FPGA an Intelligent Digital Integrated Circuit: Evolution, Development and Applications

S. PULLTEAP
Department of Mechanical Engineering
Faculty of Engineering and Industrial Technology
Silpakorn University (Sanam Chandra Palace), Thailand
saroj@su.ac.th

Abstract— **This paper describes the evolution, development and applications of the Field Programmable Gate Array (FPGA) in engineering. FPGA is a digital integrated circuit device (IC) which the designed functions can be programmed into the chip by the developer/programmer via a specific application program. This digital IC technology, now, is rapidly developed and also high significant for the automatic controlling system. Many advantages of the chip over the ASIC technology are exploited in terms of low fabrication cost, short time development, operated in specific functions, and low power consumption. Several applications use the FPGA chip for engineering worked and also electrical & electronics equipments such as home automation products, office automation products, medical equipments, communication equipments, automatic machines, and computer components etc. Although, the FPGA technology is very interested and admired in the world market, however, it's just beginning grown up in Thailand due to the lacks of the FPGA specialist and also the FPGA price is still too expensive in the Thailand's market.**

Keywords- Field Programmable Gate Array, ASIC technology, digital integrated circuit, automatic controlling system.

I. INTRODUCTION

Field Programmable Gate Array (FPGA) is a typical of digital integrated circuit (IC) which the desired programming code can directly be downloaded into the chip via a personal computer. Several advantages of this chip can be performed in terms of flexible to operate, reducing cost for the IC fabrication and capability to reprogrammable etc [1]-[2]. With a special function of reprogrammable into the FPGA chip leads to high benefit over using the ASIC technology, a technology of the IC fabrication that designed and produced by the manufacturer [2]. However, it might not be concluded that all of the engineering applications using only the FPGA technology. Caused, there are many IC fabrications for example, in the mass productions or the general IC devices still use the ASIC technology. Basically, the FPGA technology is a family to the ASIC. This implies that the IC fabrication processing can thus be required by the designed production. Moreover, it can be classified into 3 groups: full-custom, semi-custom and programmable, respectively. The full-customer is a fabrication process which the required functions from the customer is directly produced by the manufacturer. Anyway, the semi-custom is storing a half area of the IC for a general propose function and the rest is an area of the required function. The latter group is a special propose of the IC fabrication that any functions can be programmed and/or reprogrammed by developer.

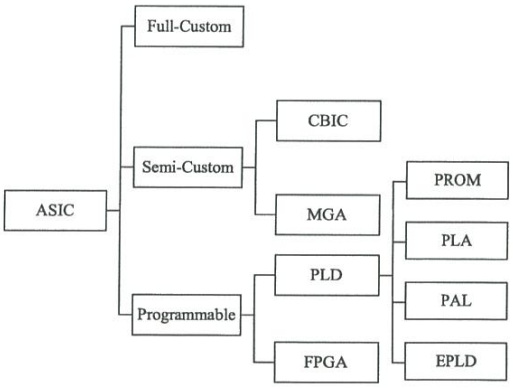

Figure1. Classifications of ASIC Technology

As illustrated in Fig. 1, it regards that the FPGA is a programmable group. Further, if we consider the capacity of the register cell inside the chip, it can observes that the FPGA thus has the cell smaller than the full-custom and semi-custom leads to specifying to use in the special purpose function. However, the other advantages of the FPGA technology over the full-custom and/or the semi-custom are exploited in terms of saving for the time processing, reprogrammable, and low cost etc.

Furthermore, there is another important procedure for designing and fabricating the desired circuit that is the process of software development. This software is, however, used for interfacing any data to the hardware components and also writing/burning the developed code into the chip. Moreover, it can be divided into 2 purposes: simulation and burning program. It might be noted that both software operations must

be synchronized. This implies that the simulation software would have some functions related to the burning software.

The FGPA has been applied for several engineering applications, especially, in high speed processing works such as data processing, digital signal processing, image processing, data compressing, and automatic control engineering etc [3]-[5]. Although, there are many advantages over the ASIC technology for developing in engineering, unfortunately, there is not popular enough for the Thai researchers. In Thailand, this technology has been used only two purposes. The first is used for the education while the latter uses the chip for researching. No one in Thailand, currently, develops this chip for a commercial purpose. It might have 2 reasons to concern this problem. The first reason is high production cost while the problem of the lacks of the FPGA specialist is the latter. These affect to amount of the publication paper compared to the foreign countries.

