Summary of Fujitsu SoC Technology and Related Business

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The system-on-a-chip (SoC) first appeared in the LSI market about 12 years ago. Since that time, continuous advances have been made in SoC process technology and design methodology. Given the increasing complexity of SoCs, the relationship between semiconductor vendors and customers has changed from a simple "sell & buy" relationship to one based on a more complex mutual dependency. This paper describes the recent general trends in SoC technology and business, along with Fujitsu's response to these trends. This paper also describes how Fujitsu plans to handle SoC and LSI business in the future.

1. Introduction

There are various theories about when the system LSI (i.e., system-on-a-chip [SoC]) was first achieved. As for the generations of technology, however, it can be said that the SoC was realized in the age of 0.35 μm technology, when the total integration of circuits on a single printed circuit board (PCB) became possible.

About 12 years ago, in 1994, Fujitsu launched the 0.35 μm process. I still clearly remember how all employees involved in marketing and the members of the design and development teams were excited about the arrival of a new age, the "age of the SoC," succeeding that of the conventional LSI. We all felt the breath of the new age at that time.

The subsequent road was not always smooth as we faced a variety of ongoing challenges in technology and business posed by the development of core intellectual property (IP), including JPEG, MPEG, and the digital signal processor (DSP); the advancement of a new bus architecture and embedded memory; and the distribution of IP.

SoCs have been applied not only to personal computers, but also to cell phones, digital AV products, and even automobiles. It can therefore be said that SoCs have been established as a vital segment of the semiconductor industry.

Now that we have entered the SoC age, customers have naturally demanded that entire systems be embedded in silicon and constantly expect improvements to be made in terms of integration. Moreover, because semiconductor vendors hold the key to the cores of systems, the relationship between semiconductor vendors and customers has changed from a simple "sell & buy" business relationship to one based more on a complex mutual dependency. Fujitsu has continued responding to these demands and changes. With its latest 90 nm technology, Fujitsu remains active in markets by leading the industry in both technology and business models.

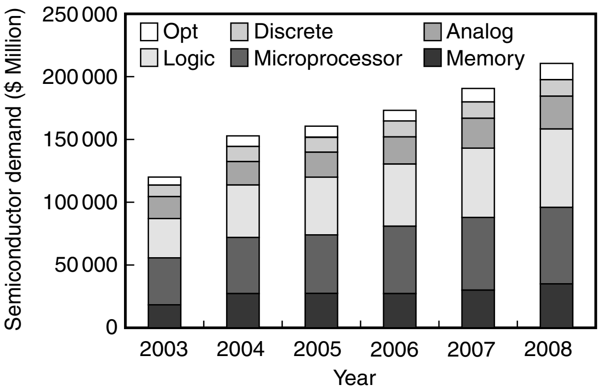
This paper describes the recent general trends of SoC technology and business as reflected in wide-ranging product fields and Fujitsu's response to these trends. It also describes how Fujitsu plans to handle SoC and LSI business in the future.

2. Market and technology trends

The global SoC market suffered from the collapse of the telecommunication bubble. However, this market has maintained favorable long-term growth due to the introduction of new fields such as information electronics, broadband communications, and ubiquitous devices that will stimulate future growth. As shown in **Figure 1**, a high growth rate is forecast for the logic and microprocessor fields where SoCs are applicable.

A review of current market trends reveals remarkable globalization, with other industries entering the market. For example, the globalization of digital home electronics has advanced in every market segment, for example, DVDs, digital cameras, and digital TVs. Moreover, beginning with 3G (third-generation) cell phone models, the use of a standard communications protocol will become mainstream so that cell phones can be used across national borders. Consequently, there is an urgent demand for SoC technology to respond to this trend.

Furthermore, the digitization of various products has encouraged other industries to enter the market. The entry of PC-related vendors in the field of digital home electronics has recently attracted much attention, and the SoC market is expected to change dramatically as well.



Source: JEITA. Mid/long-term view of semiconductor market for major electric products in the world (2005).

Figure 1
Semiconductor demand classified by product.

