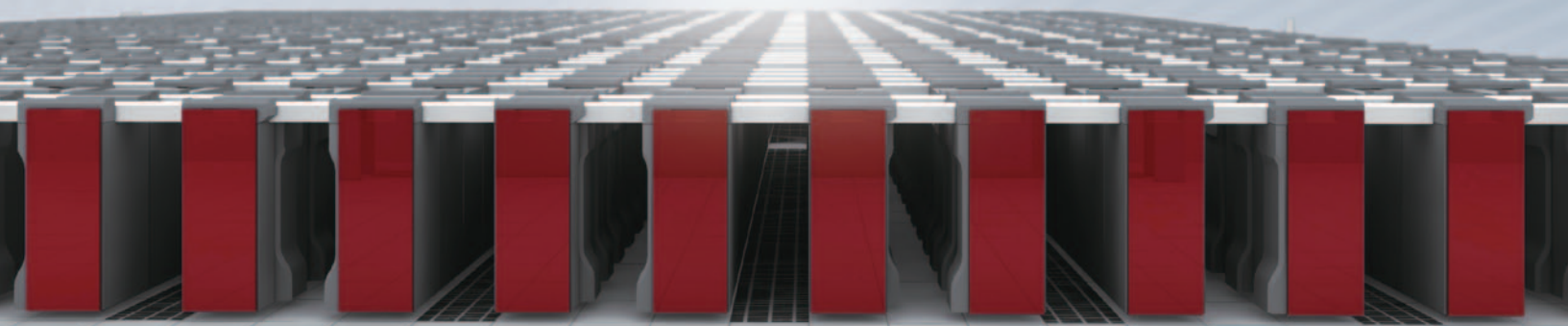




Technology of FUJITSU SEMICONDUCTOR Utilized in Supercomputer "K computer"*



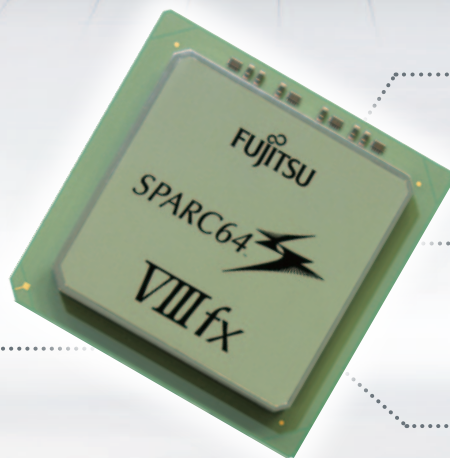
K project system development

Next Generation Technical Computing Unit, FUJITSU LIMITED

The Supercomputer "K computer" was developed to contribute to the development of science and technology with a focus on versatility that enables it to be used in a wide range of research studies and to offer the world's best performance.

CPU development

To produce more than 80,000 high-performance CPUs with the highest reliability and quality without delay, the development project was carried forward diligently, with close communication maintained among all of the related parties.



CPU process development

The main CPU, which realizes a computing speed of 128 billion times per second by packing approximately 760 million transistors in 1 piece, is produced by the 45nm microfabrication technology that is a collection of the essence of the processing technology.

CPU package development

To achieve high performance, the CPU package for the K computer is produced using leading-edge technology. The board to mount the chip on is made of ceramic in which as many as 19 layers of circuits are printed with a thickness of less than 2mm.

Package development and testing

Although considerable damage was done to the production facilities as a result of the East Japan earthquake disaster, the tireless efforts of our staff and vendors enabled the resumption of production in just 10 days and ensured that delivery dates were kept and quality standards were upheld.



The Technology that Achieved the World's Fastest Computing Speed Lives in Our Products

June 2011. The supercomputer "K computer," developed jointly by RIKEN and FUJITSU, took first place in the world on the TOP500 list, which ranks the performance of the world's supercomputers.

