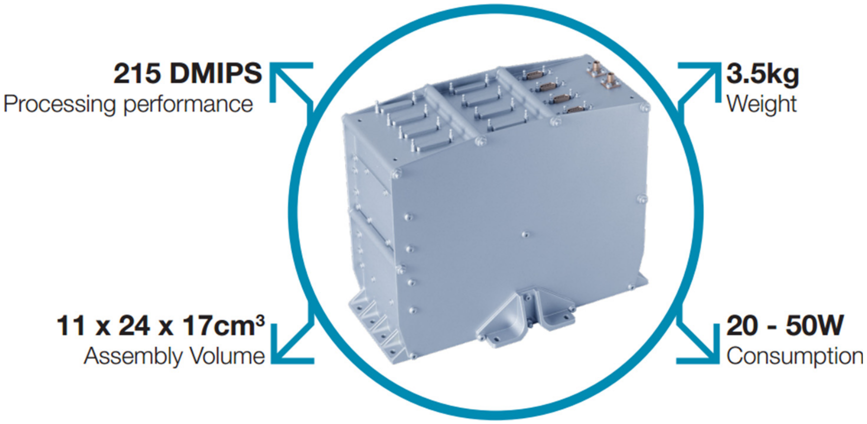


Fig. 1. Amethyst appearance

Amethyst adopts a dual-core automotive electronic-grade ARM processor as the core with 215 MIPS processing and floating-point processing capacities. Regarding the satellite bus, Amethyst uses CAN bus and Spacewire bus (for the latter, the bus communication rate is 200 Mbps) with the overall weight of 3.5 kg and the power consumption of 20~35 W (Fig. 2).

The specific parameters of Amethyst are shown in the following table (Table 1).

It can be seen from the above introduction that the Amethyst integrated electronics is composed of 4 modules in 2 categories, namely the core processing modules (active/standby) and the interface expansion modules (active/standby). Among them, a core processing module is mainly composed of a computer minimum system, a GPS and PPS (pulse per second), TM/TC interfaces, AES code function, a bus interface circuit (incl. CAN and SPW) and other functional circuits, while an interface expansion module is mainly composed of a RS422 interface, an analog acquisition interface, power supply control and distribution, a sensor, executive components and other functional circuits.

When designing the integrated electronic system for a domestic LEO constellation satellite platform, we can also draw on this idea and benchmark its technical parameters to meet the service needs.

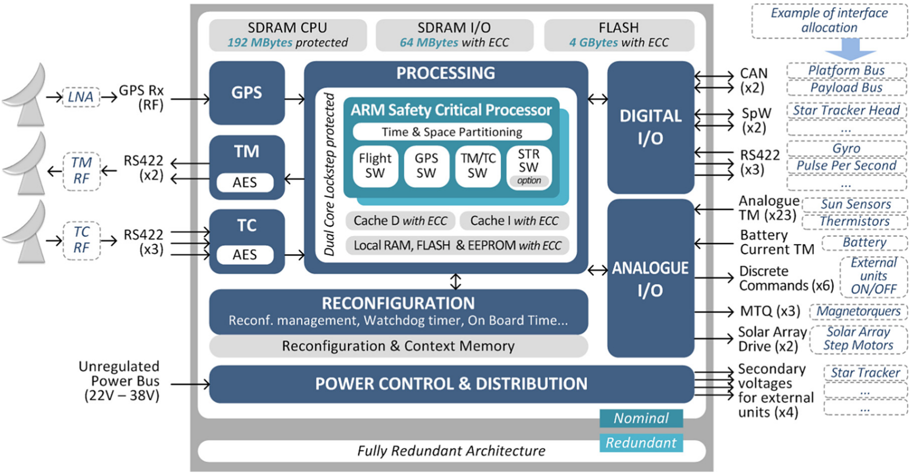
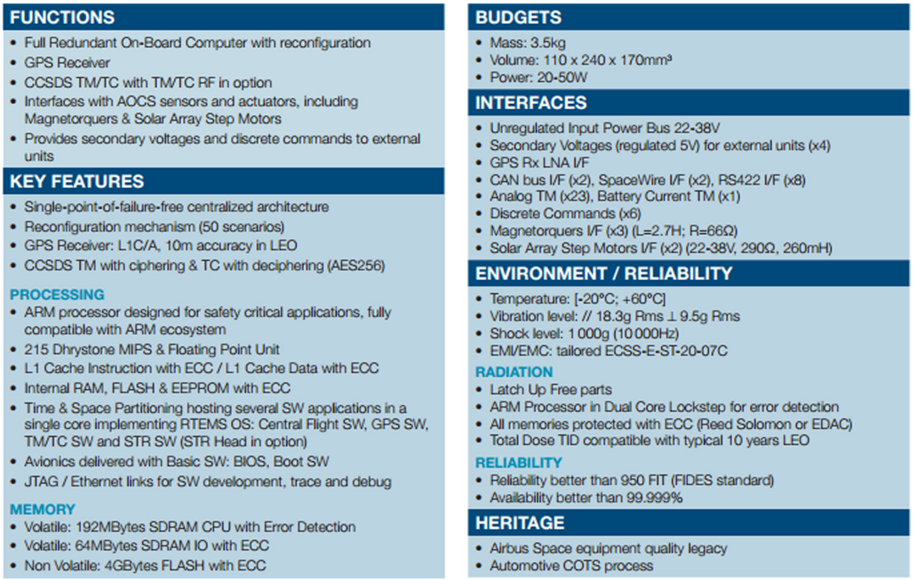


