ON-BOARD COMPUTER SYSTEM FOR KITSAT - THE FIRST KOREAN SATELLITE

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Abstract—**In this paper an on-board computer system for the first Korean satellite, KITSAT is presented. The design technologies for large commercial satellites cannot be directly used for the microsatellite due to the compactness. The design drivers and decisions made in the development of the KITSAT on-board computer system are described to fulfill the microsatellite design constraints. The features of on-board computer hardware and operating system are presented. The in-orbit performance of a mission control computer(MCC) is also discussed with the memory subsystem error log and the attitude control subsystem results.**

I. Introduction

Satellites have continued to increase their size to implement reliability and functionality on board the spacecraft. However, long development time and such high development costs for a large satellite makes such satellite projects hard to survive these days. This trend enforces the role of small satellites in space. Satellites which are small, cheap, and fast to develop are replacing the works that have been done by large, expensive satellites before [1][2].

KITSAT is a microsatellite of 50 kg and it is designed to develop space technology. KITSAT-1 which was launched in 1992 carries four scientific experimental payloads: packet data communication experiment(PCE), earth imaging system(EIS), digital signal processing experiment(DSPE), and cosmic ray experiment(CRE). KITSAT-2 was launched in 1993 and carries five experimental payloads of PCE, infrared sensor experiment(IREX), DSPE, low energy electron detector(LEED), and EIS. KITSAT-1 revolves around the earth every 120 minutes with 66 degree inclination at 1300 km altitude while KITSAT-2 moves around the earth every 90 minutes with 98 degree inclination at 820 km altitude.

The primary on-board mission control computer(MCC) for KITSAT-1 is called OBC186, which uses an INTEL 80C186 as its CPU. Also, Z80-based secondary MCC, the T800 EIS controller and the TMS320C30 DSPE controller can be used as backup MCCs in case of primary and secondary MCC failure. These computers communicate each other through a data sharing serial network. A commercial multitasking operating system named Spacecraft Operating System(SCOS) was used for the various OBC186 tasks. The OBC186 has demonstrated a stable performance in space on KITSAT-1, but its processing time is overloaded by housekeeping, attitude control and payload management. The program memory space was not enough to run more useful tasks on-board. The KITSAT-2 KASCOM(KAIST Satellite Computer) was designed to overcome the problems in OBC186 system. KASCOM is a 32-bit INTEL 80960 based MCC and its mission objective is to test its capability as the primary MCC for future small satellite missions. A new compact real-time multi-tasking operating system was developed named KASCOM Real-Time OS(KROS).

This paper summaries the works on KITSAT on-board computers OBC186, and KASCOM hardware architecture and the software development.

The OBC186 and KASCOM design drivers are described in section II. The implementations of the design parameters are also discussed. In section III, we describe the KASCOM and OBC186 software architecture including the SCOS(Spacecraft operating System) and KROS operating system. In section IV, the MCC implementation and test procedures are described. The in-orbit operation results are discussed in section V. The conclusion on the KITSAT MCC research is shown in section VI.

II. Design of the KITSAT on-board Computer

The KITSAT mission control computer functions include attitude determination and control, housekeeping and health monitoring, command processing, bus subsystem management, payload management, and

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communication. The design of MCC must consider the design criteria of throughput, memory capability, input/output capability, power consumption, reliability, parts qualification, technology and availability, and radiation hardness[3]. From the software developer's point of view, emulator availability, development tool support, and reusable reliable software module are the design parameters to be considered[4]. The microsatellite constraints requires KITSAT MCC to have low power consumption, compact size and weight, and it must be designed within a limited budget and development time. These factors were the design drivers for KITSAT MCC.

In this section, the characteristics of the two KITSAT MCCs, OBC186 and KASCOM, are explained by the above seven design criteria and the design drivers that affected the MCC features are also described.

A. Throughput

OBC186 is a 16 bit CISC(Complex Instruction Set Computer) and runs at 7.3728 MHz which will give about 0.8 MIPS(Million Instruction per Second). KASCOM is a 32 bit RISC(Reduced Instruction Set Computer) and runs at 7.867 MHz which will give about a maximum of 4 MIPS. The 80960 provides high speed 32 bit pipelined instruction execution, on-chip floating point unit, multiple register sets and built-in interrupt controller. The 80C186 is a highly integrated chip and it contains programmable timers, interrupt controllers, and DMA channels on chip.

The 80C186 has been operating in space on many microsatellite space missions[5][6] and the high integrity of 80C186 was one of the reasons it was selected as MCC for their missions. KASCOM had to be run on suppressed clock rate to reduce power consumption sacrificing performance. Figure 1 shows the architecture of KITSAT-2 MCC KASCOM.