The K computer is a super-parallel computer that enables high-speed and high-throughput data processing through the simultaneous operation of a large number of CPUs. It was equipped with 68,544 CPUs when the prior speed record was achieved and there was a goal to address a computing speed of 1 kei (10¹⁶) times per second ("kei" is the origin of the computer's name) by eventually equipping more than 80,000 CPUs. The K computer achieves the world's top-level performance not only in terms of speed but also in terms of versatility to support

many programs, effective performance that allows it to operate constantly at a high speed, and low power consumption for the performance level.

FUJITSU SEMICONDUCTOR manufactured the CPU, or SPARC64™ VIIIfx that comprise the core of the computer. This was a true "challenge," where perfection in performance, reliability, and quality beyond any preceding level was required in order for the heart of the national project to be the best in the world. Every ounce of our leading-edge technology was put into every level of design, development, and production.

Technology, reliability, and quality live in the products. FUJITSU SEMICONDUCTOR will continue to tackle challenges in the future.

* "K computer" is the nickname given by RIKEN in July 2010 for the next-generation supercomputer.



K computer
Challenge to be
the world's No.1



Science and Technology Advance by Utilizing the “K Computer”

Next Generation Technical Computing Unit, FUJITSU LIMITED

The goal of the development of the K computer is not to win the competition for speed, but to deliver the best performance with stability and to contribute to the development of science and technology. The man who led the development of the world's most advanced supercomputer worked on its development with a focus on both reliability and computing speed.

“The K computer is a supercomputer of such a large scale that it would be impossible to realize if it was not a national project. It was, of course, challenging, but failure was not an option, as the entire nation was paying more attention than ever before. We thus established a new team for development and proceeded with it carefully.”

Yuji Oinaga of the Next Generation Technical Computing Unit, FUJITSU LIMITED reflects on the development of the K computer. He is an experienced engineer who has worked on supercomputer development for over 30 years. He was in charge of the overall development of this massive system along with Aiichiro Inoue who mainly led the project's processor development team.

Research and development of the supercomputer was begun in the Peta-Scale Computing Research Center of Fujitsu Laboratories Ltd. There, the conceptual design that could be boiled down to specifications to address the world's top-level performance was made. The specific designing (that is, the detailed design) was begun in April 2007 after presenting it to the national government. Development was eventually conducted by a very large team of more than 300 hardware and software developers (only counting in-house workers).

“Since this was the first time we have developed a system that operates more than 80,000 CPUs, there were things that we did not know until we tried. The K computer adopts direct networking in which all of the CPUs are networked in bulk, instead of the indirect networking that is utilized in conventional systems where relay points are set in the middle of the network. To realize this, excellent communication performance among CPUs is essential, as is the performance of SPARC64 VIIIfx, which is the main CPU. The world's best computing speed was realized through the cooperation of FUJITSU Group and many vendors.”



Kawasaki Plant, FUJITSU LIMITED

Special attention was paid to reliability during the development process.

“In general, the failure rate is said to be once a year in a system with 100 CPUs. However, when such a rate is applied to the K computer, this would mean that there would be a few failures each day. We therefore needed to eliminate this problem thoroughly during the development stage.”

He said that there would be no problems even if there were a few bugs in the system if the sole aim was to deliver the world's best computing speed using the program called LINPACK, which is used to rate the TOP500 computers. However, the goal of the K computer was to support many programs that are useful in various studies in the five strategic fields specified by the government and to deliver the results in the form of scientific and technological evolution. To achieve this, something perfect had to be developed to account for all possible situations.

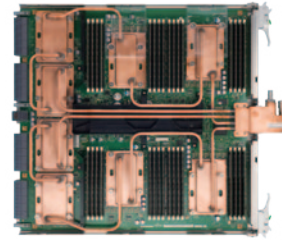


Next Generation Technical Computing Unit
FUJITSU LIMITED

Yuji Oinaga



Advanced Institute for Computational Science (AICS) in Kobe, where the "K computer" is installed
Source: RIKEN



"It was for this reason that we used an open-source program, for which applications can be easily developed, as the built-in software program instead of a special program. Furthermore, a water-cooling system was adopted for the hardware equipment, something that is not widely used for supercomputers. Decisions were made to adopt materials with good past track records of use on the conduits and, for communication between computer racks, to avoid the use of optical cables that offer high speed but also carry with them risks of trouble. As a result of these decisions, the organizers of the TOP500 list evaluated our system highly for the fact that it realized a high efficiency ratio of 93% during 28 hours of continuous operation in addition to the calculation speed," he says.

