The special radiation-hardened processors for new highly informative experiments in space

O V Serdin¹, A A Antonov¹, A G Dubrovsky, E A Novogilov and A L Zuev

¹Scientific Research Institute of System Analysis of the Russian Academy of Sciences, Nahnovskij Prospect 36/1, Moscow, 117218, Russia

E-mail: serdin@cs.niisi.ras.ru, antonov@niisi.msk.ru

Abstract. The article provides a detailed description of the series of special radiation-hardened microprocessor developed by SRISA for use in space technology. The microprocessors have 32-bit and 64-bit KOMDIV architecture with embedded SpaceWire, RapidIO, Ethernet and MIL-STD-1553B interfaces. These devices are used in space telescope GAMMA-400 data acquisition system, and may also be applied to other experiments in space (such as observatory "Millimetron" etc.).

1. Introduction

In general, new computer system is created for every scientific experiment [1]. Currently there is a significant increase in the complexity of the experiments. In this research the cost of equipment increases dramatically. Due to the high cost and complexity, many experiments in space become international. This situation calls for standardization of electronic equipment and components for use in space technology. The base of satellite computing systems is a multi-channel device for collecting and storing information. Combining circuits may occur at the level of microprocessor cores, external interfaces, communication media, memory, external storage devices and data transmission protocols for the ground equipment. Also unification may occur at the system software level.

The article deals with the chips, designed and developed in SRISA for computing and control systems used in space technology.

2. Radiation-tolerant processors

SRISA has more than 10 years experience in designing electronic components for space application. ICs for use in space technology must have the following characteristics:

- resistance to accumulated dose,
- resistance to hard charged particles with energy below 60 MeV×cm²/mg,
- resistance to the neutrino flux up to $10^{13}$ neutrinos/cm²,
- continue to operate after 50 ns pulse irradiation to $10^{12}$ rad/s,

To improve IC resistance to single failures special circuits of functional elements and triple modular redundancy (TMR) are used. For manufacturing is using SOI process 0.25 - 0.35 mkm and radiation-resistant library of basic elements. Operating temperature of the chip ranges from -60 to +125 °C.

When creating the tools for scientific experiments in space, including GAMMA-400 telescope, set of microprocessors designed by SRISA is used.

The following interfaces are used when creating space systems:
- SpaceWire to create a highly reliable multiprocessor computer systems, this interface is standard for the average power space systems;
- Serial RapidIO for creating high-performance multiprocessor systems; this standard is also purchased by US leading space companies for the development of modern computing systems and space systems;
- Ethernet 10/100 Mbit/s for transmitting non-critical data, and compatibility with existing systems;
- multiplex channel according to MIL-STD-1553B to provide a highly reliable low-speed exchanges.
- RS232/RS485 to provide low-speed exchanges, primarily with manufactured products;
- JTAG for testing organization;
- general purpose input-output lines;
- SPI serial interface for connecting slow devices;
- I2C serial interface for connecting slow devices;
- CAN.
List of radiation-tolerant chips is shown in table 1.

**Table 1.** The list radiation-tolerant chips.

| Chips    | Technology | Description                                                                 |
|----------|------------|-----------------------------------------------------------------------------|
| 1907VM038| 0,25 µm SOI| High-performance microprocessor with integrated interfaces Serial RapidIO and SpaceWire |
| 1907VM028| 0,25 µm SOI| High-performance 64 bits microprocessor with integrated interfaces Serial RapidIO |
| 1907VM044| 0,25 µm SOI| System on chip (SoC) with TMR and with integrated interfaces SpaceWire |
| 1907VM066| 0,25 µm SOI| Microprocessor with built-in coprocessor processing and comparison of images (a correlator) and a built-in Serial RapidIO and SpaceWire controllers |
| 1907VK016| 0,25 µm SOI| SoC with 32-bit microprocessor with integrated interfaces                      |
| 1907VM056| 0,25 µm SOI| Microprocessor with built-in c 6-port switch SpaceWire channels               |
| 1907KX018| 0,25 µm SOI| 6-port switch Serial RapidIO channels                                         |
| 9011BA016| 0,25 µm SOI| System on package                                                            |

SRISA has developed two versions of real time operating systems (RTOS): “Baget 3.0”; “Baget 2.0”.

RTOS “Baget 3.0” has been developed in SRISA, and is intended for software development for single and multiprocessor computer systems working in real time. High quality and reliable operation are confirmed by the long operation experience (more than 10 years with “Baget 2.0”) on industrial and scientific equipment in SRISA [2].

RTOS “Baget 3.0” is based on standards ARINC 653 and POSIX, it is working on various hardware platforms, has flexible planning tools, has developed diagnostics and error handling and recovery after failures monitor and has wide configuration tools.

To improve the mobility of the operating system it is divided into three basic parts: independent of the hardware part; part of supporting the CPU work and board support package (BSP).

The majority of the system is written in C language and does not depend on the hardware. The second part of the system that depends only on the type of processor is written partially in C language and Assembler. BSP contains the part of the OS, which depends on the particular hardware. BSP, in particular, contains the device drivers and partially the interrupt manager.
For using in flight control systems, space-based systems with high demands on reliability is system-on-chip 1907VM044 [3].