Fig. 2. Amethyst functions

Table 1. Amethyst parameters



FUNCTIONS
- Full Redundant On-Board Computer with reconfiguration
- GPS Receiver
- CCSDS TM/TC with TM/TC RF in option
- Interfaces with AOCS sensors and actuators, including Magnetorquers & Solar Array Step Motors
- Provides secondary voltages and discrete commands to external units

KEY FEATURES
- Single-point-of-failure-free centralized architecture
- Reconfiguration mechanism (50 scenarios)
- GPS Receiver: L1C/A, 10m accuracy in LEO
- CCSDS TM with ciphering & TC with deciphering (AES256)

PROCESSING
- ARM processor designed for safety critical applications, fully compatible with ARM ecosystem
- 215 Dhrystone MIPS & Floating Point Unit
- L1 Cache Instruction with ECC / L1 Cache Data with ECC
- Internal RAM, FLASH & EEPROM with ECC
- Time & Space Partitioning hosting several SW applications in a single core implementing RTEMS OS: Central Flight SW, GPS SW, TM/TC SW and STR SW (STR Head in option)
- Avionics delivered with Basic SW: BIOS, Boot SW
- JTAG / Ethernet links for SW development, trace and debug

MEMORY
- Volatile: 192MBytes SDRAM CPU with Error Detection
- Volatile: 64MBytes SDRAM IO with ECC
- Non Volatile: 4GBytes FLASH with ECC

BUDGETS
- Mass: 3.5kg
- Volume: 110 x 240 x 170mm³
- Power: 20-50W

INTERFACES
- Unregulated Input Power Bus 22-38V
- Secondary Voltages (regulated 5V) for external units (x4)
- GPS Rx LNA I/F
- CAN bus I/F (x2), SpaceWire I/F (x2), RS422 I/F (x8)
- Analog TM (x23), Battery Current TM (x1)
- Discrete Commands (x6)
- Magnetorquers I/F (x3) (L=2.7H; R=66Ω)
- Solar Array Step Motors I/F (x2) (22-38V, 290Ω, 260mH)

ENVIRONMENT / RELIABILITY
- Temperature: [-20°C; +60°C]
- Vibration level: // 18.3g Rms ⊥ 9.5g Rms
- Shock level: 1 000g (10 000Hz)
- EMI/EMC: tailored ECSS-E-ST-20-07C

RADIATION
- Latch Up Free parts
- ARM Processor in Dual Core Lockstep for error detection
- All memories protected with ECC (Reed Solomon or EDAC)
- Total Dose TID compatible with typical 10 years LEO

RELIABILITY
- Reliability better than 950 FIT (FIDES standard)
- Availability better than 99.999%

HERITAGE
- Airbus Space equipment quality legacy
- Automotive COTS process

3 The Design and Realization of a Domestic LEO Constellation Satellite Integrated Electronic System

An Internet satellite integrated electronic system is the core for whole-satellite information fusion and comprehensive decision-making. Considering the constellation requirements of high integration and miniaturization, an integrated solution with good expansibility and adaptability should be adopted as far as possible. Besides, the integrated electronics of foreign LEO constellations all use highly-integrated platform computers. Therefore, viewed from the perspective of optimizing the integrated electronics of the whole satellite overall, it is necessary to reduce the number of in-satellite computers.