Provision of the best tool for Japan, the world leader in science and technology, to survive

Oinaga says that this project was meaningful in terms of fulfilling various types of responsibilities.

"Japan has recently been lagging behind in the research and development of massively parallel supercomputers, which was the current global trend for supercomputer development. Meanwhile, we had many young engineers who joined the company with a passion to develop supercomputers. We needed to pass on the technology that our generation had accumulated. The national project of the K computer was a challenge in that we had to take responsibility to simultaneously address both."

Conventional Japanese supercomputers adopted a system called the vector type, which had previously been the mainstream type. As we had no platform for the current mainstream massively parallel type, the

development of applications to support it was also behind.

"If the supercomputer performance is improved, the programming technology to support it will also be created. Massively parallel systems have an intrinsic feature of being easier to adapt to various different applications. The K computer strives to raise the level of overall technology in Japan through this process."

Achieving the world's top computing speed was only a stepping stone. They still have to follow up on application development in coordination with RIKEN in preparation for the full-scale operation launch of the K computer in November 2012.

"We did not develop the supercomputer merely to compete in speed. Technology and academia will be the great pillars that will enable Japan to keep up with the world despite the fact that it has fewer resources. We believe that the K computer will be the best tool for this. It is our ultimate goal to contribute to the country and humanity through advances in research and development as well as industry by allowing researchers to use this supercomputer to its full capacity. In the future, it would be ideal to continue to the stage at which researchers demand better tools. We would definitely like to work on the next-generation exa- (10^{18}) machine."

He says that they were able to learn the basics of the massively parallel technology necessary for the development of an exa-machine from the K computer.

"Only FUJITSU and one other company have the technology for both CPUs and networks. In the future, these technologies will be fully utilized in commercial supercomputers."



Hideyuki Saso, Corporate Senior Executive Vice President of FUJITSU LIMITED and Director of FUJITSU SEMICONDUCTOR, commented on the award after taking first place in the thirty-seventh TOP500 list at the Twenty-Sixth International Supercomputing Conference-ISC'11 (Germany, June 2011)



K computer
Challenge to be
the world's No.1



The Highest Level Was Required for Every Part of the CPU

The challenge to reach the highest peak where no one has gone before always comes with risks, however advanced the technology is. Nevertheless, this project could not fail. The engineer who led the development of the main CPU worked on a careful design that would realize both high performance and high reliability.



It was the spring of 2007 when Masayoshi Kimoto of the Advanced Product Business Unit of FUJITSU SEMICONDUCTOR was asked to be the project leader for the development of the CPUs to be equipped on the K computer. Mr. Kimoto honestly reflects, "I knew that this was going to be a difficult job."

"For SPARC64 VIII fx, eight cores with the world's best performance, which is twice that of normal CPUs, are equipped on the world's largest class 23-mm-square chip using 45nm production technology, which was the most advanced technology at the time. This alone was a great technical challenge. We were going to manufacture the network CPU to enable the accurate and simultaneous communication of more than 80,000 of these CPUs."

In SPARC64 VIII fx, each CPU is required to deliver the outclassing computing speed of 128 billion times per second. Such high performance cannot be addressed by the same development process as conventional special-order CPUs. Therefore, we established the optimal technology using the conventional SPARC64 as the basis. At the same time, in order to match the production technology, we maintained close communication with the Next Generation Technical Computing Unit, FUJITSU LIMITED, which was in charge of the overall design of the K computer.