These developments can be considered technical trends related to SoCs, which have gradually become visible over the past 10 years, from the standpoints of higher integration and the incorporation of customer-oriented functions. The trend toward higher integration is discussed below. The next and subsequent sections discuss the incorporation of customer-oriented functions in detail.

Regarding the trend toward higher integration, the basis of SoC technology depends on advances made in silicon technology for realizing highly integrated circuits. To that end, Fujitsu has steadily introduced leading-edge technologies, beginning with 0.35 μm technology. For the 90 nm-generation of technology in particular, Fujitsu led the way by fostering leading-edge technologies for server products and by being the first to establish stable mass production (**Figure 2**).

Another important point, especially for SoCs, is how to implement practical customer requirements in silicon through cooperation with the customer. At first, the world of SoCs was focused on working to increase the level of integration. When viewing the flow of past development from the standpoints of customer demands and development efficiency on the semiconductor vendor side, several key trends can now be seen.

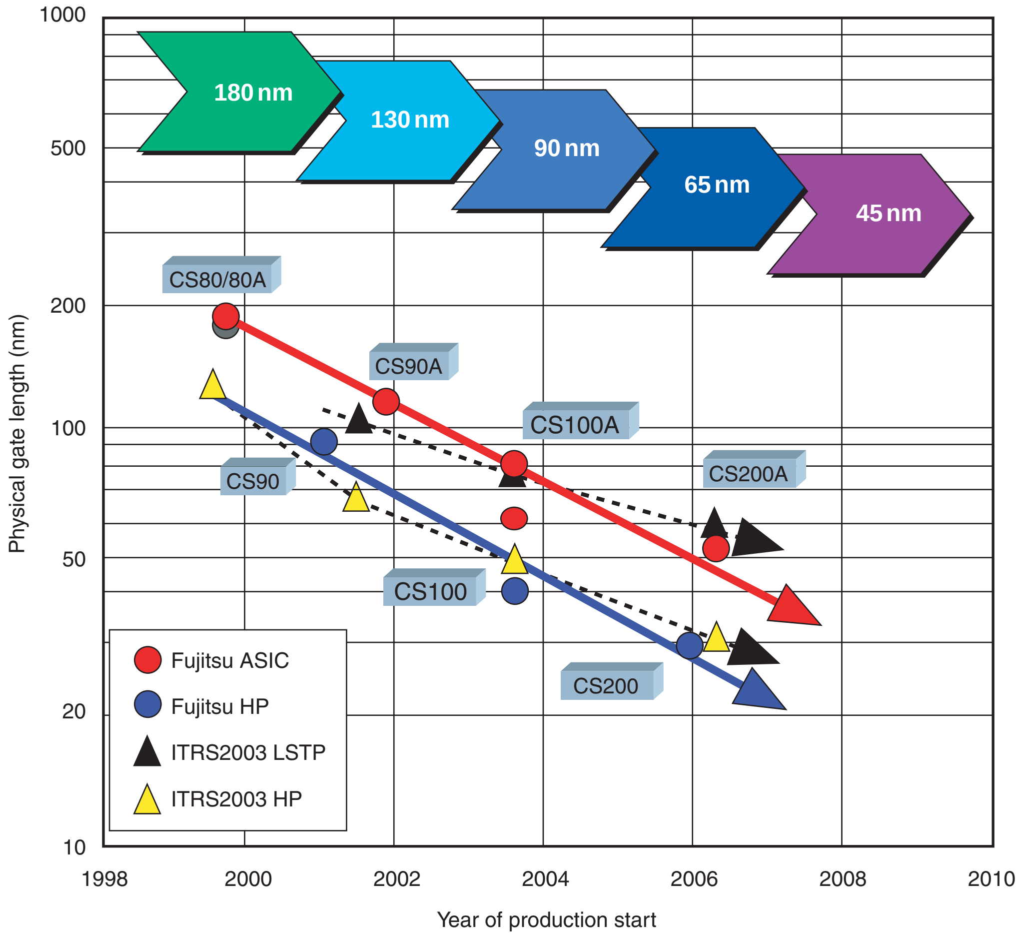
The next three sections describe recent general trends in SoC technology and Fujitsu's response to these trends:

3. Response to diverse interface technology

Because SoCs continue to incorporate the system functions of electronic devices, the handling of diverse digital/digital and digital/analog interfaces with other electronic devices is indispensable.