B. I/O Capability

The two 80C186 DMA channels are linked to three Z8530 serial communication controllers(SCC) for 9600 bps up/down link communication. Interrupt driven I/O services are provided in OBC186 and KASCOM as well. The 8530 supports three up-links and two down-links in a doubly duplicated manner. The subsystems which requires fast data transfer are connected to MCC using two 8255s by parallel interface.

C. Memory

The OBC186 memory system consists of bootstrap ROM, program memory and RAMDISK for data storage. The 4Kbyte PROM contains two copies of bootstrap codes in two separate ROM pages. Each ROM

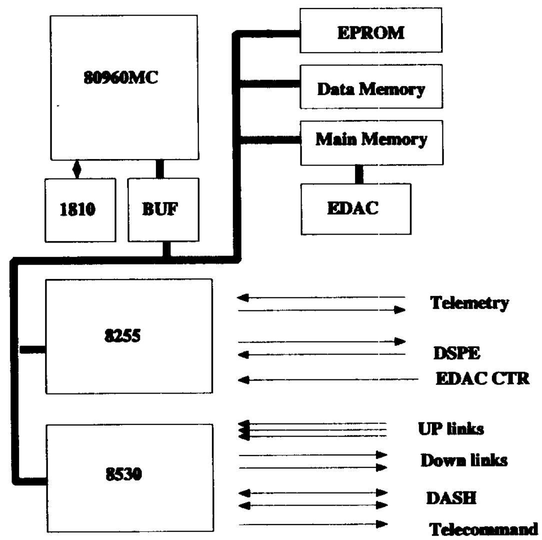

Fig. 1. KITSAT-2 MCC KASCOM

page is selected by telecommand. The program memory area is managed by OS kernel and it consists of four 128 KByte SRAMs. A hardware EDAC(Error Detection and Correction) circuit is implemented to correct one bit and detect two bit errors using (8,12) Hamming code. This scheme requires extra 512 KByte memory space for the code storage. A two bit EDAC counter was implemented to count program memory error on read operation. The 13 Mbyte RAMDISK consists of four banks. Each bank contains four 1 Mbyte hybrid SRAMs and the bank 4 contains four 256 KByte hybrid SRAMs. Instead of using hardware EDAC circuit, RAMDISK uses a block coding similar to Reed-Solomon code to correct one byte error from 252 byte data block adding three bytes codes to the data block.

KASCOM has a different memory architecture from OBC186. The bootstrap image is stored into 64 KByte EPROM. The program memory is configured with the hardware EDAC protected 2 MByte program memory and 8 MByte data memory. Instead of using the space proven hybrid 1 MByte SRAMs, 512 KByte monolithic SRAM was chosen for KASCOM to test out its capability in the space radiation environment.

The SOS(Silicon on Saphire) RAMs were excluded from consideration for use due to its cost and long delivery time. The vertical single-in-line and high density chips were favored for the MCCs' data memory to save space and the chips with the low power version were used. The EDAC processor was not used because of its high power consumption rate though it may save the space used for EDAC circuit.

D. Power Consumption

Due to the limited amount of power generated from the solar panels, OBC186 design was driven mainly by reducing power consumption while keeping minimum required computing power. OBC186 uses mostly CMOS technology and this naturally saves current in the circuitry. Memory subsystem was designed to consume about 75 mW using low power version when in operation and 10 μW for standby. 80C186 has a power-save mode which programmably reduces operating frequency sustaining the normal operation. The OBC186 SCOS controls this mode. Most of the time CPU stays in the power save mode consuming about 75 mA and when a task is scheduled it consumes 150 mA at +5V. KASCOM was designed to have more computation capability than OBC186 and this increases power consumption. In average, it consumes 300 mA at +5V. The 80960 on chip cache option was disabled for power save. An EPLD was used to help development procedure and to reduce the number of chips on the KASCOM board, though it has increased power consumption.

E. Reliability

The reliability for KITSAT MCC is achieved by the quality control of the hardware population process. Each hardware modules for flight model is inspected all the time by quality control group. Up links and down-links are duplicated to prevent single point failure. Many other data channels are duplicated in that sense. OBC186's memory system is reconfigurable in case of memory chip failure. The defect memory chips are isolated and with the reduced amount of memory subsystem, still OBC186 can continue its housekeeping operation. Instead of having duplicated computer system, the functional redundancy having different computer system but the same I/O interface was implemented. This backup MCC will be operated as cold standby mode. The parts reliability is achieved by using only space proven ones. However, space-qualified components are discarded due to its cost and delivery time.

F. Parts qualification, Technology and availability

Almost all the parts used on OBC186 and KASCOM are classified of MIL-STD-883 screening level. In some cases, Industrial standard rated parts were used by previous mission operation results. Usage of new components are limited to the non-mission critical subsystem and only used for component performance monitoring. KASCOM has put newly developed 512 KB X 8 SRAM on-board to test their performance in space. Due to its short development time of one and a half year, the available and cost effective but space proven parts were favored to the expensive and long delivery ultra reliable components.