3.1 Overall Architecture Design

Constellation satellite integrated electronics integrates traditional platform telemetry and tele-control units, a satellite house-keeping computer, business units, a control computer, a GNSS receiver, a star sensor circuit box, an array driver circuit box and other functions into a central management unit (CMU), which improves the system integration and information fusion, reduces the amount of whole-satellite computer systems, and minimizes resource requirements such as weight, power consumption and volume.

The topology of the whole-satellite integrated electronics with the CMU as the core is shown in the figure below (Fig. 3).

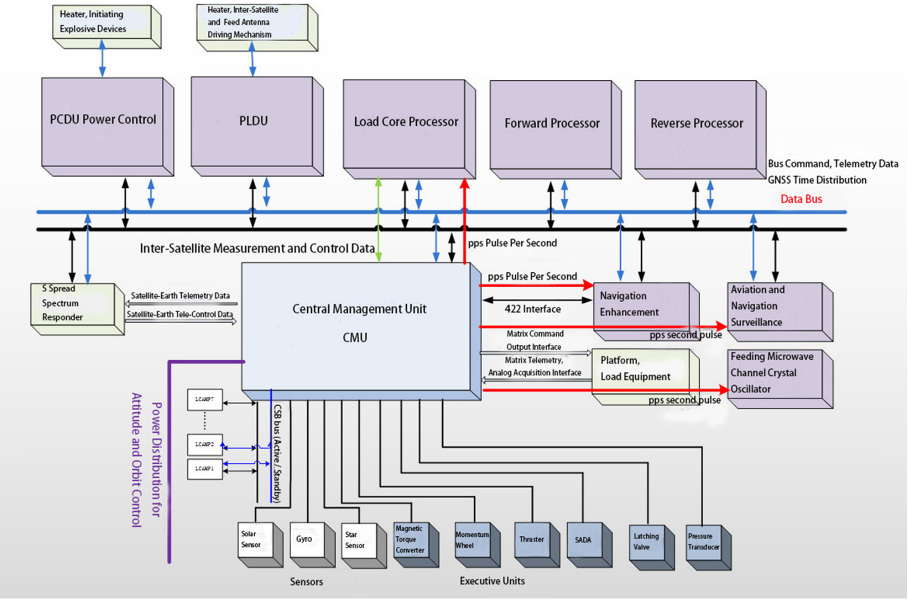


Fig. 3. Topology of whole-satellite integrated electronics architecture

The system uses CMU as the main control terminal, and the components are connected through data buses to build a distributed network system. Distributed data collection and command output, and centralized operation and control are realized through the data bus network, thereby improving the efficiency of system processing.

Based on the module division of Amethyst integrated electronic equipment, the above functional modules can also be divided into two categories—the core processing modules and the interface expansion modules. Among them, a core processing module includes two major functions—data management and tele-control, which specifically cover a CPU core system, time management, system buses, inter-satellite/satellite-earth measurement and control communications, measurement and control encryption and decryption, important data storage, and large-volume data processing. The core processing modules are divided into the active and standby machines configured in 2 panels with completely same functions. Among them, the satellite-earth tele-control and important data storage are processed with dual-machine hot backup, while the rest are processed with dual-machine cold backup. An interface expansion module includes command acquisition, load communication, sensor communication, attitude and orbit control drive, power distribution, GNSS and other functional modules.

(1) **CPU Selection**
The core issue for a core processing module is the selection of CPU. Amethyst uses a dual-core ARM processor with a performance of 215 MIPS. Considering from the perspective of independence and controllability, domestic constellation satellite integrated electronics should use a domestic CPU. However, existing domestic mainstream on-board computers generally have a performance of below 100 Mips and a main frequency of below 100 MHz, suggesting a gap with foreign products. Therefore, after extensively investigating domestic devices, the new-generation SPARC V8-structured BM3823 processor was selected as the CPU. The processor is characterized by the main frequency of 300 MHz and the performance of above 258 Mips, suggesting the same level as foreign products.