One remarkable recent trend is the proliferation of wireless interface technology, which represents one type of digital interface.

Through incorporation in SoCs, such inter-



ITRS : International Technology Roadmap for Semiconductors
LSTP : Low Standby Power
HP : High Performance

Figure 2
CMOS technology roadmap showing trends in physical gate length.

face technologies are becoming key factors affecting system performance and features. Therefore, over the past 10 years there has been a growing recognition of this trend as being extremely important.

The following sections summarize the trends for each category of interface.

3.1 Digital interface

The digital interface was developed to interconnect digital devices in line with the popularization of these devices. Historically, the mass production of SoCs began during the golden age of PCs, when Intel Corporation and other peripheral equipment manufacturers actively expanded into SoCs. The propagation of SoCs therefore progressed in the PC and other industries.

Moreover, digital interface standardization contributed significantly to promoting SoC development, which benefited both semiconductor vendors and their customers. In other words, this standardization encouraged separate approaches to be taken for core components that became common (i.e., standardized) and differentiated components in order to achieve more efficient development.

Based on the core components being prepared in this way, development efforts were focused on differentiated components. As a result, the product development time was reduced and more diverse products were developed.

Using typical examples, **Figure 3** shows the transition in annual shipments of product types that have a USB port for connection to a PC or peripheral equipment. **Figure 4** shows the transition in annual shipments of product types in which Controller Area Network (CAN), a network interface standard originally devised for automotive applications, is embedded.

Although the use of digital interfaces has become more widespread, among the remaining technological problems to be resolved is the major one posed by compliance testing.

It cannot be said that, given the progress of standardization, there are no more connection problems. In fact, the methods of installing devices and the detailed specifications still vary, which can cause such problems as not being able to connect.

In many cases, ensuring such interoperability in the early stages is the key to the timely distribution of products to customers.

Fujitsu has emphasized the prompt distribution of high-quality digital interfaces by quickly incorporating standardized specifications, improving the verification system, and collaborating in development with certain customers who have fueled the initiative in their respective industries.

Moreover, another recent general trend is the growing use in mass consumer products of special high-speed I/O circuits capable of 10 Gb/s or higher speeds, which were conventionally used only for storage systems and communications equipment. Based on its experience in developing such products in conjunction with in-house (system) users, Fujitsu has prepared an environment in which the digital interface can also be easily used for application-specific integrated circuits (ASICs) and application-specific standard products (ASSPs).

3.2 Analog interface

On the other hand, the analog signal interface is a challenging topic today and will continue to be so in the future. Each success or failure in analog interface technology will have a major impact on the performance of systems that utilize SoCs.

Immediately after the launch of the SoC, the industry took a somewhat shortsighted view by assuming that analog technology would only play a secondary role because SoCs were digital devices. However, the analog interface is now recognized as an important key technology in demonstrating the power of SoCs.

Beginning with its high-speed, high-precision, analog-digital (AD) and digital-analog (DA)

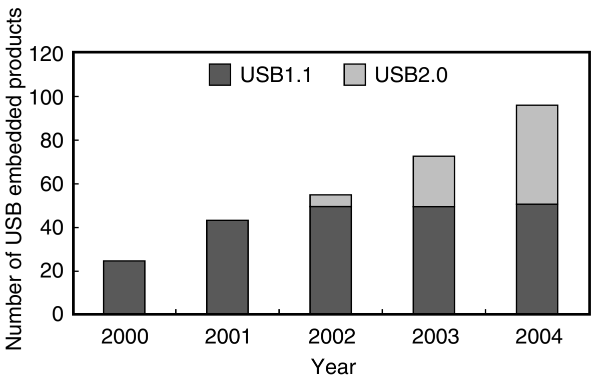


Figure 3
Annual shipments of USB embedded product types.