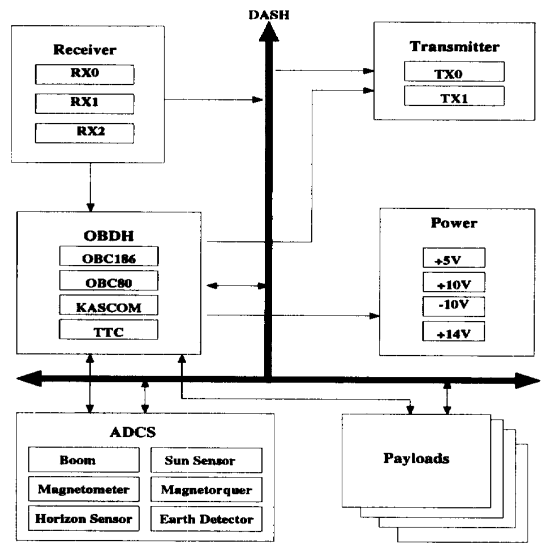

Fig. 2. Control of KITSAT subsystems

G. Radiation Hardness

There is no shielding on KTISAT MCCs for radiation hardness. The only protection mechanism is the SEU protection by hardware EDAC and software coding for memory subsystem. This SEU protection scheme works quite good and corrects almost all SEUs over SAA(South Atlantic Anomaly) area. When MCC software crash occurs, it is extremely difficult to find out the source of the crash. However, the in-orbit operation result shows the SEU phenomenon on the memory chips is dominant to any other latch-up events.

III. Design of the KITSAT On-board Computer Software

KITSAT MCC supports and controls all the bus subsystem and payload operations. Figure 2 shows the control of KITSAT MCC on other subsystems.

The control of the KITSAT subsystems is performed by a multi-module group called "OBDH(On-board Data Handling System)". It consists of OBC186, TTC(Telemetry and Telecommand) and KASCOM. MCC monitors the status of the telemetry point and processes commands to the subsystems. The OBDH controls ADCS actuators, transfers s/w codes to payloads through DASH(Data Sharing) network and dedicated parallel interface, stores payload results to its data storage for download, controls power module, exchanges data with groundstation.

A real-time multi-tasking operating system is required to control the various on-board tasks. For OBC186, a commercial operating system, called SCOS, was purchased and used as its operating system. The SCOS has been used on many 80C186 based MCCs [5] [7] [6] because of its availability and PC-based development environment. The SCOS provides priority based preemptive scheduling and intertask communication facility using message stream. The DMA based I/O drivers for synchronous and asynchronous communication were also supported with a AX.25 protocol driver.

A new real-time multi-tasking operating system was developed for KASCOM named "KROS". The KROS was implemented from a commercial real-time executive kernel. This executive is a real-time, pre-emptive, executing operating system designed for multi-tasking embedded environment. The kernel had to be modified to meet the KITSAT MCC OS requirements other than normal OS operations. These were:

- SEU protection
- Tele-extendibility
- Dynamic task loader

To correct SEUs in the program memory, a hardware EDAC drive routine was added to kernel and executed at a certain rate. The tele-extendibility means the capability which enables extending functions of kernel at run time after it is installed at ROM. The start pointers of procedures used in the kernel and considered to be useful to extend the system is inserted in the *system procedure table* and can be used to access resources of kernel such as task control block, system timer, and kernel memory. In addition, tools for interprocess communication and process handling queues and timer interrupts can be initialized from the outer procedures. The entries of the system procedure table are reserved for the extendibility of kernel services. The process manament part of the executive which creates processes only statically when the kernel is initialized was extended to enable the dynamic task creation. Figure 3 shows KASCOM S/W architecture.