"In this project, the highest level was demanded not only in performance but also in reliability. We needed to deliver a level of

reliability that would allow the product to operate stably even when exposed to intense cosmic radiation. Double or triple safety measures were taken in circuit design for the network and so forth to ensure that the overall operation would not be affected even if an error occurred in a single CPU. It would be impossible to operate an unprecedented supercomputer simultaneously running more than 80,000 CPUs unless we took such extreme measures."

"Even with our leading-edge technology and facilities, the target values for performance, reliability, yield, and so forth required for SPARC64 VIII fx were in uncharted territory and we had no idea what would happen until the end, despite the fact that these values had been confirmed by simulations and experiments in advance."

"Even in terms of the temperature for thermal processing during production, the performance can change due to minute errors that are usually neglected in regular products. Until the job was complete, I was always worried that something unexpected would occur."

Although compatibility between performance and reliability is a common challenge for all products, the requirements for SPARC64 VIII fx were far beyond normal levels. The driving force that led to its realization was the passion of all of the people who worked on its development and production.

"We first heard that we had taken the world's first place from Mie Plant, which was responsible for chip production. They were extremely conscientious and always checked the news, even after product delivery." This dedication led to the successful achievement of their challenge.



Advanced Product Business Unit
FUJITSU SEMICONDUCTOR

Masayoshi Kimoto



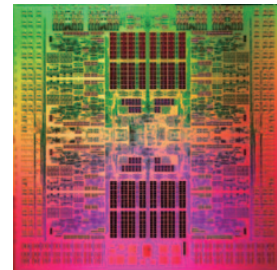
Mie Plant, FUJITSU SEMICONDUCTOR



The engineers of Mie Plant are delighted to have achieved first place in the world.

Process in Which the 45nm Leading-edge Technology Lives

The main CPU for the K computer was produced by 45nm technology, which was the most advanced technology at the time. The passion and competitive spirit of the developers were condensed in the technology to accurately engrave an unbelievably vast quantity of semiconductors on a silicon chip as small as 2cm square.



In integrated circuits such as CPUs, large-scale circuits can be packed into a smaller size as the circuits and semiconductor devices are made smaller. It is also possible to reduce the failure rate and suppress the power consumption by reducing the number of parts.

The circuits and devices of SPARC64 VIIIIfx, which packs approximately 760 million transistors per piece, are made with 45nm technology, which was the most advanced technology at the time of its development. Forty-five nanometers is 1/1700 the width of a human hair. While the chip size of 23 mm square for SPARC64 VIIIIfx is the world's largest for a CPU, the size would be about twofold larger if a chip of the same performance were to be developed with the one generation older 65 nm technology. To develop the K computer equipped with more than 80,000 CPUs, this technology was essential.

Motoshu Miyajima of the Device Development Div. of FUJITSU SEMICONDUCTOR, who promoted the development of this chip by adopting the leading-edge nanotechnology, speaks of how high the hurdle was for this project. "The technology used in SPARC64 VIIIIfx is the product of the element technologies we have accumulated. However, we needed to integrate the element technologies at a comprehensively high level in order to achieve compatibility in the extraordinary computing speed and reliability demanded in the K computer. If one of them failed, everything would be ruined."

Our 45 nm production technology started from research and development using 200 -mm-diameter wafers at the Akiruno Technology Center in 2005. We applied the outcomes to the 300mm wafer production facility at Mie Plant in 2008 and achieved mass production of more than 80,000 pieces of SPARC64 VIIIIfx in just one-and-a-half years.

In semiconductor production processes, a film called a photoresist that reacts with light is applied on a thin silicon wafer and various patterns are printed in a fashion similar to photograph development using exposure apparatus and a reticle on which a circuit pattern is formed. Devices and circuits are formed through the repeated injection of impurity ions for P-type or N-type and the addition of various films and their etching. Naturally, more advanced exposure is required as the printed pattern is further refined.

"To deliver the more minute patterns in 45 nm technology (unlike 65 nm), we used liquid immersion lithography, in which a film of water is formed between the lens of the exposure apparatus and the wafer. To adopt this method, we needed the technology to maintain a stable water film without the formation of bubbles as well as the new correction technology to form the minute patterns."