(2) **Bus Selection**
After a comprehensive evaluation, we referred to Amethyst integrated electronics for the internal bus of the domestic constellation satellite integrated electronics. The internal buses were divided into high-and-medium-speed and low-speed ones. Spacewire bus was selected for the former, while CAN bus was selected for the latter, realizing a general, modular and standard design.

3.2 Overall Structure Design

The structure plan of CMU should also meet the requirements of a modular design, standardization and scalability. Currently, the common mechanical structures include bus mechanical structures such as VME, PCI, cPCI, and VPX. Among them, VME, PCI, and cPCI are parallel bus structures (which can be customized, but become a non-standard architecture after customization), and VPX is a new architecture proposed for high-speed serial buses.

The buses used in the CMU are Spacewire serial bus and CAN bus, but it makes little sense to adopt a standard bus structure, since there are abundant non-standard signals such as power supply, command and telemetry transmitted between boards. In view of the large power consumption of a single board, the "cage drawer" structure was proposed. The schematic diagram of the whole-machine architecture is shown in the figure below (Fig. 4).

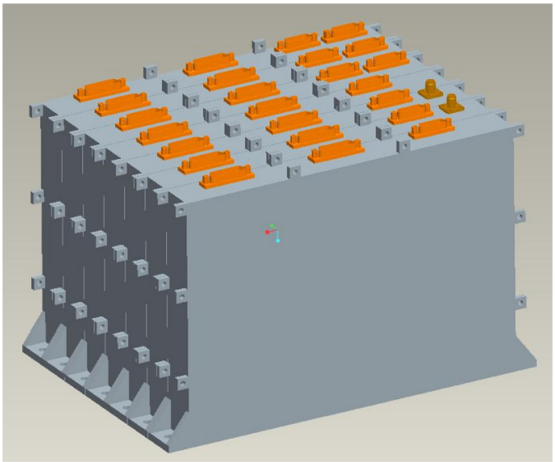


Fig. 4. Schematic diagram of the CMU structure

After detailed evaluation, the system weighed no more than 5 kg, and the overall power consumption was 20~50 W. Then, we finally obtained a domestic LEO constellation satellite integrated electronic system that can benchmark Amethyst integrated electronics and have similar overall performance.

4 Reliability Prediction Analysis on the LEO Constellation Satellite Integrated Electronic System

According to public information, the Amethyst on-board computer has the service life of 10 years, and the computer reliability at the end of the service is not less than 0.99999. In order to benchmark the Amethyst satellite-based computer, we set a same reliability requirement (not less than 0.99999 at the end of 10 years) on the domestic LEO constellation satellite integrated electronics.

In the following part, we will reversely infer the reliability requirements on the computer and modules based on the above requirement, and analyze the possibility of realizing the requirements.

The integrated electronic solution was provisionally determined to contain six functional modules, of which the active and standby processor modules accounted for one panel each, and the active and standby modules of the other five functions share a panel (the modules on a same panel are independent of each other). Accordingly, the on-board computer consists of seven panels. For the analysis convenience, it is assumed that the failure rates of all modules are the same, and the failure rates of the module does not change with time.

In order to facilitate the comparative analysis, the following several working modes were considered, including the dual-machine standby backup mode for whole machine switchover, the multi-machine parallel backup mode, the backup mode for module switchover, and the repairable dual-machine mode.

It was assumed that the failure probabilities of the system and the system components followed the exponential distribution; the failures of the system component were independent of each other; and the system components only had only two states– normal or failure, and there was no intermediate state [7].

5 The Dual-Machine Backup Mode for Whole Machine Switchover

We adopted the dual-machine backup working mode. It was assumed that the two single machine components were completely the same; a single machine is switched for a switchover; the reliability of the switchover control part is 1; and the internal modules of the on-board computer form a serial-and-then-parallel structure. The reliability model structure is shown as below (Fig. 5).