II. EVOLUTION OF FPGA TECHNOLOGY

The first FPGA chip has been developed in 1985 for improving the capability of the digital cell over the programmable logic array (PLA) and the programmable logic device (PLD). The main prominence point of the chip over the PLA/PLD is performed in terms of the number of digital gate and also the capability to reprogrammable as the general software. In preliminary development, the fabrication cost of the chip was too high. However, this cost is currently reduced and the application software for FPGA development can also be free downloaded on Internet. These lead to the expansion of the FPGA developers in the world's market.

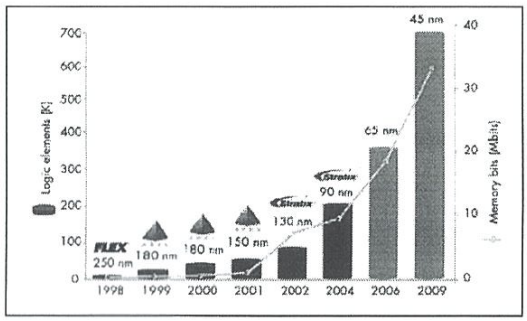

Figure2. Evolution of FPGA Technology [7]

As shown in Fig. 2, we can observe that during ten years of the FPGA fabrication, this technology was grown up such as, the argumentation of the digital gate, or the reduction of the memory size inside the chip. These situations bring to the reduction of the production cost and also increasing to the amount of developer. There are few reasons to explain why this technology is interested for those people. It can thus be concerned in terms of easily to implement, capability to reprogrammable, and easily for testing the developed program [6]. The FPGA technology was begun with a few digital gates inside. However, the amounts of digital gate are, now, achieved more than one million gates leads to the capability to use in the complicated works such as in medical instruments, encoder/decoder, or signal processing etc [4]-[6].

In Thailand, this technology still not admired enough due to lacks of the specialist and a high performance of the digital IC device is not required. However, if the world technology is grown up, or any engineering systems require the high performance of the digital device, the using of the FPGA technology in Thailand might be increased together.

III. DEVELOPMENT OF DIGITAL CIRCUIT BY FPGA

The FPGA technology is a digital IC device that can be operated as the hardware programmable and also capability to reconfigurable. These bring to the flexibility to operate and easily to implement for the developer. Moreover, it can also be used with several programming software. The software might be exploited in forms of a bundle package or an individual package, depended on the developer selection. A main advantage of the software over other ASIC software's is performed in terms of the developer do not need to understand the structure of the chip but they only have to know the logic design system. Further, the logic design system can be developed by using a hardware description language (HDL) which a tool for the digital designing circuit. Moreover, this language still has a few advantages over the other software such as high speed, flexible, and no need to understand the structure of the chip.

Furthermore, there is another special tool for designing the digital circuit that called "Electrical Design Automation (EDA)". This tool is operated on a technique of the Top-Down design Methodology (TDM), considering large system to small system. In general, the TDM technique uses the HDL-based to details the hardware. The famous of the HDL-based currently are "VHSIC Hardware Description Language (VHDL)" and "Verilog". Further, there are 4 steps for designing the digital circuit [7]-[8] as illustrated and detailed in Fig. 3.

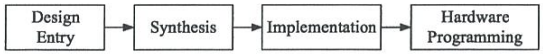

Figure3. Procedure to design digital circuit by FPGA

A. *Design Entry* is a procedure to put the data into the system. It's obtaining the characteristic of the desired circuit into computer system and then uses the developed software for designing or developing (tracking the circuit or creating the block diagram). This method is, however, called "Schematic Design Entry". Noted that the characteristic of the digital devices is directly obtained from the FPGA library or the designed software. Further, by using the VHDL for designing or developing the circuit, any problems can be eliminated. Moreover, the developer doesn't need to understand the structure of the chip.