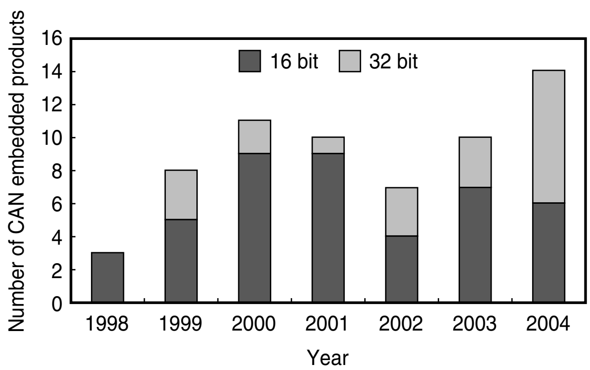


Figure 4
Annual shipments of Controller Area Network (CAN) embedded product types.

converters used in market-leading digital AV products, Fujitsu is also proud of being the industry leader in terms of SoC-embedded analog circuits.

A new concept in analog signal interfaces has recently become necessary given the fact that the technology is becoming more detailed. For AD converters, for example, analog and digital processing have been actively merged, and such methods as Δ-Σ conversion to reduce the dependency on technology have been put to practical use. Fujitsu is also actively involved in these efforts.

3.3 Wireless interface

One future trend to be noted is that for the wireless interface.

The spread of Bluetooth and wireless LANs, for which mass production has already begun, is now the center of focus. From here on, however, new standards such as super low power, ultra wide band (UWB); standards for cards used in short-distance wireless communications; and 802.16 for fixed and mobile communications over wide areas are also on the waiting list.

A new age that will include a paradigm shift in interfaces involving the use of wireless interfaces, not only between systems but also between chips, is also expected. This future trend should be watched carefully.

Fujitsu has provided devices by focusing on high-frequency technology and utilizing conventional bipolar complementary metal oxide semiconductor (BiCMOS) technology. Recently, however, in response to the trend toward integrating wireless applications on SoCs, Fujitsu has begun developing and offering circuit elements, based on Fujitsu's leading 180 nm and smaller CMOS technologies developed for use in RF fields.

Fujitsu has also responded to the spread of short-distance wireless applications by stressing the inclusion of various standards, beginning with standards for cards installed in ferroelectric RAM (FRAM) products, for which Fujitsu has achieved satisfactory results.

4. Continued increases in SoC scale

Because cell phones and digital AV products represent the major markets for SoCs, it is necessary to add more functions, reduce power consumption, and curtail costs through the integration of functions. To meet these requirements, 130 nm and 90 nm technologies (now being employed in mass production) are being utilized. There is no doubt that the scale of SoCs will continue to increase.

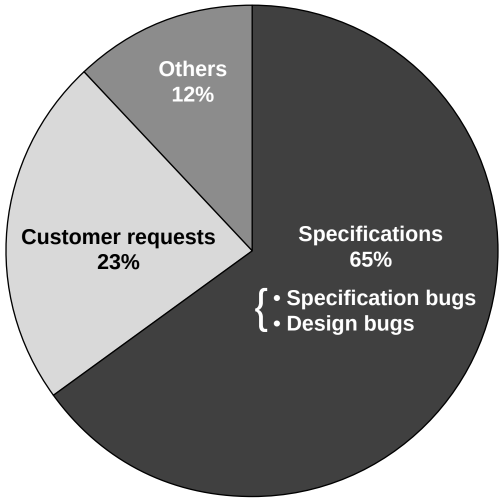
To respond to this scale increase in a quickly changing market, it is essential to avoid the need to redesign during product development. The key to achieving this is to respond to the complexity and advanced level of micro- and nano-technology by establishing a design flow that emphasizes verification at the higher levels of design. In response to advances in micro- and nano-technology, physical design techniques such as those for suppressing noise must also be established.