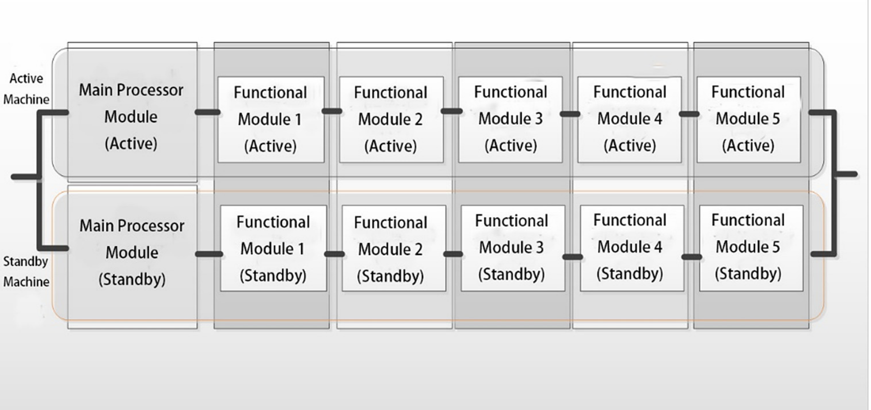


Fig. 5. Block diagram of dual-machine backup reliability

The formula below is to estimate the computer reliability under the dual-machine cold backup mode.

$$R(t) = e^{-\lambda t} + \lambda t e^{-\lambda t} \tag{1}$$

In the formula, t = 10 years = 10 × 365 × 24 = 87,600 h, and R(t) is not less than 0.99999. The results are shown in the following table (Table 2).

When the single machine failure rate is 0.00000005/h, it can be seen from the Table that the on-board computer under the dual-machine cold standby mode can meet the reliability requirements of not less than 0.99999 at the end of 10 years and not less than 0.999 at the end of 12 years.

Table 2. Calculated reliability in the service cycle under the dual-machine cold backup mode (λ = 0.00000005/h)

No.	Year	Day	Hour	Calculated reliability
1	0	0	0	1.0000000000
2	1	365	8760	0.9999999041
3	2	730	17520	0.9999996165
4	3	1095	26280	0.9999991374
5	4	1460	35040	0.9999984669
6	5	1825	43800	0.9999976053
7	6	2190	52560	0.9999965527
8	7	2555	61320	0.9999953092
9	8	2920	70080	0.9999938751
10	9	3285	78840	0.9999922505
11	10	3650	87600	0.9999904355
12	11	4015	96360	0.9999884303
13	12	4380	105120	0.9999862352
14	13	4745	113880	0.9999838502
15	14	5110	122640	0.9999812756

According to the model in Fig. x, the relationship between the failure rate of a single machine and the failure rate of every internal module is as below.

$$\lambda_{\mathrm{single-machine}} = \sum_{i=1}^{6} \lambda_{\mathrm{i}} = 6\lambda_{\mathrm{module}} = 0.00000005 \quad (2)$$

It can be obtained that λ module = 0.0000000083. Correspondingly, the requirement on the module reliability at the end of 10 years is R module = 0.9993; and the requirement on the module reliability at the end of 12 years is R module = 0.9991.

In this case, excessively high requirements are posed on the module reliability, and are difficult to realize in reality.

5.1 The Multi-machine Parallel Mode

Based on the (1) description, a change was made to increase the number of parallels.

It was assumed that all functions of a single machine were all realized on one panel; a panel accounted for a single machine; and a satellite-based computer is composed of several same single machines. A switchover is based on a single machine, and the reliability of the switchover control part is 1.

For this case, the block diagram of the reliability model of the onboard computer is shown in the figure below (Fig. 6).