B. *Synthesis* is a part to convert the characteristic of the desired circuit from the schematic design entry or VHDL to

the digital logic. The designed circuit will thus be synthesized by the software for investigating the optimization of the system. By using this procedure, the time operation and any environmental systems will be reduced. Consequently, the digital logic which demodulated from the method would be obtained in the standard format and that called "Electronic Design Intermediate Format (EDIF)". Subsequently, the output format from the method as mentioned above could then be exploited in forms of the Netlist file, a format that explains the connection details of the digital logic inside the FPGA chip. Further, the developer can directly use this format to implement the system.

C. *Implementation* is a part for mapping the data from the previous section to the technology of the FPGA chip. The objective of this procedure is simulating the designed circuit by using the developed software for example, replacement the digital logic and routing the line signal into the digital cells. This procedure will also inform any designed problems to the developer before saving to the burning file. Moreover, by using the simulation program, any logic status can directly be regarded by the developer.

D. *Hardware Programming* is a final section of the digital circuit designing. The simulation file from the previous section will be loaded into the FPGA chip. However, the modification of the designed code can thus be reprogrammed as the developer need. This can be operated by stepping back to the synthesis section. With an option for modifying the designed code leads to the words of "Reprogrammable Hardware" for the FPGA technology.

Another technique for designing the digital circuit can be created by using the design flow technique. It can be classified into 7 procedures, which each procedure are illustrated and detailed in Fig. 4.

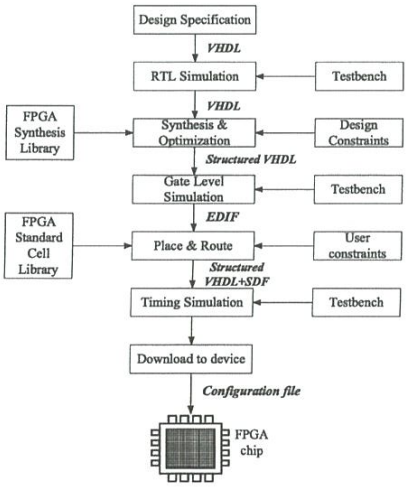

Figure4. Procedure to design digital circuit on FPGA by using design flow technique

a. *Design Specification* is a process to define the details of the designed circuit such as the input/output components, the operational speed of the designed system, or the power consumptions etc. These definitions will thus be constructed in forms of the schematic design entry or VHDL code.

b. *Register Transfer Level Simulation* (RTL) is a process of the design flow technique. It's used for simulating the VHDL code on the register level. By using this procedure, an input waveform will be generated by the simulation program. However, if the designed circuit is very complicated, a "Testbench" technique, the technique to simulate the signal in several waveforms, will be used for transferring the simulated signal into the designed circuit. The output from the procedure will thus be exploited after putting the input waveform into the designed system.

c. *Synthesis & Optimization* is a procedure to synthesize the digital circuit from the VHDL code. The code will be translated to the logic circuit and then compared to the FPGA synthesis library inside the chip. Further, the corrected logic circuit correlated to the standard format is thus obtained from the procedure. Moreover, this process is operated under the menu of "Design Constrain" from the software. Consequently, the corrected circuit is then stored and converted the data to the VHDL for displaying the gate level simulation and also saving that to the EDIF format.

d. *Gate Level Simulation* is a process to simulate the VHDL code to the gate level, which obtained from the synthesis section. The purpose of the procedure is checking the logic status of the components and also calculating the logic status of the transmission line of the system. These bring to small error, improving the resolution, and also saving an operation time before operating with the hardware.

e. *Place & Route* might be called "Implementation". It demodulates the EDIF format into the programming software and then places into the FPGA chip. Consequently, the developer has to track the line into each component on the software. Further, the developed software is then calculating the logic status and let out the data to the "Standard Delay Format (SDF)" format. This format will be used for the simulation time of the FPGA operation.

f. *Timing Simulation* is operated as the synthesis section. It simulates the digital circuit after passed the synthesis section. There are two aims of the procedure: calculating the logic status and investigating the connection time between hardware and developed software. The results from this process are, normally, closes to the hardware operation time.

g. *Download to Device* is a process for burning the developed program (after synthesizing) into the FPGA chip. There are 2 methods for burning the program. The first is directly downloads the developed program into the chip via the programming software while the second, the developed program is stored into the flash memory on the chip and then transferred to the FPGA processor.