Other papers in this journal describe efforts for coping with advanced micro- and nano-technology. Here, I would like to introduce the Cedar method for verifying large-scale circuits, which has recently been developed by Fujitsu and is showing good results.[1)]

Large-scale SoCs often need to be redesigned and remanufactured due to the occurrence of failures that might seriously affect LSI vendors and their customers. A survey conducted by the Japan Electronics and Information Technology Industries Association (JEITA) revealed that 65% of the reasons for such redesigning are related to specifications (**Figure 5**).

In other words, the enlarged scale and greater complexity of SoCs have resulted in specifications that are often mismatched with the actual usage methods, environments, or procedures demanded by the customers, markets, and standards. Consequently, the specifications become incorrect or ambiguous, resulting in design errors.

The Cedar method involves a third party that



Source: JEITA System Level Design Study Group, Biwako Workshop Paper P.9, LSI Biwako Workshop 2000.

Figure 5
Reasons for design changes on SoCs.

thoroughly analyzes the specifications of an SoC and eliminates any ambiguities they may contain. The Cedar method therefore provides a procedure for assuring that all items are verified.

To realize this procedure, a method of describing and analyzing specifications based on Unified Modeling Language (UML), a method of evaluating architecture, and various coverage checks have been prepared to facilitate effective use of the Cedar method. The Cedar method makes full use of the superior functions of the development verification procedure and verification process, as well as effectively linking and executing these functions.

In addition to being an effective verification method, the Cedar method is intended to improve design quality from higher levels. This is accomplished by setting a procedure as an active component of the evaluation process in order to achieve the desired specifications by using formulas that offer superior cost performance.

Figure 6 shows the key points of the Cedar method, and **Figure 7** shows the effect of introducing the Cedar method.

Applying this verification method has proven successful in the creation of a two-million gate SoC used for multimedia processing that includes various algorithms and data transfer processes. The SoC was developed within a short period and without the need to redesign/remanufacture.

The scale of SoCs continues to increase without showing any signs of abating. Beginning with the Cedar method, Fujitsu will continue to develop verification methods that can respond to the ever-increasing levels of complexity.

5. Software and services

One current and future trend of SoCs that should be observed is the trend of software. Recently, more than 50% of SoCs feature an installed CPU that is operated by embedded software.

The scale of embedded software is rapidly increasing. For example, the embedded software of CPUs installed in SoCs used for cell phones has increased on average by 50% annually due to the addition of new functions. The scale of embedded software has also significantly increased in other devices.

Therefore, ongoing SoC development requires technology that supports the development of this ever-growing software. The necessary methods of development can be roughly classified as follows:

1) Optimum partitioning of hardware and software in SoCs
2) Development and debugging techniques for achieving reliable SoC software operation at an early stage

Various tools to achieve these methods have been developed individually. Providing a simulation model of an entire system and installing the software confirmed by the simulation model as CPU programs quickly and reliably are the keys to enabling linked operation of these tools, as well as providing effective development techniques for system and software designers.

For example, Fujitsu jointly operated the virtual product simulator of its Software Service