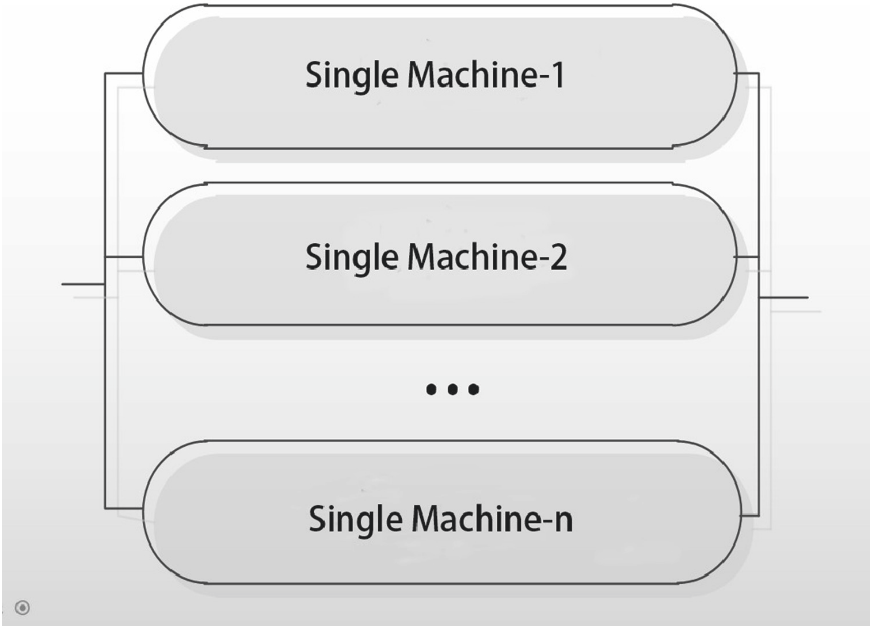


Fig. 6. Block diagram of the reliability under the multi-machine parallel mode

According to the model above, the relationship between computer reliability and module reliability is as the following.

$$\mathrm{R_{computer}} = 1 - \left(1 - \mathrm{R_{single-machine}}\right)^{n} \tag{3}$$

- When n = 3,

$$0.99999 = 1 - \left(1 - \mathrm{R_{single-machine}}\right)^{3}$$

$$0.999 = 1 - \left(1 - \mathrm{R_{single-machine}}\right)^{3}$$

Therefore, at the end of 10 years, the requirement on single machine reliability is $\mathrm{R_{single\text{-}machine}} = 0.981$; and at the end of 12 years, the requirement on single machine reliability $\mathrm{R_{single\text{-}machine}} = 0.9$;

- When n = 4,

$$0.99999 = 1 - \left(1 - \mathrm{R_{single-machine}}\right)^{4}$$

$$0.999 = 1 - \left(1 - \mathrm{R_{single-machine}}\right)^{4}$$

Therefore, at the end of 10 years, the requirement on single machine reliability is $R_{\text{single-machine}} = 0.944$; and at the end of 12 years, the requirement on single machine reliability $R_{\text{single-machine}} = 0.822$.

Under the multi-machine parallel mode, the on-board computer based on the existing technology can basically meet the reliability requirements of not less than 0.99999 at the end of 10 years and not less than 0.999 at the end of 12 years. However, under this mode, since the functions of a single computer are gathered on a single panel, the size of the panel would be too large; besides, multiple machines in parallel are required, and it is difficult to meet the service requirements in terms of volume and weight.

5.2 The Dual-Machine Mode for Functional Module Switchover

On the basis of the (1) description, the module cross-switch hot standby mode was adopted. A switchover is made for module, and the reliability of the switchover control part is 1.

The block diagram of the on-board computer reliability model is shown in the figure below (Fig. 7).

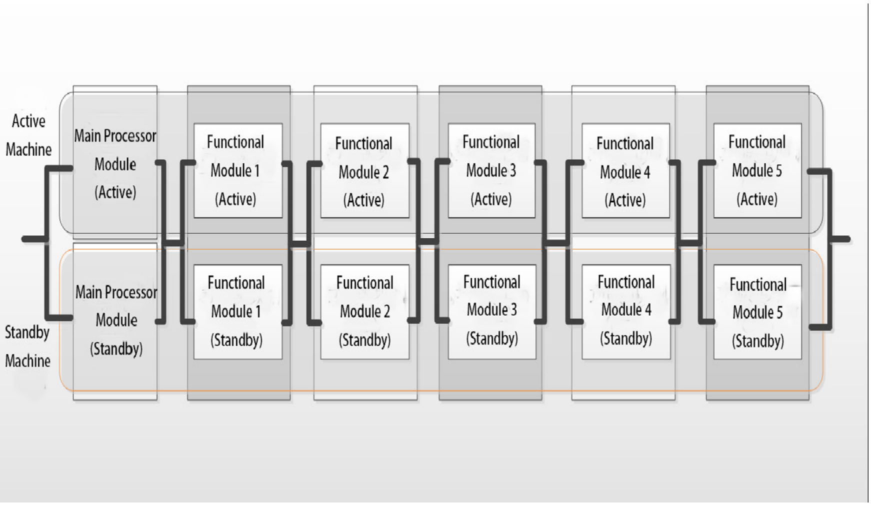


Fig. 7. Model of the reliability under the dual-machine module switchover mode

According to the model above, the relationship between the computer reliability and the module reliability is as the following.