Even for circuits that are linear on the completed chip, complex shape correction is given on the pattern formed on the reticle by considering the light diffraction effect and so forth.

"To improve the performance, we developed the circuit formation technology using a low-permittivity insulating film called porous NCS, which has molecular-level voids. We also incorporated thermal processing technology using a laser to form shallow impurity joints and various distortion technologies to facilitate the movements of electrons and holes so that high-speed operation could be possible and the leak current from the transistors was reduced. Especially for P-type MOS, we developed the technology to enable the epitaxial growth of SiGe at a temperature that was lower than other manufacturers by nearly 200 degrees. Although SPARC64 VIIIIfx is created using delicate technologies in which the performance and reliability may vary as a result of a change in film type or just one of the processing conditions, we were able to develop it thanks to the efforts of all of the engineers involved in the development and the cooperation of our partners who provided the materials and equipment."

Mr. Miyajima calmly explained the various advanced technologies that were developed in the microscopic world that is invisible to the naked eye. He expressed no self-confidence about taking on the challenge to be the best in the world.

"I was quite worried that there would be failures in test operation after delivering the products. This meant that it functioned as a chip only when the planned system performance was delivered."

Although the K computer project was a great challenge to lead the world, for him, SPARC64 VIIIIfx, which was used in the project, could only be considered worthwhile once the customer was satisfied with the product that was produced by many people, just like all of the other products he and his colleagues deliver to their customers on a daily basis.



Device Development Div.
FUJITSU SEMICONDUCTOR

Motoshu Miyajima



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LSI Package Is Also an Important Function to Support the High Performance

The package that the general public thinks of when the term “CPU” is mentioned is not just a container for the chip. It assumes many important roles, including interfacing with peripheral devices as well as cooling, and micron-level accuracy is required.

The process that also affects the CPU performance is supported by advanced technology.



CPU production does not end when a chip that integrates semiconductors is made. It becomes a product only when it is equipped on a board, inserted in a package that is familiar to the public, and has an interface to connect to other devices attached. This packaging work (called downstream processing) was conducted at Miyagi Plant of FUJITSU INTEGRATED MICROTECHNOLOGY.

Susumu Endo of the Product Development Dept. I LSI Packaging Div. of FUJITSU SEMICONDUCTOR, who was in charge of the backend process explains: “The operation efficiency of a CPU varies greatly depending on the package. For example, our high-performance CPU uses ceramic to deliver high-speed transmission whereas conventional general-purpose products use organic materials such as printed circuit boards as the substrate. On the substrate for SPARC64 VIII fx, 19 layers of ceramic are overlaid on a thickness of less than 2mm to form the circuits and 16,000 bumps are connected to the chip.”

The technology to precisely finish the ceramic, whose dimensions change by sintering, was also developed jointly with the supplier. Each bump is a solder ball with a diameter of 80 microns, and many bumps are aligned with an precise interval of 175 microns. If either the pad on the substrate or the bump on the chip is shifted only slightly, it would not be a product.

“In consideration of the environment, SPARC64 VIII fx uses lead-free solder.” This solder was also our proprietary technology that can be used

under temperatures lower than those of conventional solders.

“The CPU package assumes the important role of a radiator to release heat—its formal name is ‘heat spreader’.” The SPARC64 VIII fx package is made of 3-mm-thick copper, and high-purity gold plating is provided on the surface to be joined with the chip. This contrivance delivers a high radiation effect by soldering the top surface of the chip and the heat spreader uniformly. This enables the smooth running of solder and even joining under low temperatures.”

To increase the contact area with the water-cooling system and deliver maximum cooling efficiency, there was a strict demand for smoothness of the heat spreader surface.

Technology is lavishly utilized even in the processes employed to assemble these parts.

“The packaged substrate for SPARC64 VIII fx is 55mm square, which is the largest in the world. The substrate may be cracked by stress unless it is accurately joined with the heat spreader, and the stress from the chip can also be a problem. In addition, the difference in the coefficient of thermal expansion among the ceramic substrate, silicon chip, and copper heat spreader also needed to be balanced well.”