Microcircuit 1907VM044 is a system-on-chip with fault-tolerant 32-bit RISC processor KOMDIV architecture and the following set of interfaces: controller of exchange with external memory with fault-tolerant exchange protocol; controller GPIO; controller interface MIL-STD-1553B with a redundant channel; SpaceWire interface controller with a backup channel; two controller RS-232 interface; controller serial interface SPI.

The main feature of the chip is the implementation of TMR in entire logical structure of the VLSI. All the blocks of memory have a special circuit and topological solutions for protecting data against failures. The controller exchanges with an external storage device implements the fault-tolerant exchange protocol, allows major booting from the PROM. Power consumption of the chip is about 7W on the frequency 66MHz. Ceramic package contains 256 pins.

For developing onboard systems aiming at digital signal processing with the requirements of increased radiation resistance and resistance to high-energy particles microcircuit 1907VM038 has been created.

1907VM038 is a 128-bit high-performance microprocessor, includes a control processor with the architecture of the KOMDIV32 and the coprocessor with SIMD architecture for digital signal processing. Microprocessor allows the execution of the 2 to 20 operations with 32-bit floating-point numbers in one clock cycle of the operating frequency.

Main features:
- 128-bit internal data bus to the controller RAM;
- 2 Gbit/s speed of data exchange with the external storage device (RAM).
- more then 2 GFlops performance on real single-precision operations.

1907VM038 has the following interfaces: external memory controller (RAM) DDR2; high-speed channels RapidIO and SpaceWire; two controller serial interface RS-232; controller serial interface SPI; controller GPIO; controller JTAG. Block diagram 1907VM038 shown in Fig. 1.

Nominal values of the supply voltage of the chip are 3.3 V and 2.5 V, power consumption is not more than 8 W at a clock frequency of 125 MHz. The device has a ceramic package BGA with 675 pins.

![Figure 1. Block diagram 1907VM038.](image-url)
In navigation and other onboard systems microcircuit 1907VM066 can be used. 1907VM066 is a radiation-hardened microprocessor KOMDIV32 architecture with a built-in coprocessor data processing and image comparison (correlator).

1907VM066 contains the following interfaces: external static memory (SRAM); PCI bus; serial RapidIO interface (SRIO); 4-channel SpaceWire switch; serial interface SPI master and slave functions; RS232 (UART); I2C bus with master and slave functions; GPIO, JTAG.

The nominal value of the supply voltage is 3.3 V, the maximum power consumption is 6 W at a clock frequency of 100 MHz. The device has a ceramic PGA package with 407 pins.

Multi-port switch 1907VM056 can be used in systems based on SpaceWire interface. 1907VM056 radiation-resistant multi-port SpaceWire switch with embedded processor KOMDIV32 architecture is designed for building compact on-board multiprocessor data processing systems for space applications technology.

1907VM056 consists of: SpaceWire interface with 8 channels of built-in switch; MIL-STD-1553B interface; JTAG interface (IEEE-1149.1), boundary scan supporting; external memory controller; general purpose input-output signals (GPIO); RS-232 interface; SPI interface; CAN interface.

Embedded memory blocks are protected by parity codes and have topological methods to protect stored data against failures. The external memory controller implements the fault-tolerant exchange protocol, allows fault-tolerant booting from the PROM. The supply voltage: 3.3 V, the maximum power consumption is 6 W at a clock frequency of 100 MHz; the microcircuit has a ceramic package PGA with 407 pins.

The switch 1907КХ018 contains six ports serial RapidIO interface, with independent transmission for each port: LP-Serial 4X or 1X [4]. The maximum transfer rate on each channel is 1.25 Gb/s. 1907КХ018 has a separate switching table for each port, system performance monitor, built-in control errors system. The switch can directly connect up to 256 end devices, which is typically sufficient for embedded systems. Individual table switching allows to configure network. System performance monitoring is used to determine the characteristics of the data flow in the channel, to determine the problem network nodes. Maximum power consumption when using six ports is less than 6 watts. Power supplies: 2.5 V and 3.3 V, 1907КХ018 has ceramic package type BGA with 399 pins. For automation of scientific experiments in outer space universal 32 bit microprocessor with integrated co-processor and built-in SpaceWire controller has been developed.

Currently the following chips are developing by SRISA:
- SOC with following functional units: DDR2 controller external memory with a data bus width of 64 bits plus ECC; controller serial RapidIO with data transfer speed of 2.5 Gb/s; two SpaceWire controller; built-in RAM with capacity 64 KB; built-in ROM with capacity of 64 KB; three programmable timers; built-in programmable clock generator; low-speed ADC with 8 channels; JTAG.

- Microprocessor with integrated co-processor contains the following units: DDR2 controller external memory of type with a bus width of 64 bits without regard to ECC with a frequency of 200 MHz; four SpaceWire controller with data transfer speed of at least 200 Mb/s each; eight RapidIO interfaces with data transmission speed 2.5 Gb/s each; controller direct memory access (DMA); power control module; JTAG.

3. Conclusion

SRISA offers set of microcircuit for space solutions with set of all necessary characteristics and interfaces. SRISA offers ready solutions based on two types of standards: VPX (Euromechanics 6U) for building high performance computing systems and PCI/104-Express or PCIe/104 for small systems. GAMMA-400 project is created based on the VPX standard. SRISA offers operating system "RTOS Baget 3.0" for such system.
References
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