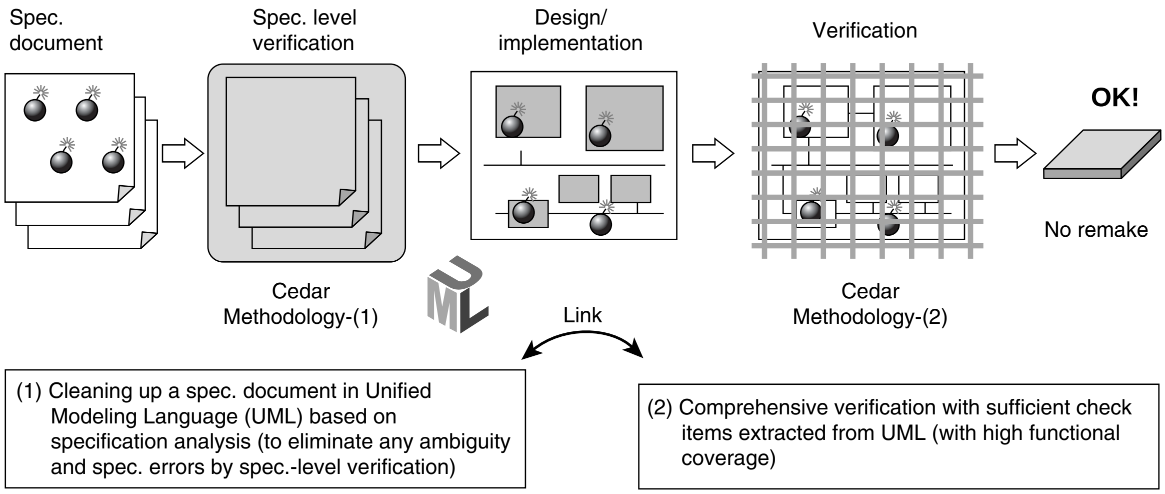


Figure 6
Key points of Cedar method.

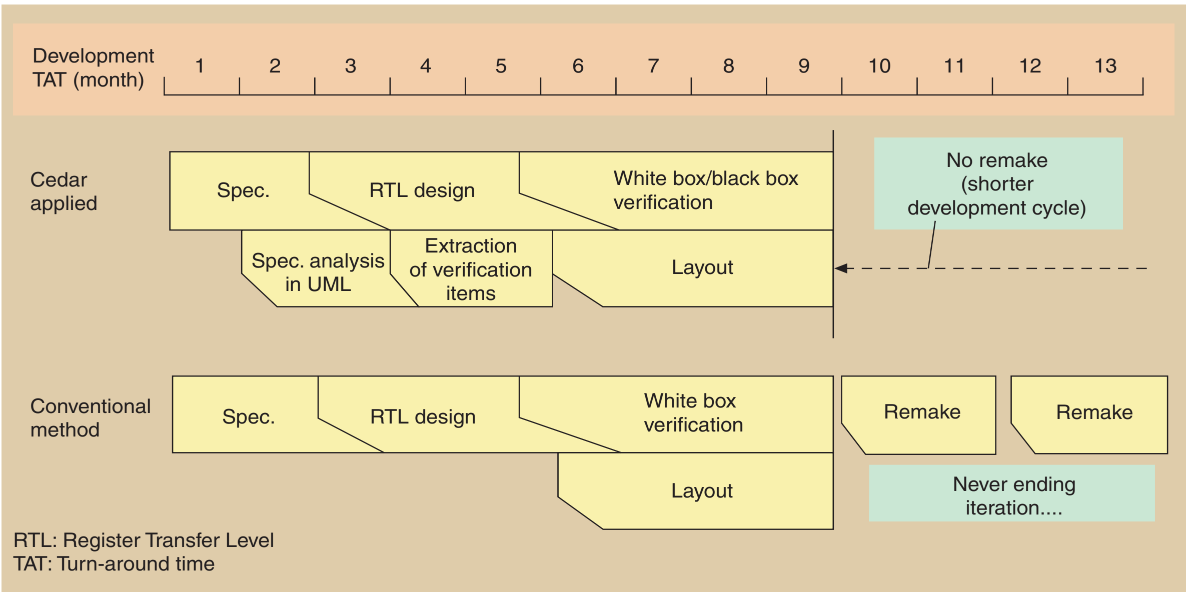


Figure 7
Effect of introducing Cedar.

Division and the CPU development tools of its Electronics Device Division for business negotiations about an SoC and verified the system by using the simulator as requested by the customer, thereby achieving automatic generation of the required CPU programs (**Figure 8**).

This is an example of method 2) described above. Because software written at the system level could be directly connected to the simulation and debugging of the SoC's operations, the efficiency of software development was significantly improved.