Technology as advanced as chip production and minute sensitivity are contained into the assembly of a CPU small enough to fit in the palm of one’s hand.



Product Development Dept. I
LSI Packaging Div.
FUJITSU SEMICONDUCTOR

Susumu Endo

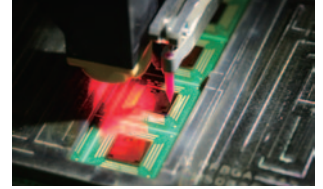


Headquarters/Aizu Plant (Aizu LSI Test Center)
FUJITSU INTEGRATED MICROTECHNOLOGY



Miyagi Plant, FUJITSU INTEGRATED
MICROTECHNOLOGY

Production Was Resumed Only Ten Days After We Suffered Damages from the East Japan Earthquake Disaster



The East Japan Earthquake Disaster occurred when Miyagi Plant was at its peak in terms of packaging work. Frantic restoration work was carried out on site while some doubted the possibility of continuing production. Production was able to resume in a surprisingly short period of 10 days. First place in the world was achieved thanks to their efforts.

Kazuyuki Imamura of the Product Development Dep. II LSI Packaging Div. of FUJITSU SEMICONDUCTOR, who supervised the package development, reflects as follows.

"The development process for SPARC64 VIIIfx was going well. It was the outcome of close communication with related departments and minute advance simulation and evaluation."

However, just after the production had been launched as planned and had reached its peak, the East Japan Earthquake disaster struck Miyagi Plant.

"I was in Tokyo that day. I received the call that they were going to evacuate the plant and it subsequently became impossible to make contact. That day and for two days the following weekend, both the transportation network and the communication network were down. I was extremely worried."

Fortunately, the plant was located inland and there were no human casualties. However, the damage to the production facilities was considerable. The workers at the plant were courageous. Although Mr. Imamura worried about their safety, they waited for the building safety check to be completed by the construction company. A suicide squad with oxygen masks and flashlights went into the pitch-black plant without electricity to assess the damage. Their sense of mission and responsibility to not delay a national project must have moved them.

"When the situation finally became clear early the next week, they discussed moving the production to a different plant. However, Miyagi Plant had a great crisis management system based on past experience of large earthquakes striking the Tohoku region. While the outage and aftershocks continued, they checked the conditions of the work pieces in process and ensured that the delicate raw materials that needed to be stored in refrigerators were properly maintained with thorough measures for restoration. Although I was unable to visit the plant because the transportation network was down, I checked their restoration status via a telephone meeting every morning. They began trial production using the work pieces in process in five days, and resumed the full-scale production

of SPARC64 VIIIfx just 10 days after the disaster."

Even the slightest change in temperature or humidity or the smallest piece of dust is prohibited in package production. The Miyagi Plant staff who were victims of the disaster did their best to resume production without sleep or rest, even while they were running short on the heavy oil used for air conditioning and the raw materials that were usually delivered just in time and despite being low on food.

"In addition to the skills of the plant workers who quickly restored the production machines that require precise installation, FUJITSU Group gave us full support by diverting heavy oil from other plants and relaying bullet trains and company cars to carry the spare parts. The delivery date was kept thanks to the cooperation of all related parties, including material manufacturers, device vendors, and construction contractors, and the products produced after the disaster were delivered with the same high quality as before. What pleased us the most was that everyone from the related parties we visited to explain the situation expressed their concern about Miyagi Plant. It was also gratifying that people from RIKEN mentioned our efforts after the disaster in their press conference for the K computer's achieving first place in the world."

We produced the world's best CPU with the highest quality by overcoming this unprecedented and massive disaster. We take pride in the fact that the greatest quality of SPARC64 VIIIfx was the aspiration of the many people who achieved it.

Product Development Dept. II
LSI Packaging Div.
FUJITSU SEMICONDUCTOR

Kazuyuki Imamura