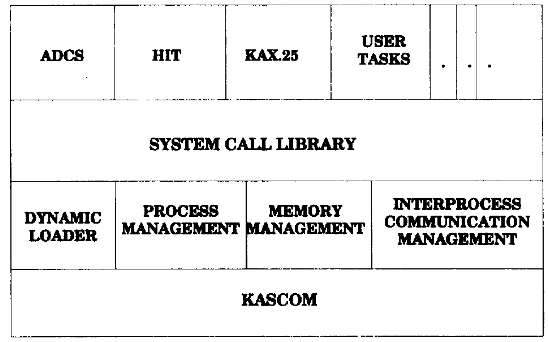

Fig. 3. KASCOM S/W Architecture

The KITSAT MCC forms a flexible, reprogrammable on-board data-handling system. Only simple bootstrap loader code is stored in the flight ROM and all the other programs are reloadable using this ROM loader after the launch of satellite. The on-board tasks for KITSAT MCC consist of telemetry and telecommand server task, mini-file system task, ADCS task, KAX.25 task and other payload and bus subsystem control tasks. The telemetry and telecommand server controls interrupt driven telemetry interface and generates and decodes telecommand packets. The mini-file system is a task that manages the data memory in a DOS file system manner. The ADCS task determines KITSAT's attitude from the sensor readings given by the telemetry task and controls magnetorquers to spin stabilize KITSAT. The KAX.25 task is a communication library task that offers global procedures for other tasks that requires up-link and down-link communication channel services. The payload control tasks include CCD EIS task and DSPE task and bus subsystem tasks include transmitter control task and power control task. All the MCC tasks for OBC186 are developed using Microsoft C 5.0 compiler and tasks for KASCOM are developed with GNU960 compiler.

IV. Implementation and Test

Before the flight module, every subsystem must produce an engineering model to test out its function. For KASCOM, a prototype model was developed before engineering model to test our initial design because it was a new subsystem on KITSAT. Each subsystem engineers carries out module function check out using test box for telecommand and power sub-module function. After engineering model function check out, the module is integrated to other subsystems and an integration function test is performed. After all the function check, the spacecraft goes through environment test. The KITSAT environment test consists of thermal vacuum test, vibration test, shock test, and EMI/EMC(Electromagnetic Interference/Electromagnetic Compatibility) test. Thermal vacuum test varies temperature from -40 °C to 60 °C in the vacuum chamber. The MCC memory test and normal operation mode test are performed during the temperature cycling. Vibration test applies random vibration of 11 G and sine wave vibration and after the test the MCC module is inspected for any broken components. Shock test is to simulate the separation process from the rocket to see its effect to the MCC and it is performed by firing pyro technique circuitry so that the pyros cut the separation bolts. EMI/EMC test is to see if MCC generates any prohibited electromagnetic waves on the rocket.

V. Operation Results

The OBC186 on KITSAT-1 and 2 is carrying 13 MByte RAMDISK as its file system.

Satellite	KITSAT-1	KITSAT-2	KITSAT-2
MCC	OBC186	OBC186	KASCOM
Memory	Hybrid 13 MB	Hybrid 13 MB	Monolithic 8 MB
SEU/bit/day	6.32E-7	5.21E-7	4.59E-7

Table 1. KITSAT MCC SEU Rate(Dec.1993)

The file system task washes 1 KByte cluster of the RAMDISK area every second for SEU correction. The KASCOM on KITSAT-2 has a on-board task which monitors the 8 MByte data memory area all the time. The SEU rate monitored for one month period on these three missions is shown in the table 1.

No multiple event has monitored for the month on the KASCOM as the memory test task keeps on cleaning up the memory area. Five or six multiple event occurred on OBC186 and this is because of the long exposure time before the next wash period begins as it washes 1 KByte per second.

The KITSAT MCC ADCS task reads attitude and position information from the magnetometers, sun sensors, and earth horizon sensors and controls attitude by firing three axis magnetorquers. The target attitude for KITSAT is to have the bottom of the satellite point center of the earth. The angle between the line from the center of the earth to satellite and yaw axis is called pointing error. If it shows 0° of pointing error, the target attitude has achieved. Figure 4 shows an ADCS task performance for one orbit. It shows that the ADCS on-board task controls KITSAT within the pointing error of 5°. Current ADCS algorithm guarantees 5° pointing accuracy all over the orbit.

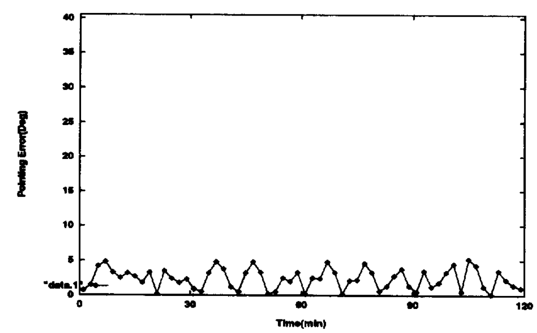

Fig. 4. OBC186 pointing error(21.Mar.94)

VI. Conclusion

In this paper the design of KITSAT mission control on-board computers and its operating systems, their implementation and in-orbit results were presented. The design of microsatellite MCCs is driven by the tight constraints of small mass, low power consumption, short development time and limited budget. The SCOS spacecraft real-time multi-tasking operating system is used for OBC186 and KROS is for KASCOM. The in-orbit result of KITSAT MCC operation have proven that the KITSAT microsatellite MCC design has been successful so far. The research on the design of MCC for microsatellite or small satellite will be continued with KITSAT-1, KITSAT-2 and their capability will be further proved on KITSAT-3 in near future.

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