When viewed from a different perspective, however, this example may suggest that a direct development method (such as the use of SoC software development tools) as well as the provision

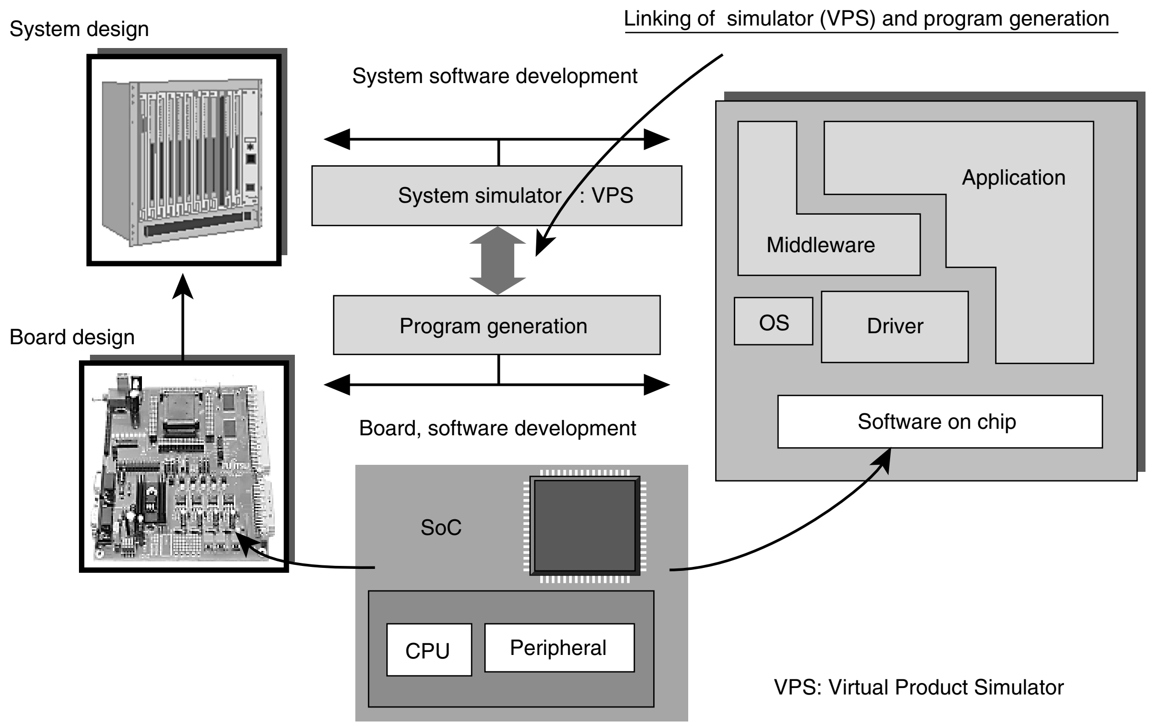


Figure 8
Generation of software from simulator.

of various services required for total system development will likely be future trends in response to customer demands.

Fujitsu has recently been providing service-level support such as PC board noise analysis and prechecking using Field Programmable Gate Arrays (FPGAs) and an emulator. The product shown in Figure 8, for example, was developed with this support.

For these services, Fujitsu is strengthening the collaboration between the Software Service Division and Installation and Board Design Division to provide services not offered by other companies for both technology and distributed support.

6. Fujitsu's challenge: Business innovation

The previous sections described the recent trends in technology and problems involving SoCs and cited examples of Fujitsu's unique response to these trends.

This section looks at the dramatic changes that have occurred in the SoC business and Fujitsu's response to these changes.

It is well known that the driving force behind the SoC business since its inception in the 1990s was the partnering of a fabless maker of America and various specialty manufacturers (foundries) such as those in Taiwan. This was because two different companies separately assumed the increasingly complex design process for SoCs and process technology development for mass production, thereby obtaining a superior position in terms of development turn-around time (TAT) and cost.

Nevertheless, along with the advances made in micro- and nano-technology, the superior position of an integrated device manufacturer (IDM) capable of consistently matching design and manufacturing technology has become widely recognized.

As an IDM, Fujitsu has been supplying the SoCs demanded by customers through services that are closely linked to Japanese home electronics and automobile manufacturers. Along with the start of mass production using 90 nm technology, Fujitsu has been involved in promoting a new IDM model and a more global business. More specifically, Fujitsu is approaching business as a new IDM.

The description "new IDM" was chosen because Fujitsu's efforts extend beyond the conventional IDM framework; therefore, Fujitsu is constructing a new business model with an emphasis on partners.