$$R_{\text{computer}} = \left[1 - (1 - R_{\text{module}})^2\right]^6 \tag{4}$$

Bring in the relevant data, and obtain the followings.

$$0.99999 = \left[1 - (1 - R_{\text{module}})^2\right]^6$$

$$0.999 = \left[1 - (1 - \mathrm{R}_{\mathrm{module}})^2\right]^6$$

It can be solved that at the end of 10 years, the requirement on the module reliability is $\mathrm{R}_{\mathrm{module}} = 0.9987$; and at the end of 12 years, the requirement on the module reliability is $\mathrm{R}_{\mathrm{module}} = 0.987$.

The reliability of the two module are relatively high, and it is also difficult to realize them in practice.

- Under the same mode, refer to the structure of Amethyst (four panels and two-stage series connection).

The total number of modules was reduced to four (incl. 2 main processor modules and 2 functional modules), and every module accounted for a single panel. Then, the computer was composed of only four panels, and the series number was reduced to two. The above method was used to analyze the reliability requirements of related modules.

Bring in the relevant data, and obtain the followings:

$$0.99999 = \left[1 - (1 - \mathrm{R}_{\mathrm{module}})^2\right]^2$$

$$0.999 = \left[1 - (1 - \mathrm{R}_{\mathrm{module}})^2\right]^2$$

It can be solved that at the end of 10 years, the requirement on the module reliability is $\mathrm{R}_{\mathrm{module}} = 0.9977$; and at the end of 12 years, the requirement on the module reliability is $\mathrm{R}_{\mathrm{module}}$ 0.977.

Under this mode, the requirements on the module of the two-stage series connection are slightly lower than those of the six-stage series connection structure, but they are still very high requirements that can barely be realized in practice.

5.3 The Repairable Dual-Machine Mode

It is noted the "Availability" is used in the product manual of Amethyst to describe the reliability of 0.99999 at the 10-year service end, and the "Reconfiguration" mechanism described in the main feature part description can respond to 50 scenarios. Obviously, Amethyst is a repairable on-board computer that uses reconfigurable technology. Such repairability is not only for the whole machine, but also likely for the local parts (such as channels, storage areas, specific area programmable logic, etc.) within a single machine under the situation of no affecting the operation of the single machine. Restricted by the space and weight of small satellites, an Amethyst computer has limited hardware resources. It is speculated that the technology is mainly based on software and programmable devices, and the hardware logic resource redundancy plays a supplementary role [8–10].

The on-board computer performs single-machine switchover mode, the reliability of the switchover control part is 1, and the internal modules of the computer form a serial-and-then-parallel structure. Because the service cycle is relatively long, the steady state availability of the computer can be used to characterize the reliability at the end of the service. It was assumed that both machines were in a normal state at the initial moment. The single machine failure rate is λsingle-machine, and the single machine repair rate is μsingle-machine.

The repair rate is calculated according to the reciprocal of the repair time. The repair time here is estimated according to the time of detecting a fault, isolating the fault, repairing the fault, and entering the ready-to-use state. According to the previous analysis, the repair is mainly carried out through software and programmable devices, and would not take long. In this paper, the repair time is estimated at 10, 30 and 60 min.

In the initial state, the two machines are powered on at the same time. When the active is faulty, it is switched to the standby machine. The original host performs online repair, and is then in the standby state after returning to the normal condition. The steady state availability of the computer is estimated with the following formula, and the target availability at the end of 10 years is 0.9999:

$$A = \frac{\lambda * \mu + \mu^2}{\lambda * \mu + \lambda^2 + \mu^2} = \frac{\frac{\lambda}{\mu} + 1}{\frac{\lambda}{\mu} + \left(\frac{\lambda}{\mu}\right)^2 + 1} = 0.99999 \tag{5}$$

It is solved that (λ/μ) = 0.00317 (Table 3).