IV. APPLICATIONS OF FPGA TECHNOLOGY

The FPGA technology, now, is very interested to the IC developers or researchers. This technology can, however, be applied into 2 fields. The first is used for producing the digital equipments such as modem equipments, mobile phone, computer equipments [8]-[9]. The latter uses the technology for creating the original digital model or the hardware simulation in the digital system [4]. In general, this technology is often used in engineering applications which can thus be divided into 3 groups as shown a diagram in Fig. 5.

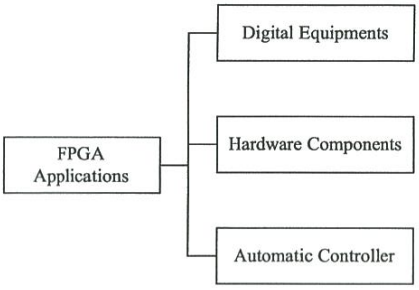

Figure5. Classifications of FPGA technology in engineering applications

- *First group* is using the chip as the digital equipments in the computer system which does not require the large amounts of the logic gate. However, if the equipment requires much more functions over the performance of the FPGA operation, the ASIC must be used for this situation.
- *Second group* uses the FPGA as a part of hardware components. These components can be operated in multi-functions leads to the energy reduction and also the capability to reprogrammable in multi-functions.
- *Third group* is applying the FPGA chip for the smart sensor, digital system, or automatic machine system. The circuit can be designed as the developer need. The equipments which produced from this group will have an update function for making the hardware simulation in the digital system. It leads to increasing of the developed time and also capable to develop the software and hardware in properly time.

The FPGA technology currently has been used in many organizations. Three main objectives to use the chip in engineering are summarized in Fig. 6.

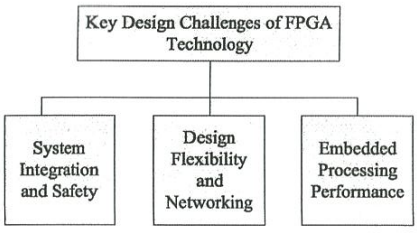

Figure6. Design objectives of FPGA technology in engineering

The system integration and safety is a first objective to use the FPGA technology. Several digital equipments or electronics parts are composed for a compact system. Therefore, the FPGA is an excellent choice to operate in this situation. The applications of this objective are often applied in the automatic machines or surveillance cameras, and also in aerospace components. The second objective is applied in the networking or the flexibility designed applications. This objective uses the FPGA as co-processor of the system. It implies that the developed system must have many processors to process the desired signals and then transfer that to the main/another processor. This system has been used in medical imaging, aerospace, airplane, military equipments, or computer networking equipments etc. The final objective uses the chip in the embedded system. The FPGA chip, in this case, is always used for the automatic controlling system such as in robots, smart machines, factory automation systems, or electrical equipments [1]-[5].

Noted that the FPGA technology can be operated only the digital signal, therefore, there is a tool to co-operate with the designed software. This tool currently has several series/models for example, Xilinx ISE or Altera Quartus II etc [9]. Moreover, they also have capable to operate on Windows OS as well as Linux and also Solaris. However, the price of these tools is still too high. This might be a reason of the researcher to unused the chip for any engineering applications.

V. CONCLUSIONS

The FGPA is a typical of high performance digital IC. It is very popular technology for the scientist or researcher. Several applications in control engineering system use this technology for developing the innovative products. With easily to implementation and capability to reprogrammable (could not operated in the ASIC technology), leads to the argumentation of the developers and also amounts of the publication papers. Moreover, it could be co-operated with the developed software or software tools which some of them is a freeware. This is an advantage of the technology for the digital IC researcher to develop the new products. Not only for the researcher, but the technology has been developed to the educators for investigating the body of knowledge in engineering.

Unfortunately, the FPGA technology still has been not admired enough in Thailand. There are two reasons to explain the situation: lacks of the specialist and high price. To eliminate these problems, the government and also the private sectors have to give an opportunity to the developer, researcher or educator by supporting the grants in terms of the research projects. It would be helpful and make the argumentation of the research papers in FPGA applications.

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