The following describes in concrete terms the meaning of "partners," which is a key concept for a new IDM.

We believe that partners can be categorized as follows:

The first category of partners are the manufacturing partners. These partners include the manufacturing device vendors that support micro- and nano-technology, packaging and testing device vendors, and other related vendors.

There has been a growing trend toward distributing SoCs as modules, for example, for sensors, so these modules often define the characteristics of an SoC. Accordingly, module vendors have also become important manufacturing partners.

The second category of partners are the development partners. As described in the previous section, SoCs are being implemented for entire systems. Therefore, if all the required technologies related to this trend are not worked out, SoCs will have no product value. For example, interoperability must be verified for a standard interface. When a CPU is included, the software must be verified as well. This means that highly specialized technology will be required on an individual basis.

At the dawn of the SoC, semiconductor vendors decided to provide everything, with each company developing and possessing highly specialized technologies. However, given the dramatic increase in these technologies due to the rapid progress made in integration, it became increasingly difficult for these vendors to provide everything by themselves. In addition, there has been a gradual proliferation of various IPs and software by third parties.

In other words, business groups specializing in the development and marketing of individual, related technologies began to appear. These specialized business groups can provide these technologies; however, to enable the distribution of SoCs in the final form expected by customers, LSI vendors must actively participate in making LSIs compatible with the way they will be used. For example, when a highly specialized, high-speed AD converter from a specialized company is integrated into an SoC, specifications such as the required buffer memory must be provided to enable joint operation of the SoC bus and CPU, and achieving high performance must be fully understood and shared between the LSI vendor, the providers of the individual technologies, and the customer.

Therefore, the providers of the individual technologies are development partners. The aim of guaranteeing the compatibility of related technologies is to ensure that the technology providers, LSI vendor, and SoC customer can enjoy the potential benefits.

The third category of partners are the business promotion partners. These partners complete the mechanism consisting of the support and sales channels for promoting business that Fujitsu lacks and provide customers with a full range of services and SoCs to establish a win-win relationship in which both parties benefit. Having such partners is no doubt very important within Japan, but is also considered essential for overseas, where there are various, important political and cultural differences from Japan.

In fact, even now, business promotion partners are appearing one after another due to ongoing business activities. In the future, one strategy will be to actively acquire and work in closer cooperation with business promotion partners.

Recently there have been more cases where the customers themselves are the business promotion partners. This situation has come about because LSI vendors and customers are both sharing the opportunity to make profits as well as bear the risk in development using leading-edge technology. Consequently, the traditional "sell & buy" relationship where both parties pursue profits independently has become increasingly difficult to maintain. It has therefore become necessary for both parties to cooperate as partners. For example, regarding mass production for 90 nm technology, several customer companies have committed themselves to sharing in the investments for mass production that Fujitsu will undertake. This customer commitment allows Fujitsu to count on product quantity and the customers to count on a stable supply at reduced cost.

As described above, Fujitsu is promoting a new IDM business model that focuses on a partner relationship suitable for SoCs, which are LSIs for realizing an entire system. Also, in the future, Fujitsu will continue providing technologies and services without losing its customer-focused vision.

7. Conclusion

This paper introduced the trends of the SoC since its inception 12 years ago, Fujitsu's response to these trends, and Fujitsu's new IDM business model. It is said that a given industry only lasts 30 years. The LSI already has a history of 30 years, while the SoC only has a 12-year history. Therefore, it is reasonable to assume that the golden age of the SoC is just ahead of us. Moreover, dramatic and unimaginable developments are possible in the future. Therefore, it can be said that the SoC has untapped potential.

Given its experience in both systems and software services, Fujitsu will continue to actively open up new phases to fully demonstrate its extensive capabilities.

Reference

1) *Nikkei Electronics*, July19 (2004), p.59-66.

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Dr. Murakami received the Ph.D. degree in Applied Physics from the University of Tokyo, Japan in 1977. He joined Fujitsu Ltd. in Kawasaki, Japan in 1977, where he has been engaged in development of microprocessors and microcontrollers. He is currently Executive Vice-President of the Electron Device Group of Fujitsu.