Table 3. Estimated module failure rates

No.	λ/μ	Repair time (h)	Repair rate (/h)	Sing-machine failure rate	Module failure rate
1	0.00317	0.167	6	0.0190200000	0.0031700000
2		0.5	2	0.0063400000	0.0010566667
3		1	1	0.0031700000	0.0005283333

It can be seen from the above Table that the module failure rates are relatively high. In other words, low requirements are posed on the module reliability. Under such module failure rates (0.00317, 0.0011 and 0.00053), if repairability is not considered, the module reliability will drop to below 0.205, 0.577 and 0.767, respectively, after 500 h, and the reliability of a module with a high failure rate decreases fast.

But after considering the repairability, on the premise of not exceeding (λ/μ) = 0.00317, the availability of the computer at the end of 10 years and t 12 years can meet the requirements.

When the failure rate is constant, adopting advanced technology to reduce the repair time can contribute to a relatively high repair rate of the on-board computer, make it much higher than the failure rate, improve the availability at the end of the service, and thus improve the on-board computer reliability. Refer to the attached table below (Table 4).

Based on the above analysis, it can be seen that the LEO constellation satellite integrated electronics proposed in this paper cannot achieve the reliability requirements of

Table 4. The change of availability with repair rate (failure rate unchanged)

No.	Module failure rate	Single-machine failure rate	Repair time (h)	Repair rate (/h)	λ/μ	Availability at the end of 10 years
1	0.00317	0.01902	0.0167	60.00	0.0003170000	0.9999999000
2			0.167	6.00	0.0031700000	0.9999900000
3			0.5	2.00	0.0095100000	0.9999100000

0.9999 in 10 years and 0.999 at the end of 12 years with the conventional dual-machine cold backup approach. However, adopting the repair and reconstruction technology combining software and programmable devices and designing a multi-layer (single machines and modules) reconstruction strategy make the single machines repairable, consequently meeting the reliability requirements of not less than 0.99999 at the end of 10 years and not less than 0.999 at the end of 12 years for the integrated electronics and technically improving the integrated electronics to a level different from existing space computer.

6 Conclusion

Upon benchmarking foreign advanced LEO Internet satellite electronic system products, an integrated electronic system for LEO Internet constellation satellite applications is designed in the paper. By using a new domestic high-performance processor and adopting a modular design idea, the system is characterized by high performance and high integration. Besides, targeting the service requirements on long service life and high reliability of the integrated electronics, the reliability under different working modes was analyzed with the components stress analysis method, and a reliability improvement plan based on on-orbit repair was proposed. Finally, we obtained a design plan for a satellite-borne integrated electronic system for LEO mobile constellation applications. With the overall performance comparable to the those of advanced foreign solutions, it meets the needs of domestic LEO mobile constellation service.

References

1. Jiqiang, Z., Xiongfei, L.: Introduction of OneWeb system and domestic LEO internet satellite system. Space Electron. Technol. **6**, 1–7 (2017)
2. http://www.OneWeb.net/#solution[EB/OL]
3. Yingyuan, G., Niwei, W., Zhou, L.: The development research and construction suggestion of satellite internet constellations. J. CAEIT **14**(8), 875–881 (2019)
4. http://www.spaceequipment.airbusdefenceandspace.com/[EB/OL]
5. Panpan, Z., Tingyuan, G., Jianjun, G., Yong, S.: Plug-and-play on-board computer system design based on bm3803 processor. Spacecr. Eng. **22**(6), 92–96 (2013)
6. Xinsheng, W., Hanxu, S., Guodong, X., Zhihong, T.: Study on the on-board computer system based on ARM processor. J. Beijing Univ. Posts Telecommun. **28**(4), 23–26 (2005)

7. Hua, Y., Qun, L., Xinfa, Z.: Application of reliability technique in on-bard computer. Appl. Electron. Tech. **7**, 75–79 (2009)
8. Yuan, L., Zhaowei, S., Yi, S., Lei, X., Xiande, W.: FPGA pre-layout plan for reconfigurable on-board information processing system. J. Harbin Eng. Univ. **34**(7), 872–878 (2013)
9. Rui, C., Xinquan, Y., Wenfang, S., Yongfeng, L.: Design for on-orbit reconfigurable image processing devices. Space Electron. Technol. **1**, 61–65 (2017)
10. Zhengquan, J., Haichuan, Z., Shuangjian, X.: Construction of a local self-repairing system and the reliability analysis. J. Hebei Univ. Sci. Technol. **32**, 113–115 (2011)